Mulga Downs
Groundwater, Surface Water & Ecohydrological Studies
Baseline Assessment

Prepared for:

HanRoy Iron Ore Pty Ltd

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EXECUTIVE SUMMARY

HanRoy Iron Ore Projects Pty Ltd (HanRoy) on behalf of Hancock Prospecting Pty Ltd (HPPL) is proposing to develop the Mulga Downs Iron Ore Mine (the Project) located approximately 210 km south of Port Hedland and 180 km northwest of Newman, in the Pilbara Region of Western Australia. The proposed Mulga Downs Hub and Rail Spur Project is a separate, standalone project as it is intended to be constructed and operated independently to the Mulga Downs Iron Ore Mine and is not considered in this assessment.

The Project encompasses the Murray's Hill and Mulga East Deposits within the Mulga East tenement (currently Retention Licence R47/12, with Mining Lease M47/1621 pending), with no development proposed over the adjacent / nearby exploration tenements of Malay Well (E47/2117) and Mulga West (E47/1315). However, for the purpose of these water and ecohydrological studies, the Study Area comprises the Mulga East and Malay Well tenements and areas of the Development Envelope which extend outside of these tenement boundaries. The Study Area represents the area within which baseline data has been collected, with additional ecohydrological assessments and limited (preliminary) groundwater investigations undertaken on the Mulga West tenement.

The proposed Project comprises seven mining areas (from west to east): Murray's Hill, Anticline Hill, Fridge West, Fridge Central, Fridge Hill, Horseshoe West and Horseshoe Hill. Approximately 20 of the pits are proposed to extend (to varying depths) below the groundwater level and will therefore require dewatering. The lowest estimated pit elevation is 388 mRL (i.e. ~12 to 16 m below the groundwater level).

The mine area is located on the northern slopes of the Fortescue Valley, within the Goodiadarrie Swamp catchment, which includes the Koodjeepindarranna and Gnalka Gnoona freshwater claypans plus other intermittent areas of surface water pooling.

AQ2 has undertaken baseline groundwater, surface water and ecohydrological studies to develop an integrated conceptual model for the Study Area, with specific focus on the culturally and environmentally sensitive wetlands of the Fortescue Valley, inclusive of the Gnalka Gnoona and Koodjeepindarranna Claypans. The conceptual model and natural (i.e. pre-mining) baseline are summarised below.

Conceptual Model

Between 2018 and 2023 a total of 80 monitoring bores and 12 test production bores have been installed across the Mulga East, Malay Well and Mulga West tenements with hydraulic testing conducted on ten of the production bores to date and the majority of the monitoring bores. In addition, eight surface water monitoring stations have been installed (six within creek channels upstream of the Koodjeepindarranna and Gnalka Gnoona Claypans and two within the claypans themselves). Baseline groundwater and surface water monitoring has been undertaken since early 2019. It is noted that the Baseline data collection period commenced at the tail end of a significant drought in the area, which followed a sustained period of high annual rainfall totals in the Pilbara. During the Baseline period, no large, rare rainfall events have occurred.

Further field investigations have comprised ecophysiological measurements of vegetation (three dry season and one wet season programmes) at multiple locations in the Mulga East, Malay Well and Mulga West tenements and ecohydrological site inspections over the Mulga East and Malay Well tenement areas; with the latter comprising observations of hydrological features, geomorphology as well as vegetation composition and structure.

All field data from the drilling, testing and monitoring programmes have been combined with findings from previous hydrogeological investigations and groundwater level monitoring data dating back to 2008 to develop the conceptual hydrogeological model for the area. Whilst 2D flood modelling and claypan water balance modelling has been completed to assist in the development of a conceptual hydrological model for the area. Salient points regarding the current understanding of the hydrogeological / hydrological system are as follows:

- The Study Area is fully contained within the Fortescue Valley catchment, with Goodiadarrie Swamp located immediately to the south of the site. Runoff from smaller rainfall events is likely to be contained within the Goodiadarrie Swamp area, with discharge into the Lower Fortescue River likely to require larger rainfall events.

  The Koodjeepindarranna and Gnalka Gnoona Claypans have catchments that drain from both the north (Chichester Range) and the south (Hamersley Range) reporting to them. Very little transfer of water along the valley floor within the Goodiadarrie Swamp area is thought to occur, with no defined preferred drainage paths along the valley floor and a valley floor slope of ~0.01% (10 m elevation fall over 80 km length). Baseline surface water flood modelling has been used to assist in the definition of the claypan catchment areas, which vary depending on the magnitude of the rainfall event. Based on water level monitoring data collected across the site, it appears that rainfall events exceeding a rainfall depth of 35 mm are required to generate runoff in the Chichester Range drainage lines and 90mm of rain to result in inundation in the claypans. Inundation within the claypans appears to occur frequently and it is likely that hydrologic responses from average, relatively frequent rainfall events are important in maintaining ecosystem function at the claypans (i.e. ecosystem function does not just rely on high magnitude low frequency runoff events). The low salinity of the ponded water within the claypans and the recorded depth to groundwater below the claypans indicates that the water is sourced from surface water runoff. Comparing the observed water level recession in the claypans from recent rainfall events to evaporation data indicates that evaporation plays the primary role in removing collected water from the claypans, with only minor seepage to the groundwater system. Residual salts from this evaporative loss are leached into the groundwater system under the claypans by the small component of seepage. Over time, this is thought to have resulted in saline groundwater beneath the claypans.
- The groundwater system is hosted in predominantly high permeability bedrock and valley fill, with the only low permeability aquitards being the fresh dolomite of the Wittenoom Formation underlying the valley area and the fresh Jeerinah and Marra Mamba Formations that underlie the orebodies and outcrop along the northern boundary of the Study Area. Secondary permeability resulting from mineralisation, fracturing and weathering, is evident throughout most of the Marra Mamba Formation and the overlying West Angela Member; these units are in hydraulic connection and are believed to form a transmissive basement aquifer. Although no faults have been mapped in the area to date, it could be that this basement aquifer has a lower bulk-permeability than currently adopted with a compensatory increased permeability along particular fault lines. Additionally, it is anticipated that faulting in the Malay Well area has resulted in complexities which are not represented in the current geological model.
- The valley fill has been categorised into the following units: Basal Crete, Pisolite / CID, Undifferentiated Tertiary (inclusive of alluvial fans and scree on the valley flanks) and Upper Calcrete. Although the composition and nature of these units are variable, derived permeabilities are generally high for all the units, with only limited intervals of low permeability clay which do not seem to be continuous.
- The transmissive nature of the bedrock and valley fill is reflected in the low hydraulic gradient observed across the orebody area and valley area, with a steeper gradient only evident along the northern boundary of the Study Area (across the low permeability Jeerinah Formation). Groundwater flow generally follows the topography, flowing from the higher elevations into the valley and then in a northwesterly direction along the valley. The depth to groundwater is shallow in the lower lying, valley

areas (i.e. approximately 3 to 5 mbgl) and increases with elevation, to depths of up to 45 mbgl in the more elevated areas.

- Groundwater across the Study Area ranges from fresh (180 mg/L TDS) in the upper reaches of the groundwater system, to saline (17,000 mg/L TDS) across the valley area, with salinity profiling data confirming saline groundwater originating from the claypans and extending along the valley as well as beneath the orebodies closest to the claypans (although the mining of these orebodies is not part of the proposed mine plan).
- Recharge to the groundwater system occurs as diffuse recharge from rainfall events, both on the valley flanks where the Marra Mamba outcrops and as infiltration into the Tertiary / Quaternary overburden where runoff is focused on the valley floor.

The findings of the ecohydrological site inspection, combined with remote sensing data and available vegetation mapping and soil assessments was used to evaluate the ecohydrological behaviour of the landscape and define ecohydrological units (EHUs) for the Study Area. Table ES1 summarises the key elements and functional aspects of each EHU.

A detailed ecohydrological baseline assessment of the Fortescue Valley environs has also been undertaken, involving characterisation of major vegetation types and evaluation of the ecological water requirements of the E. victrix woodland communities. The potential groundwater dependence of vegetation in the Fortescue Valley has been evaluated using seven assessment tools outlined in the Australian groundwater-dependent ecosystems toolbox (Richardson et al. 2011). It is concluded that groundwater dependent vegetation does not occur in the Study Area, based on the following supporting evidence:

- Groundwater underlying the Fortescue Valley environs is generally brackish/saline and therefore does not constitute a favourable water source for floodplain vegetation.
- Regolith characteristics in the Fortescue Valley environs suggest that vegetation rooting depth is impeded by massive calcrete or dense, low permeability clay layers. Owing to access and ground disturbance constraints due to heritage values in these areas, direct observation of tree roots were limited to several sump pits associated with hydrogeological drilling.
- Across the Study Area, there are no areas of persistently high greenness as measured by time series NDVI imagery.
- Time series pre-dawn leaf water potentials indicate the tree-root zones are in unsaturated media with widely varying soil matric pressure, that is generally lower (i.e. more negative) than -0.5 MPa. Also taking into consideration the potential influence of brackish groundwater, this precludes the roots being in groundwater or at the capillary fringe.
- Based on water balance modelling supported by on-ground vegetation measurements (i.e. woodland tree size and density), surface water inputs were calculated to be sufficient to support the density of trees occurring in the Fortescue Valley E. victrix woodland communities. The more dense woodland stands are associated with better structured soils with relatively higher plant-available water storage capacity.

Table ES1 Summary of Landscape Ecohydrological Units in the Area of Interest

	EHU	Summary description	Hydrological behaviour
Chichester Range Uplands	Upland Rises	Peaks and upper hillslopes; shallow or skeletal soils overlying basement rocks.	Runoff source areas – shed water to downgradient landscape units.
	Upland Valleys	Broader depressions in the Chichester Range where sediments have accumulated, facilitating runoff capture/storage and denser vegetation.	Local sink area, receiving diffuse flow from Upland Rises Surplus from overtopping delivered into Upland Drainages.
	Upland Drainages	Single thread channels with cobble beds that traverse and exit the Chichester Range. Unconfined to semiconfined by hills of basement rocks. Channel beds mostly unvegetated with regular gravel bars and scour pockets. Scattered *E. victrix* trees in deeper soil pockets fringe the channels.	Transfer zones, receive runoff from upland catchments and transmit into Alluvial Fan Drainages.
	Basaltic Tablelands	Level to very gently inclined basaltic plains. Soils mostly comprise self-mulching cracking clays supporting tussock grassland communities.	Local sink area, receiving direct rainfall or locally distributed runoff
Alluvial Fans	Alluvial Fan Washplains	Banded vegetation (mulga and Snakewood) on a gently sloping stony plain. Runoff is generated in intergrove areas and mostly captured in the adjacent downslope grove.	Local sink area receiving rainfall. Surplus from overtopping delivered into Alluvial Fan Drainages.
	Alluvial Fan Drainages	Low sinuosity channels with narrow floodplains, collectively constituting drainage tracts, which dissect the Alluvial Fan Washplains. Supports relatively dense mulga shrubland.	Transfer zones, receive runoff from Upland Drainages and transmit into the Fortescue Valley.
Fortescue Valley Flats	Valley Calcrete Plains	Expansive unit of the Fortescue Valley. Variably dissected and overprinted by alluvium, giving rise to a subtle mosaic of benches, rises and depressions. Vegetation type and density related to soil depth, which is constrained by shallow calcrete (generally within 50 cm of the surface).	Benches and rises function as runoff source areas once internal storage is exceeded, shedding water to immediately adjacent units.
	Valley Stony Flats	Stony flats in the Fortescue Valley, generally on the valley margins where slope (and hence runoff) is insufficient to support banded vegetation. Prone to accumulation of salts due to poor infiltration; only sparsely vegetated. These areas support transient but not persistent ponding.	Receive inflows from Alluvial Fan Drainages. The flat stony pavement surfaces function as runoff source areas once internal storage is exceeded, shedding water to immediately adjacent units.
	Valley Loamy Flats	Broad flats typically inset from the valley margins, where accumulated sediment and organic matter create better soil structure and high infiltration rates. Relatively deep soils (may exceed 100 cm). High surface roughness contributes to some localised surface water redistribution within the unit. These areas support dense patches of woodland and grassland vegetation; with vegetation types related to subtle changes in physical and chemical soil properties.	Predominantly sink areas that receive runoff from adjacent units (Valley Stony Flats and Calcrete Plains). Overtopping is uncommon and associated with large cyclonic rainfall events.
	Valley Ponding Flats	The lowest depressions in the Fortescue Valley where water ponds; typified by high clay content topsoil that impedes infiltration. Prone to accumulation of salts due to poor infiltration; only sparsely vegetated. These areas support persistent ponding.	Sink areas that collect rainfall and receive runoff from adjacent units (Valley Stony Flats and Calcrete Plains, and more rarely Loamy Flats).

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TABLE OF ABBREVIATIONS

Abbreviation	Definition
2D	Two dimensional
ACH	Aboriginal Cultural Heritage
AEP	Annual Exceedance Probability
AMD	Acid Mine Drainage
ANZECC	Australian and New Zealand Environment and Conservation Council
AR&R	Australian Rainfall and Runoff
ARI	Annual Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BoM	Bureau of Meteorology
DEM	Digital Elevation Model
DPLA	Department of Planning, Lands and Heritage
DWER	Department of Water and Environmental Regulation
EC	Electrical Conductivity
ESA	Environmentally Sensitive Area
EPA	Environmental Protection Authority
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HPPL	Hancock Prospecting Pty Ltd
IFD	Intensity-Frequency-Duration
IL	Initial Loss
km	Kilometre
LiDAR	Light Detection and Ranging
LOM	Life of Mine
l/s	Litre per second
m	Metre
MAR	Managed aquifer recharge
Max	Maximum
mbgl	Metres below ground level
mbRP	Metres below reference point
mbTOC	Metres below top of casing
MDEC	Mulga Downs Exploration Camp
mg/l	Milligram Per Litre
mm	millimetre
mRL	Metres Relative Level
µS/cm	Micro Siemens per cm
NASA	National Aeronautics and Space Administration
ND	Nominal Diameter
PAF	Potentially Acid Forming
PEC	Priority Ecological Community
PL	Proportional Loss
RFFE	Regional Flood Frequency Estimate
RFFP	Regional Flood Frequency Procedure
ROM	Run of Mine
RORB	Runoff Routing
SCL	Stochastic Climate Library
SWL	Static Water Level
SWML	Surface Water Monitoring Location
SRTM	Shuttle Radar Topography Mission
TDS	Total Dissolved Solids
V	Volt
WRD	Waste Rock Dump

1. BACKGROUND

1.1 Introduction

HanRoy Iron Ore Projects Pty Ltd (HanRoy) on behalf of Hancock Prospecting Pty Ltd (HPPL) is proposing to develop the Mulga Downs Iron Ore Mine (the Project) located approximately 210 km south of Port Hedland and 180 km northwest of Newman, in the Pilbara Region of Western Australia. The Project encompasses the Murray's Hill and Mulga East Deposits within the Mulga East tenement (currently Retention Licence R47/12, with Mining Lease M47/1621 pending), with no development proposed over the adjacent / nearby exploration tenements of Malay Well (E47/2117) and Mulga West (E47/1315). A location plan is provided as Figure 1.1, showing these tenements. Although other HPPL tenements cover the Project Development Envelope, these have not been shown.

The proposed open cut pit footprints, referenced as MDE_LOM_20_F_20240805 (MDE_LOM_20), are shown in Figure 1.2, together with the indicative Project layout. The pit footprints comprise seven mining areas (from west to east): Murray's Hill, Anticline Hill, Fridge West, Fridge Central, Fridge Hill, Horseshoe West and Horseshoe Hill. Approximately 20 of the pits are proposed to extend (to varying depths) below the groundwater level and will therefore require dewatering. The lowest estimated pit elevation is 388 mRL (i.e. ~12 to 16 m below the groundwater level).

AQ2 has been engaged to undertake baseline groundwater, surface water and ecohydrological studies and impact assessments, to support the environmental assessment of the Project. This report details all baseline and conceptualisation work undertaken from 2018 until November 2023, with impact assessments documented in a standalone Groundwater and Surface Water Impact Assessment Report (AQ2 2024). Subterranean fauna studies have also been conducted as part of the baseline investigations and have been documented separately in standalone reports.

The Study Area is defined for this report as the area shown in Figure 1.2 which includes the Mulga East and Malay Well tenements and areas of the Development Envelope which extend outside of these tenement boundaries. The Study Area represents the area within which baseline data has been collected, with additional ecohydrological assessments and limited (preliminary) groundwater investigations undertaken on the Mulga West tenement (refer to Figure 1.1). Some of the assessments completed within this report (such as flood modelling and the delineation of ecohydrological units) extend beyond the limits of the Study Area.

HPPL are proposing the Mulga Downs Hub and Rail Spur Project as a standalone project as it is intended to be constructed and operated independently to the Mulga Downs Iron Ore Mine. Baseline assessments related to the Hub and Rail Spur Project are not presented in this report.

1.2 Objectives

The primary objective of this Baseline Assessment Report is to support the environmental impact assessment of the Project. As such, the objectives comprise:

- Defining a baseline hydrological data set that quantifies the hydrological characteristics of the ecohydrological systems.
- Formulating conceptual models for the local and regional eco-hydrological systems.
- Identifying environmental assets that may be impacted by hydrological change resulting from the Project (receptors) and quantifying their baseline hydrological behaviour.

1.3 Climate

The climate of the Study Area is described as semi-arid, characterised by hot summers, with maximum monthly temperatures often exceeding 40°C, and milder winters. Rainfall is highly variable, but on average about 75% of annual rainfall is received between December and March, in association with thunderstorms and cyclonic events. Climate is discussed in more detail in Section 2.

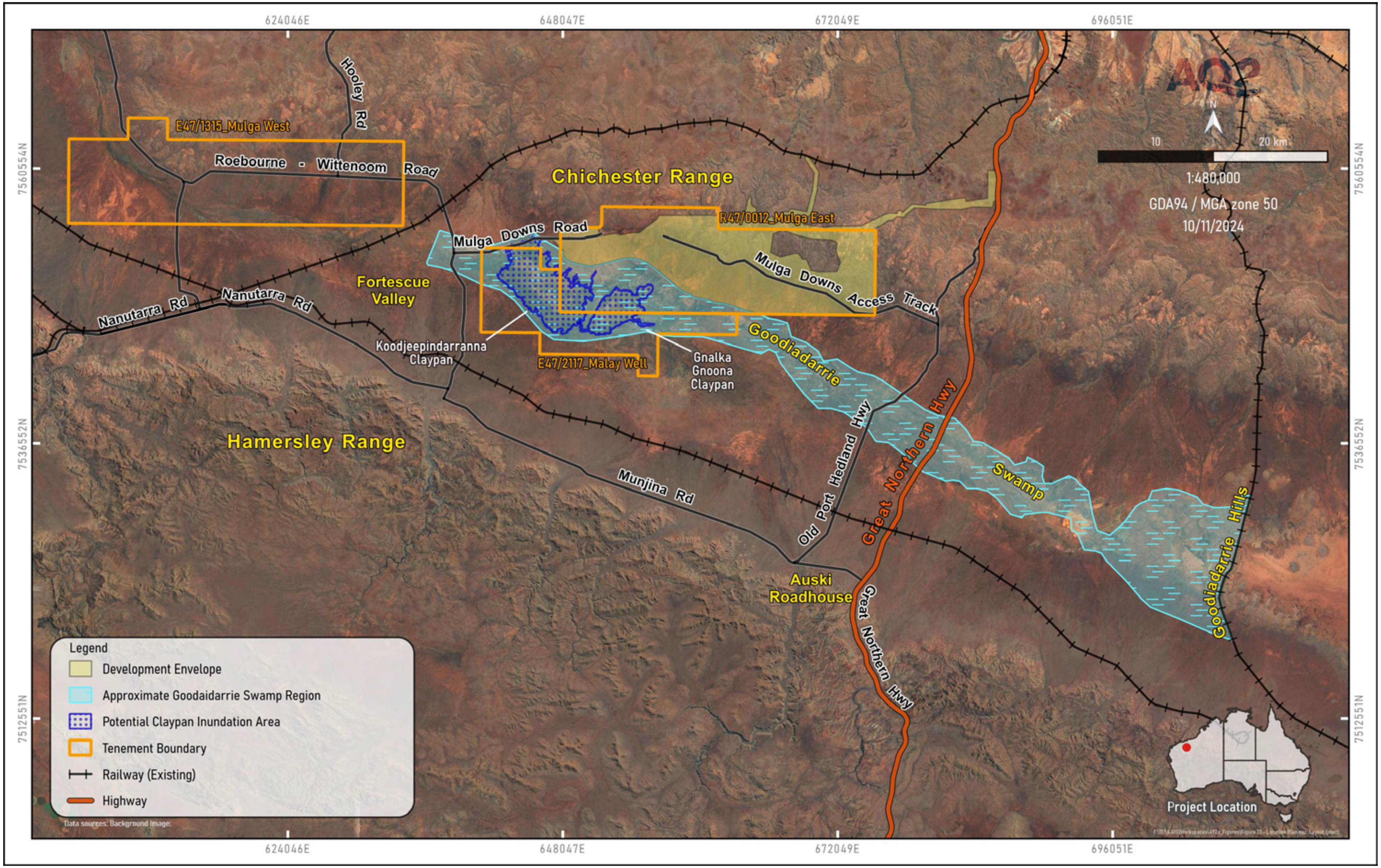


Figure 1.1 Location Plan

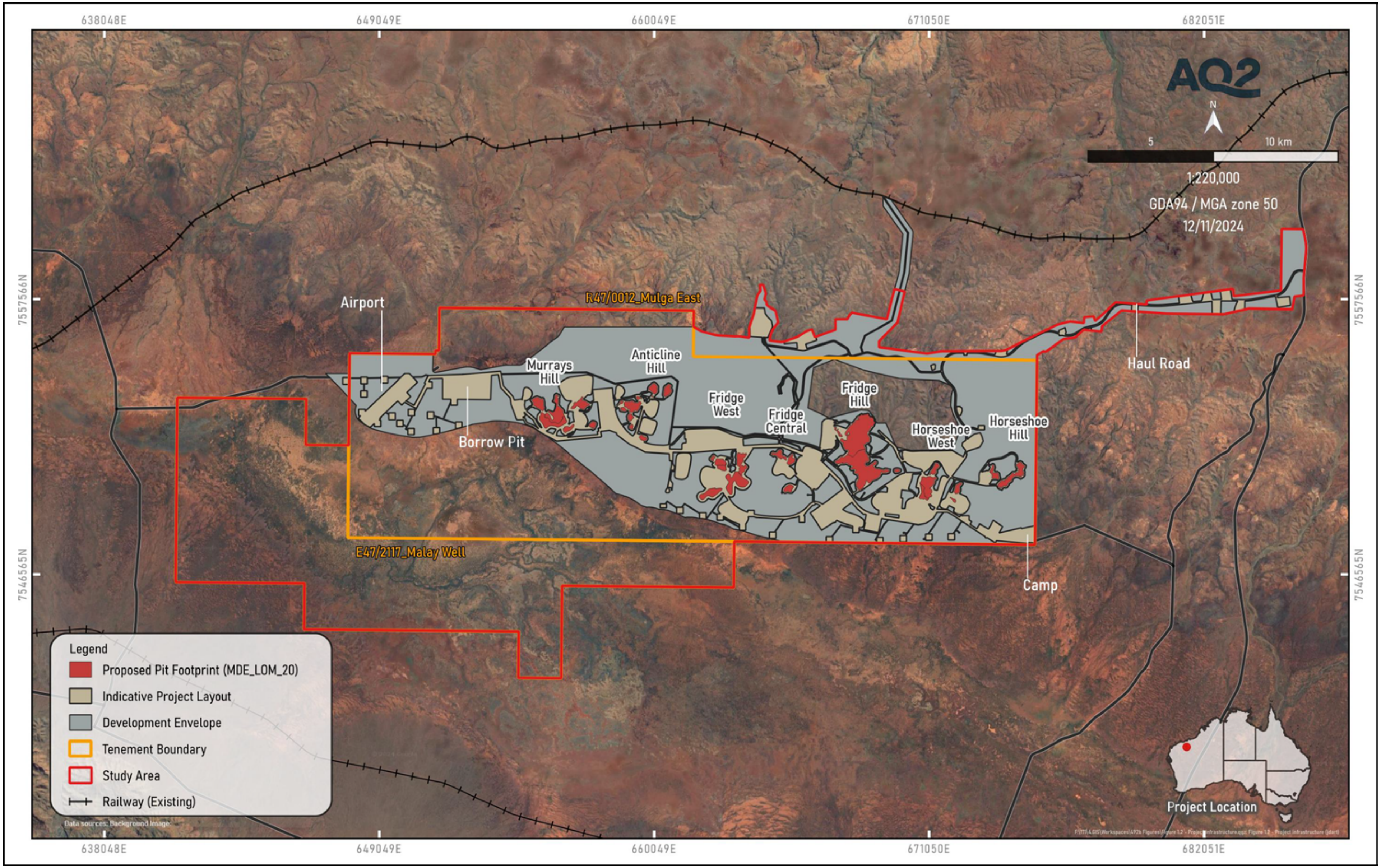


Figure 1.2 Indicative Project Layout

1.4 Physiography

The Study Area is located within the Chichester Range, on the northern flanks of the Fortescue Valley (refer Figure 1.1). The Chichester Range comprises low-lying hills which rise approximately 100 m above the level of the Fortescue Valley floodplain. The hills are cross-cut by narrow, steep-sided gullies, with colluvium and alluvial fans extending from the hills across the valley floor where drainages flow into the Fortescue Valley.

Within the vicinity of the Study Area, the Fortescue Valley comprises a network of interconnected ephemeral swamps, claypans and floodplains (collectively, an area known colloquially as Goodiadarrie Swamp), with the valley floor gently sloping in a westerly direction. The valley is some 20 km wide and is bound to the south by the Hamersley Range.

1.5 Regional Hydrology

The Fortescue Valley is split by the Goodiadarrie Hills (a ~5 m barrier that forms a surface water divide) into the (eastern) Fortescue Marsh and the (western) Goodiadarrie Swamp (refer Figure 1.1). The Fortescue Marsh (approximately 60 km to the east) is the largest ephemeral wetland in the Pilbara region and is recognised as a nationally important wetland. A second surface water divide exists to the west of the Goodiadarrie Swamp (immediately to the west of Koodjeepindarranna Claypan), separating the Goodiadarrie Swamp from the Lower Fortescue River.

1.6 Regional Geology

The bedrock within the Study Area comprises rocks of the Hamersley and Fortescue Groups (refer Table 1.1). The Jeerinah Formation (of the Fortescue Group) and Marra Mamba Iron Formation (Marra Mamba Formation) outcrop in the Chichester Range on the northern side of the Fortescue Valley. The Marra Mamba Formation and Wittenoom Formation subcrop beneath the valley floor within the Study Area, with the overlying Mt Sylvia Formation and Mt McRae Shale occurring to the south. The Brockman Iron Formation forms the Hamersley Range on the southern side of the Fortescue Valley (refer Figure 1.3). Tertiary and Quaternary deposits infill the valley. The Tertiary deposits are collectively referred as “detritals”, comprising pisolite, clay and calcrete; there is also lateritic hardcap development of Tertiary age on basement rocks, which may be ferricrete (goethite) and calcrete / silcrete. The Quaternary deposits comprise alluvium and colluvium.

The mineralisation within the Study Area is primarily associated with the Nammuldi Member of the Marra Mamba Formation (that outcrops along the lower flanks of the Chichester Range), although there is also mineralisation in the overlying Tertiary detrital deposits.

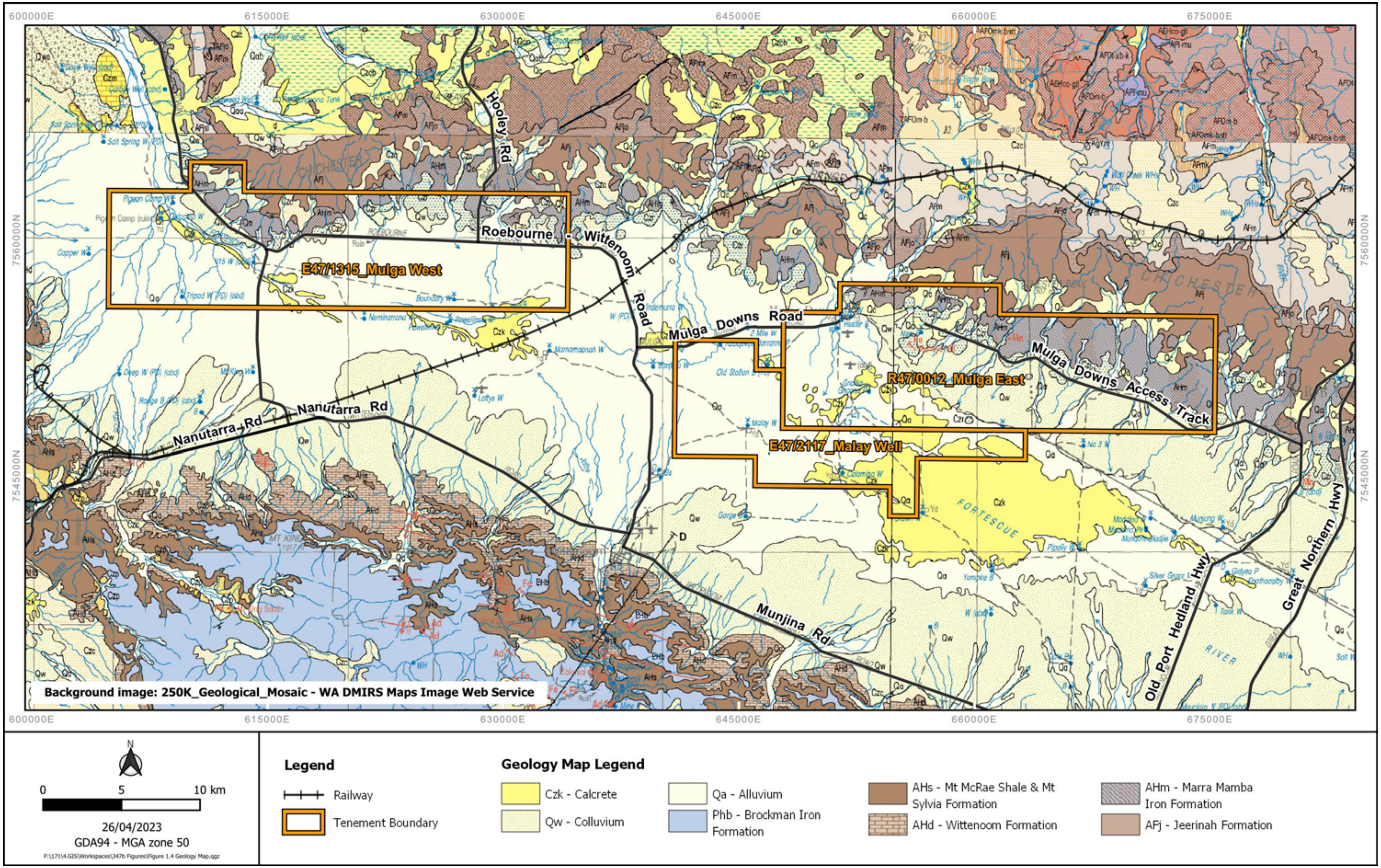


Figure 1.3 Geology Map

Table 1.1 Regional Stratigraphic Sequence within the Study Area

Group	Formation	Member	Lithological Description
Recent Alluvium / Colluvium			Unconsolidated silt, sand and gravel (clay near pans)
Tertiary Detritals (TD)	TD3		Red haematitic scree on valley sides. Increasing silt / clay content with distance from slopes / fans Increasing pisolitic content with depth
	TD2		Silcrete, calcrete (Oakover Formation), Channel Iron Deposit (CID), mottled clay
?*	?*	Pinjan Chert	Siliceous sediment with alternating laminated chert
Hamersley Group	Wittenoom Formation	Bee Gorge Member	Graphitic shale with minor sequences of carbonate, chert, volcaniclastic rock and Banded Iron Formation (BIF)
		Paraburdoo Member	Dolomite with minor amounts of chert and shale
		West Angela Member	Dolomite, dolomitic / manganese-rich shale, BIF and chert
	Marra Mamba Iron Formation	Mt Newman Member	BIF with minor shale
		MacLeod Member	Shale, chert and BIF
		Nammuldi Member	BIF, chert and shale
Fortescue Group	Jeerinah Formation	Roy Hill Shale Member	Dark grey to black graphitic shale with chert; locally pyritic
		Warrie Member	Grey dolomite with inter-bedded chert (locally ferruginous), shale and mudstone

*Age of the Pinjan Chert is uncertain

1.7 Native Title and Cultural Significance

The area covered by the water and ecohydrological studies is subject to two Native Title determinations (refer Figure 1.4). The Mulga East and Malay Well tenements fall within the native title area of the Banjima People, whilst the Mulga West tenement straddles the boundary of the Banjima People and Yindjibarndi People Native Title areas.

Mungurrdu (refer Figure 1.4) is a DPLH Aboriginal Cultural Heritage Lodged Place (ID:40484). The Banjima People are the Knowledge Holders for this place, it is culturally significant in multiple ways including as; a ritual and ceremonial area, a meeting place, a hunting place, a water source, and is associated with Creation/Dreaming stories. Banjima representatives first indicated to HanRoy the area had significant heritage values during a heritage survey in July 2023 before it was formally lodged as Mungurrdu with the DPLH in March 2024.

1.8 Land Use & Existing Groundwater Users

The Study Area lies within the administrative boundary of the Shire of Ashburton. The Mulga East and Malay tenements are wholly contained within the Mulga Downs pastoral lease area; whilst the Mulga West tenement is predominantly within the Mount Florence pastoral lease area; except for the western portion (circa 55 km^2) that intersects the northwest portion of the Mulga Downs pastoral lease and northeast fringe (circa 8.5 km^2) that intersects the Hooley pastoral lease (refer Figure 1.4). There is a long history of pastoral land use in the area, predominantly cattle grazing.

Existing groundwater users in the Study Area include the local and nearby stations (Mulga Downs, Hooley and Mt Florance Stations), for stock watering as well as the Wirrilimurra and Youngaleena Communities (refer Figure 1.5) and licenced water supplies associated with the construction of the existing FMG (Solomon) railway and RTIO (Goodiadarrie) railway.

1.9 Key Environmental Assets & Significant Fauna Habitat

Recognised conservation assets within and surrounding the Study Area, including identified Priority Ecological Communities (PECs), are summarised as follows, with spatial locations for those proximal to the Study Area shown in Figure 1.6:

- Freshwater claypans of the Fortescue Valley PEC (Priority 1) – this PEC includes a series of claypans in the Fortescue Valley, distributed over a distance of about 70 km from near the western end of the Fortescue Marsh to the Roebourne – Wittenoom Rd. The two westernmost claypans, known as the Gnalka Gnoona Claypan and the Koodjeepindarranna Claypan, are located in the Study Area (but outside the Development Envelope). The next claypan in the sequence moving east is the smaller Ebathcalby Claypan, located about 9 km south of the eastern margin of R47/12 (i.e. outside the Study Area). Note that the Koodjeepindarranna Claypan PEC buffer zone (based on Department of Biodiversity, Conservation and Attractions (DBCA) data set (DBCA 2020)) does not extend over the full ponding area which occurs during flooding of this claypan.

  DBCA surveys indicate that the wetlands of the Fortescue Valley may support over half of the aquatic fauna species present in the Pilbara (Pinder et al. 2017). Recognised values of and threats to the PEC include (DBCA 2022):

  - Values: Important for waterbirds, invertebrates and some poorly collected plants. *Eriachne* spp., *Eragrostis* spp. grasslands. A unique community with few *E. victrix* trees.
  - Threats: grazing, weed invasion, infrastructure corridors, altered hydrological flows, altered fire regimes.
- The four plant assemblages of the Wona Land System PEC (Priority 1 and 3), comprising a system of basalt upland gilgai plains with unusual grassland vegetation assemblages. The PEC occurs north of the Goodiadarrie Swamp sub-catchment divide and is therefore ecohydrologically disconnected from the proposed pit areas, however, the proposed haul road crosses through the PEC. Recognised threats include grazing, clearing for mining related activities and solar farms, altered fire regimes (DBCA 2022).
- Several small, persistent pools in or near the Study Area are considered to have potential local conservation significance including (refer Figure 1.6):
  - Channel pool within the Koodjeepindarranna Claypan complex. This was site PO5A in the Pilbara Biological Survey (Pinder et al. 2010).
  - Channel pool at UTM Zone 50 653300E and 7550400N. Identified from aerial photography.
  - Channel pool at UTM Zone 50 661600E and 7547770N. Identified from aerial photography.
  - Gidyea pool south of the Study Area, proximal to the Ebathcalby Claypan – has significant wetland floor vegetation in contrast with claypans further to the west (Pinder et al. 2017).
  - Immediately upstream of the claypans, water ponding on the northern side of the valley and at the foot of the Chichester Range is apparent. This area partially corresponds with an Environmentally Sensitive Area (ESA) mapped by DWER. The proposed pit footprints are in excess of 1 km from this area.
- Also of note is the prominence of *Acacia stenophylla* in the Fortescue Valley floodplain woodlands within the Study Area. Although this species occurs across much of inland eastern Australia, the Fortescue Valley population is a major outlier from its core distribution.

- The Fortescue Marsh PEC (Priority 1) is located about 30 km to the east of the Great Northern Highway and about 60 km to the east of the Project mining areas. It consists of saline plains and lake beds some 100 km long, 5 to 20 km wide and occupying an area of approximately 1,000 km^2 (Markey 2017). The conservation values of the Fortescue Marsh are well recognised (EPA 2013). The marsh provides habitat for a variety of plant, invertebrate and vertebrate species of conservation significance. It has particular importance as a breeding and foraging habitat for waterbirds following flood events. In 2015, much of the land encompassing the marsh was excised from four pastoral leases and now constitutes the Fortescue Marsh Nature Reserve (Nyiyaparli Country), a Class A nature reserve. Forming the terminus of the Upper Fortescue Catchment, the marsh is considered to be hydrologically disconnected from the Study Area.
- A large portion of the Fortescue Valley including the Fortescue Marsh to the east of the Study Area is listed in the Directory of Important Wetlands in Australia[1] (DIWA066, Fortescue Marshes). As outlined in Section 1.8, the Fortescue Valley in the vicinity of the Project (including the freshwater claypans) is listed as a DPLH Aboriginal Cultural Heritage Lodged Place called Mungurrdu (ID:40484), shown on Figure 1.4.
- A number of threatened and migratory species listed under the *Environment Protection and Biodiversity Conservation Act 1999* and conservation fauna under the *Biodiversity Conservation Act 2016* have been identified as potentially utilising the habitats of the Study Area (DCCEEW 2023, JBS&G 2024a).

The Study Area does not contain any Threatened Ecological Communities (TECs) listed under the *Biodiversity Conservation Act 2016* or the EPBC Act.

[1] https://www.dcceew.gov.au/water/wetlands/australian-wetlands-database/directory-important-wetlands

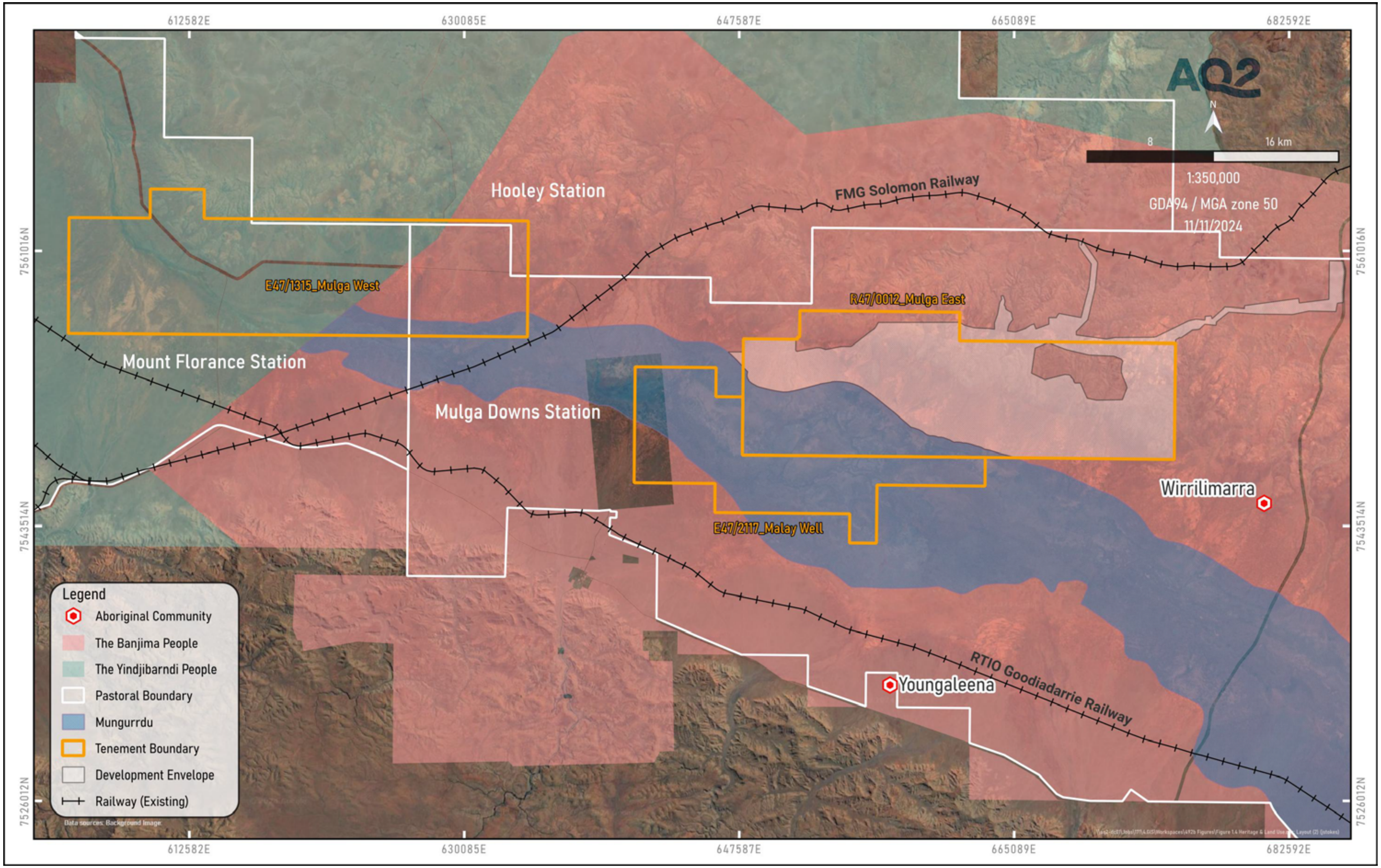


Figure 1.4 Pastoral & Native Title Boundaries

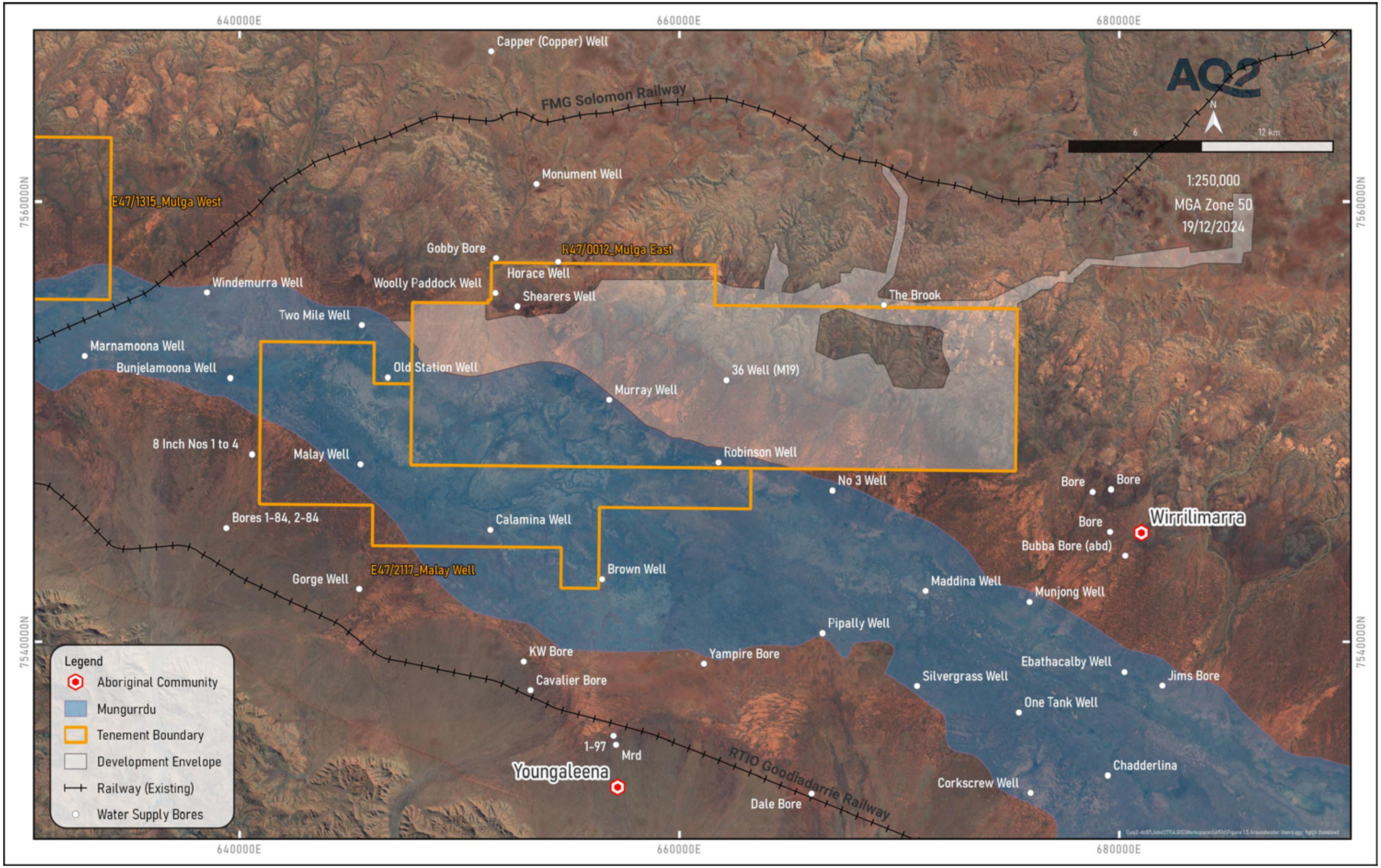


Figure 1.5 Groundwater Users

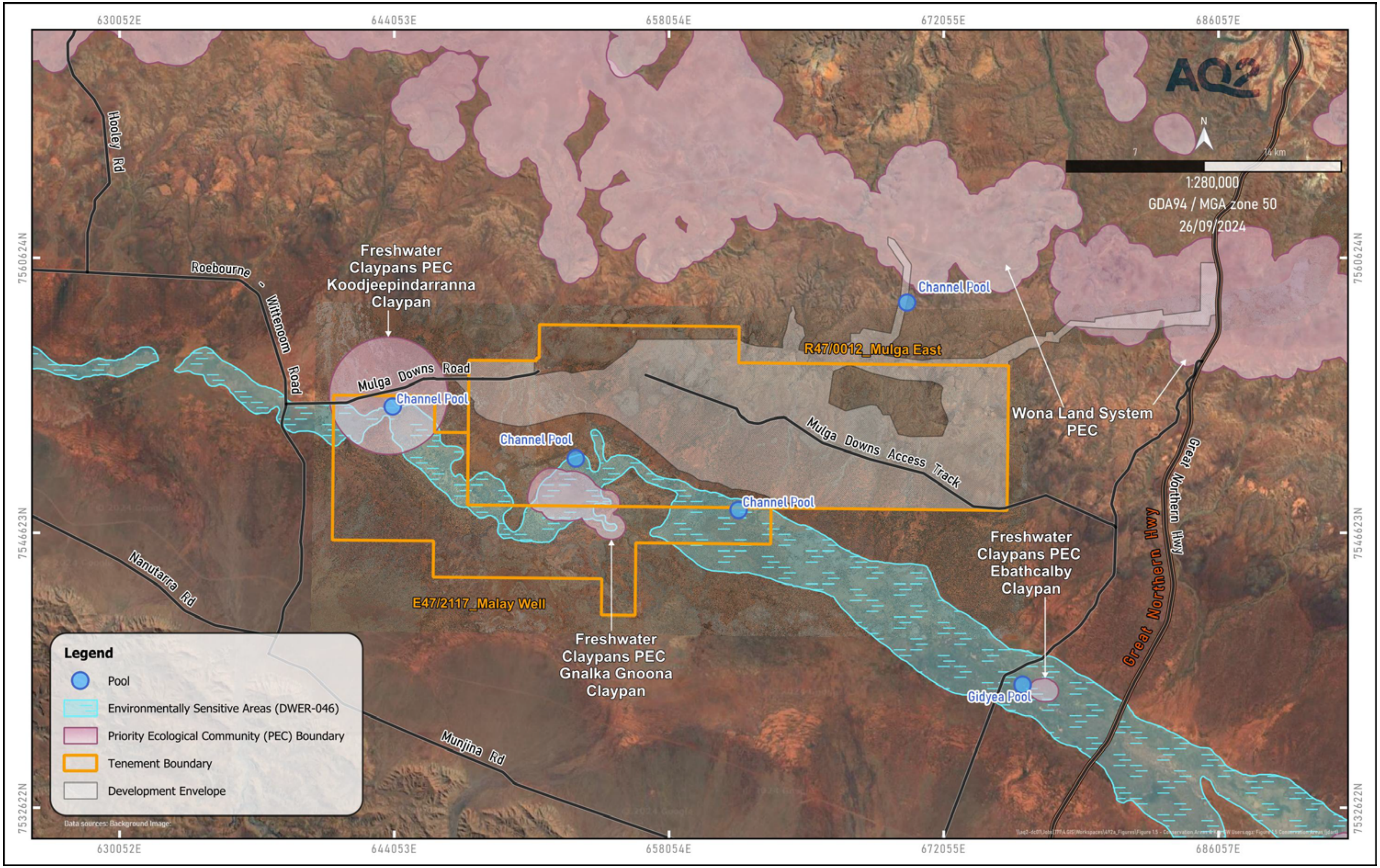


Figure 1.6 Conservation Areas

2. CLIMATE

2.1 General

The climate of the Pilbara is characterised by hot dry summers and mild winters (BOM 2024), with low average rainfall depths and highly variable rainfall. Based on mapping of the Koppen classification for climate (BOM 2024), areas within the Project location are classified as hot desert (winter drought) and hot grasslands (persistently dry).

Average daily maximum temperatures across the Pilbara are typically around 20°C in winter and exceed 30°C across the region in summer and early autumn. Average daily maxima temperatures tend to exceed 35°C from October to March and it is not uncommon to see temperatures more than 40-45°C.

Rainfall in the Pilbara is greatest during summer and autumn and least during winter and spring. It is spatially and temporally variable, with average annual rainfall totals ranging between 250-500 mm, the latter occurring in elevated areas such as the Hamersley Range situated south of the Project. Tropical cyclones, not uncommon to the Pilbara region, cause the most extreme rainfall events and generate 25–34% of the total annual rainfall near the Pilbara coast and as much as 21% up to 450 km inland (Sudmeyer 2016). Average monthly evaporation exceeds average monthly rainfall throughout the year.

The long-term average maximum daily temperature and annual rainfall at the Project is approximately 33°C and 355 mm respectively. A plot of the average minimum and maximum temperatures recorded at the Wittenoom weather station (now closed) and a comparison of average monthly rainfall to average monthly evaporation is shown in Figure 2.1.

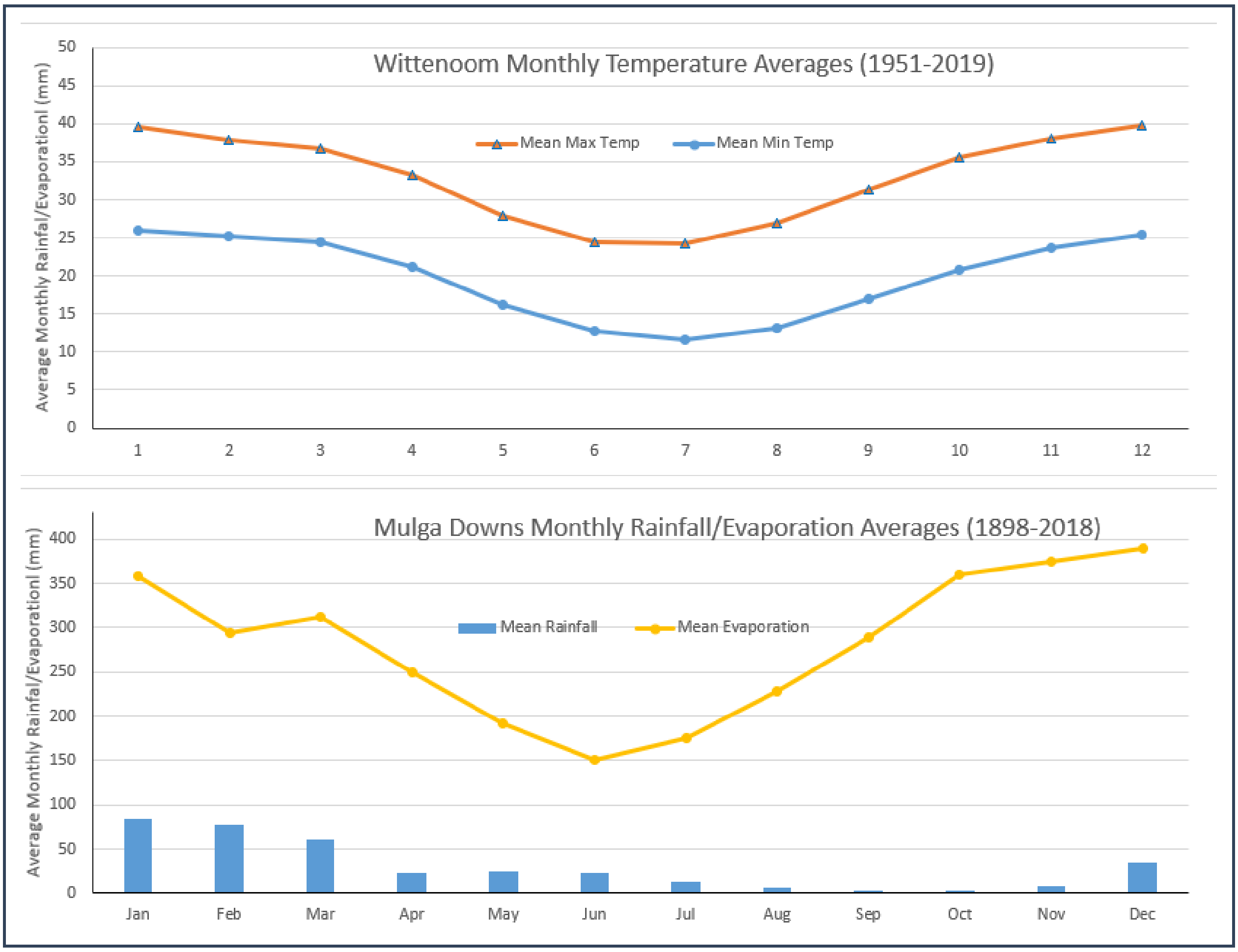


Figure 2.1 Mulga Downs Average Monthly Climate Data

2.2 Long Term Climate

In areas where measured rainfall data is sparse (spatially or temporally), interpolated rainfall data can be used from the Scientific Information for Land Owners project (SILO; Jeffrey et al. 2001). SILO provides gridded historic daily climate parameter estimates from 1889 to present, for any location in Australia to the closest 0.05° latitude/ longitude (decimal degrees).

An assessment of the long-term annual rainfall and maximum temperature totals for the Study Area has been undertaken using the SILO data for the period from 1900 to 2021, for locations -22.10 degrees south and 118.50 degrees east (Mulga East area) and -22.05 degrees south and 118.15 degrees east (Mulga West area). The data from each location were appraised to be materially similar (refer Table 2.1); as such climate data for the Mulga East area has been selected as representative of the Study Area and is plotted in Figure 2.2. Also shown is the cumulative deviation from the long-term average rainfall and temperature respectively. A deviation moving in an increasingly negative direction indicates drier (or cooler) than average conditions; an increasingly less negative (or positive) deviation indicates wetter (or hotter) than average conditions.

Three broad climatic periods can be defined:

- From 1900 until approximately 1970, there is an increasingly negative deviation from the long-term average rainfall, which indicates a dry period. There was a similarly increasingly negative deviation from the long-term average maximum temperature. Over this time only, average rainfall at Mulga East was 321 mm/year (compared with 359 mm/year as the long-term SILO average rainfall).
- For a circa 25-year period from 1970 to 1995, actual rainfall appeared to be close to the long-term average. Average rainfall at Mulga East over this period was 378 mm/year. Average maximum temperature was relatively stable.
- From 1995 to the present, the cumulative deviation became increasingly less negative indicating a wetter than average period. Average rainfall at Mulga East over this period was 445 mm/year. Maximum temperature shows a strongly increasing trend, and mean annual maximum temperature was 0.5^{0}C greater than preceding periods.

A Budyko model (Sposito 2017, Trancoso et al. 2016, Budyko 1974) was used to further investigate the energy/water balance for the Study Area, which controls the type of vegetation that can sustainably develop. Summary data for the Mulga East and Mulga West areas respectively are shown in Table 2.1. Of note:

- The aridity index (ratio of potential evapotranspiration to rainfall) varies depending on rainfall and temperature trends, but always falls within the 'arid' bandwidth.
- The Budyko model predicts that actual evapotranspiration (ET) in the Study Area is perpetually water-limited (not energy limited) despite varying rainfall inputs. Under these conditions, actual ET will approximate precipitation (i.e. almost all available water will be lost through evapotranspiration). This is consistent with the generally low rates of groundwater recharge in the Pilbara (McFarlane, 2015).
- Notwithstanding the water limitation, there is estimated to have been a significant increase (circa 25%) in actual ET due to the increased rainfall (when comparing the driest period between 1900 and 1970 and the wettest period between 1995 to current). Over this time scale, vegetation density would be expected to increase in response to increased ET (both in stem-size and leaf area of existing vegetation and in new vegetation recruitment). Thus, there are likely to have been significant changes in vegetation structure and density across the catchment over the last 100 years.

It is important to note that the Budyko estimates of actual ET (i.e. 312 to 443 mm; Table 2.1) represent a landscape scale average. In practice, actual ET will vary on a local scale and the following inferences can be drawn:

- For areas where ET is less than circa 440 mm/yr, site related limits on vegetation development can be inferred (such as constraints in substrate depth, soil quality, or infiltration capacity).
- For areas where ET is more than circa 440 mm/yr, additional plant-available-water can be inferred. This could arise from water transfers to vadose-zone storage through runoff accumulation and infiltration (e.g. such as from inundation of the claypans) and / or water-transfers from groundwater through phreatophytic water use. The storage capacity of the vadose zone is an important factor enabling vegetation utilisation of surface inflows.

Total ET (as estimated by the Budyko method) is a function of several individual components:

- Evaporation from open-water bodies in the Pilbara region is approximately 2,600 mm/yr; noting that this can be affected by site specific factors including solar shading, wind exposure, and humidity (Bourke et al. 2023; McJannet et al. 2017).
- Bare soil evaporation, which is most prominent immediately following rainfall / infiltration events and declines rapidly as the soil dries out. In a recent study in the Weeli Wolli catchment (east of the Study Area), weighing lysimeter measurements of soil evaporation were 0.2 and 0.7 mm/day during dry conditions (equivalent to around 80 – 240 mm/year) and 0.3 and 13.0 mm/day (average = 3.7 mm/day) during wet conditions (Tugwell-Wootton et al. 2020). Wet conditions only occur over short periods (days to weeks).
- Transpiration from vegetation, which is proportional to leaf area index (LAI), comprising:
    - Overstorey trees (e.g. *Eucalyptus victrix* in the Fortescue Valley). In woodlands and forests, overstorey trees dominate the vegetation LAI and hence transpiration flux.
    - Transpiration from understorey vegetation (e.g. grasses and small trees and shrubs such as *Acacia* spp. in the Fortescue Valley); which contribute to overall vegetation LAI. Some understorey species, particularly shallow rooted functional types, display seasonal water use behaviour (e.g. become dormant during dry phases).
    - Note that other factors such as soil fertility, bushfires, and cattle grazing can also influence vegetation LAI and transpiration flux.
- Interception losses comprising water intercepted and evaporated from vegetation canopies without reaching the soil surface. Higher interception losses are associated with denser vegetation. Based on global meta studies of rainfall interception in dryland vegetation types (Magliano et al. 2022)), interception by the Fortescue Valley *E. victrix* open woodlands is likely to be in the order of 5 - 10% of rainfall (i.e. about 20 to 40 mm/year).

Table 2.1 Long Term Climate Statistics (From SILO Data)

Period (Years)	Type Conditions (rainfall, temp)	PET (Morton's point potential)	Average Rainfall	Average Max. Daily Temp	Aridity Index	Budyko Actual ET Estimates (mm/yr)	Actual ET / Precipitation	ET var. from long term avg (%)
		(mm/yr)	(mm/yr)	^{0}C		Average	(%)	
MULGA EAST								
Long term average	Long-term	3,359	359	33.1	0.11	359	99.81%	0.0%
1900 - 1970	Dry, warm	3,375	321	33.0	0.09	320	99.85%	-10.8%
1971 - 1994	Average, warm	3,360	378	33.1	0.11	378	99.78%	5.3%
1995 - 2021	Wet, hot	3,319	445	33.6	0.13	443	99.67%	23.6%
MULGA WEST								
Long term average	Long-term	3,336	352	33.0	0.11	351	99.81%	0.0%
1900 - 1970	Dry, warm	3,343	312	32.8	0.09	312	99.85%	-11.2%
1971 - 1994	Average, warm	3,354	366	33.0	0.11	365	99.80%	4.0%
1995 - 2021	Wet, hot	3,301	443	33.5	0.13	442	99.67%	25.9%

Notes:

Aridity Index; based on United Nations Environment Programme Formula: $AI = \frac{Precipitation}{PET}$

Classification	Aridity Index
Hyperarid	AI < 0.05
Arid	0.05 < AI < 0.20
Semi-arid	0.20 < AI < 0.50
Dry subhumid	0.50 < AI < 0.65

Budyko estimates of Actual ET provide a catchment-wide average over multi-year timescales and are not representative of areas where water is "focussed"

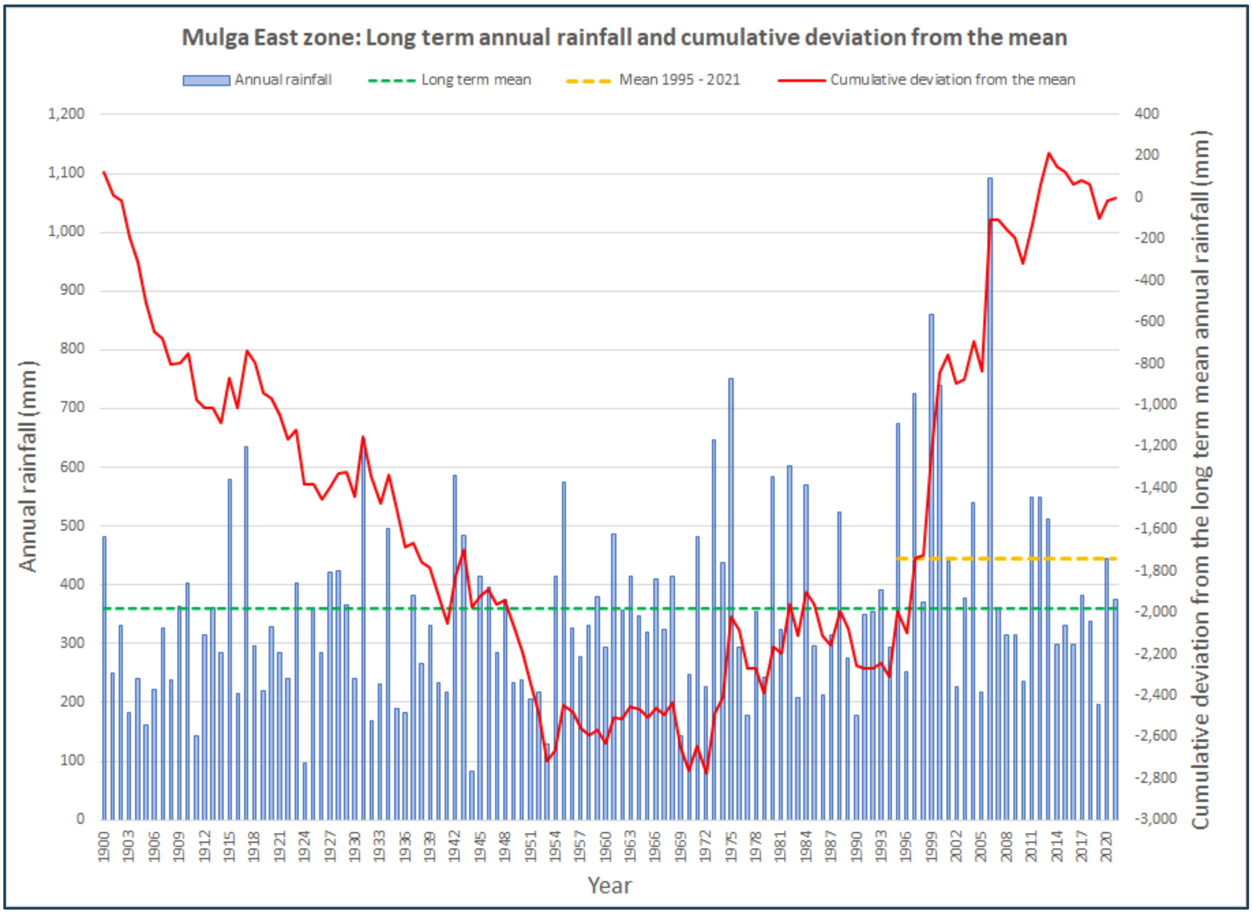
Overall average is derived from the SILO record over the period 1900 to 2021 and used as a baseline

ET variation is calculated by comparing average ET for a defined period against the long-term average

Type Conditions is a qualitative descriptor that describes the average rainfall and temperature for a defined period with respect to the long-term

Budyko Actual ET estimate is average of Budyko, Ol'Dekop and Schreiber methods (Li and Lu 2014)

Morton's point potential PET (Morton 1983) sourced from SILO database



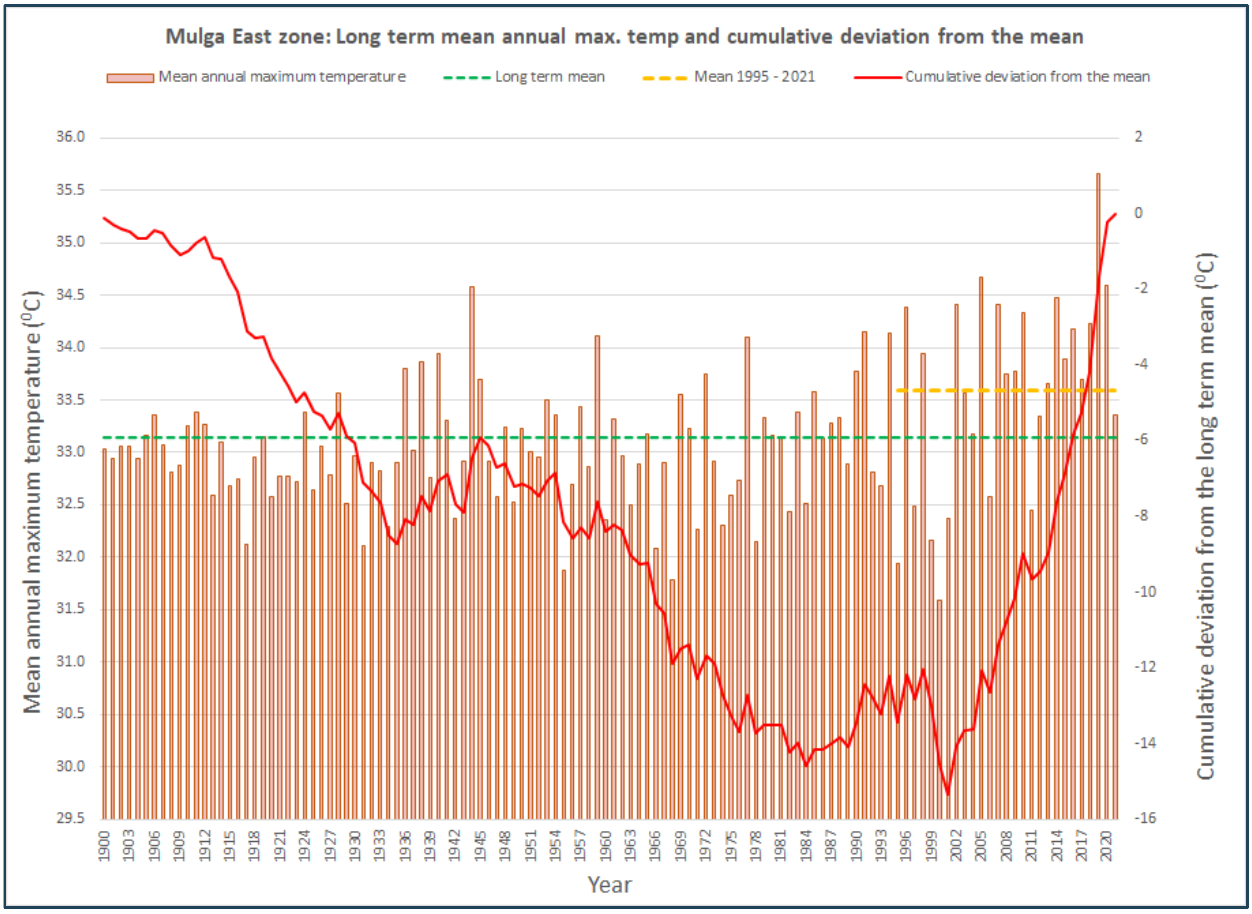


Figure 2.2 Time Series of Rainfall and Temperature at Mulga East

2.3 Recent Climate Trends

SILO rainfall data for the Study Area since 2012 is shown in Figure 2.3. Also shown is cumulative ETo (Penman-Monteith short crop reference evapotranspiration FAO56; Allen et al. 1998) between daily rainfall events greater than 25 mm, which approximates the rainfall threshold to generate significant runoff, creek flows and soil water replenishment. Notably 2019 was one of the driest years on record (198 mm) and also the hottest year on record (Figure 2.2). The rainfall data shows a prolonged period of soil water depletion and drought stress occurred between June 2018 and February 2020, which was not alleviated until a major rainfall event (93 mm) on 9 February 2020.

Further examination of drought trends was completed by using the Drought Indices Calculator (DrinC) (Tigkas et al. 2015; 2019; 2022) to calculate the Agricultural Standardized Precipitation Index (aSPI) for the period 1970 to present (Figure 2.4). The aSPI is a modification of the Standardised Precipitation Index (SPI), based on the substitution of the total precipitation by effective precipitation (P_e), which describes more accurately the fraction of precipitation that can be used productively by vegetation. Values for aSPI can be interpreted as standard deviations that the observed P_e deviates from the long-term mean. This analysis confirms that the 2018-19 drought was one of the most severe in the past 50 years, with other notable droughts occurring in 1976-77, 1978-79, 1985-86 and 2001-02.

In addition to seasonal variation in climate, heat wave frequency and severity has increased since the turn of the century (Figure 2.5). Heat waves can be characterised by consecutive days above a threshold percentile value for temperature and/or vapour pressure deficit. Vapour pressure deficit (VPD) is the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated (Breshears et al. 2021). A threshold percentile value of 99.5% for the period 1975 to present was used to evaluate heat wave severity over this period; based on SILO climate data. This corresponded to maximum temperature greater than 45^{0}C and a VPD greater than 67 hPa. Extreme heat wave events were identified to occur in February 2007, January 2010, December 2014, and December 2018.

Numerous studies have documented the lethal effects of acute heatwaves on trees (Yi et al. 2022, Breshears et al. 2021 and references therein). This includes synergistic effects of combined heat and drought. Extreme heat can cause photo-system damage and reduced photosynthetic capacity, over and above hydraulic failure and tissue desiccation caused by drought. Heat and drought can also cause chronic, sub-lethal damage to trees rendering them vulnerable to future stressors.

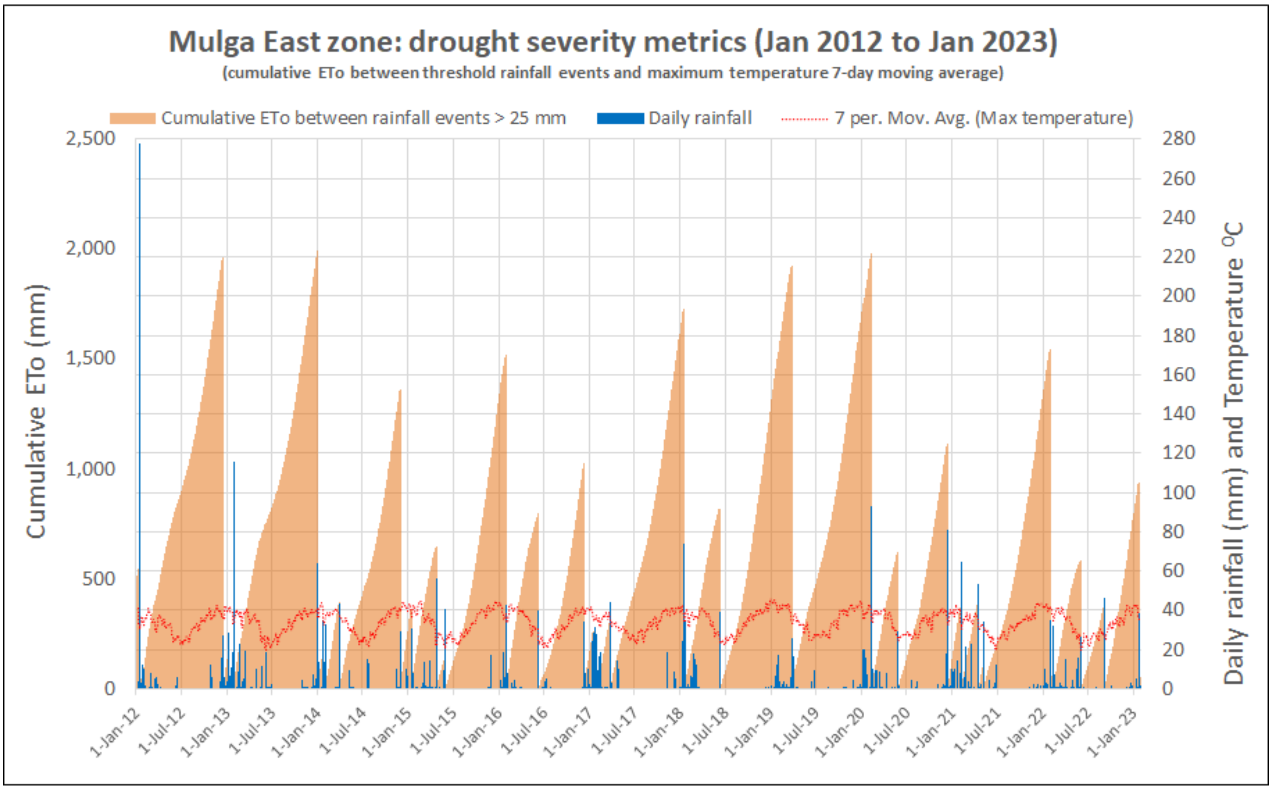


Figure 2.3 Recent Climate Trends in the Study Area

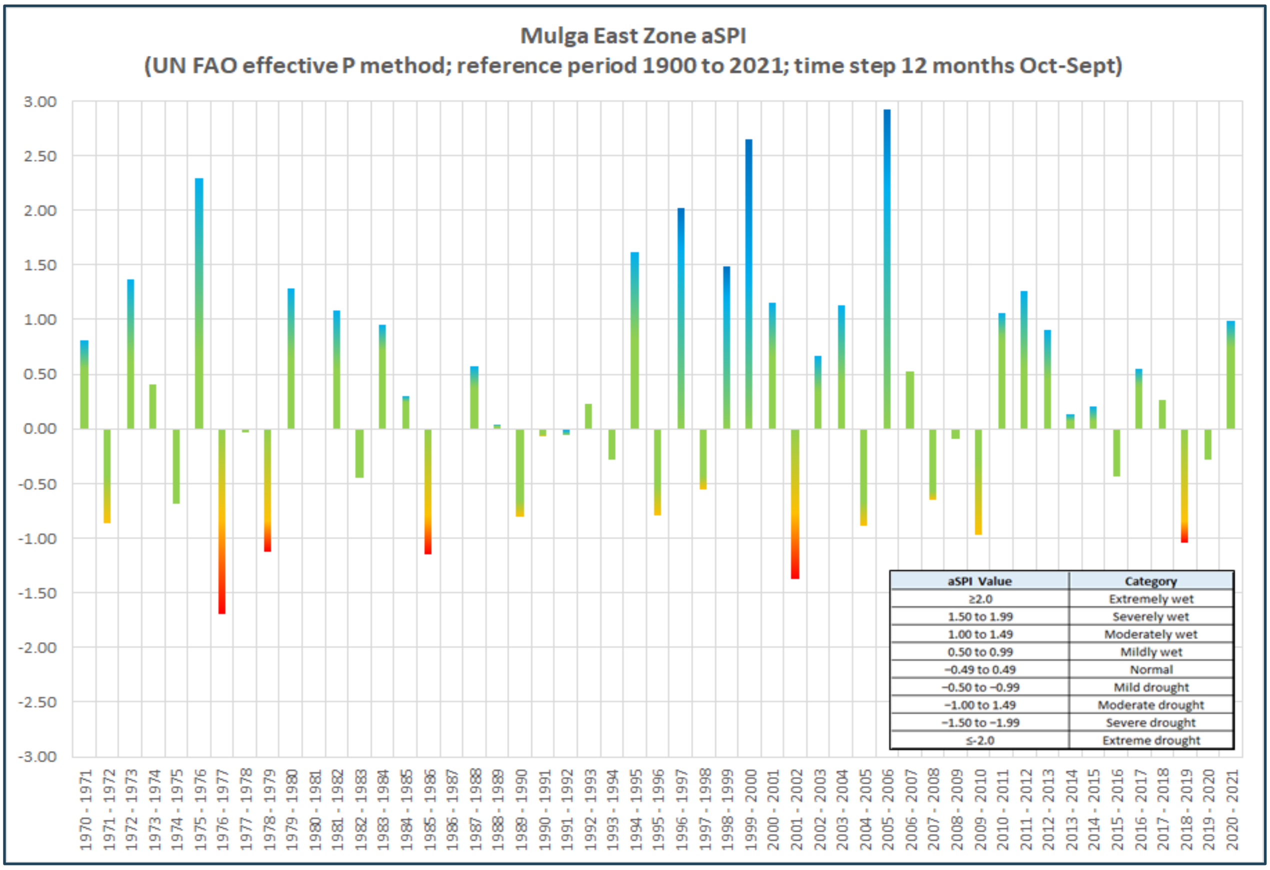


Figure 2.4 Drought Severity in the Study Area since 1970

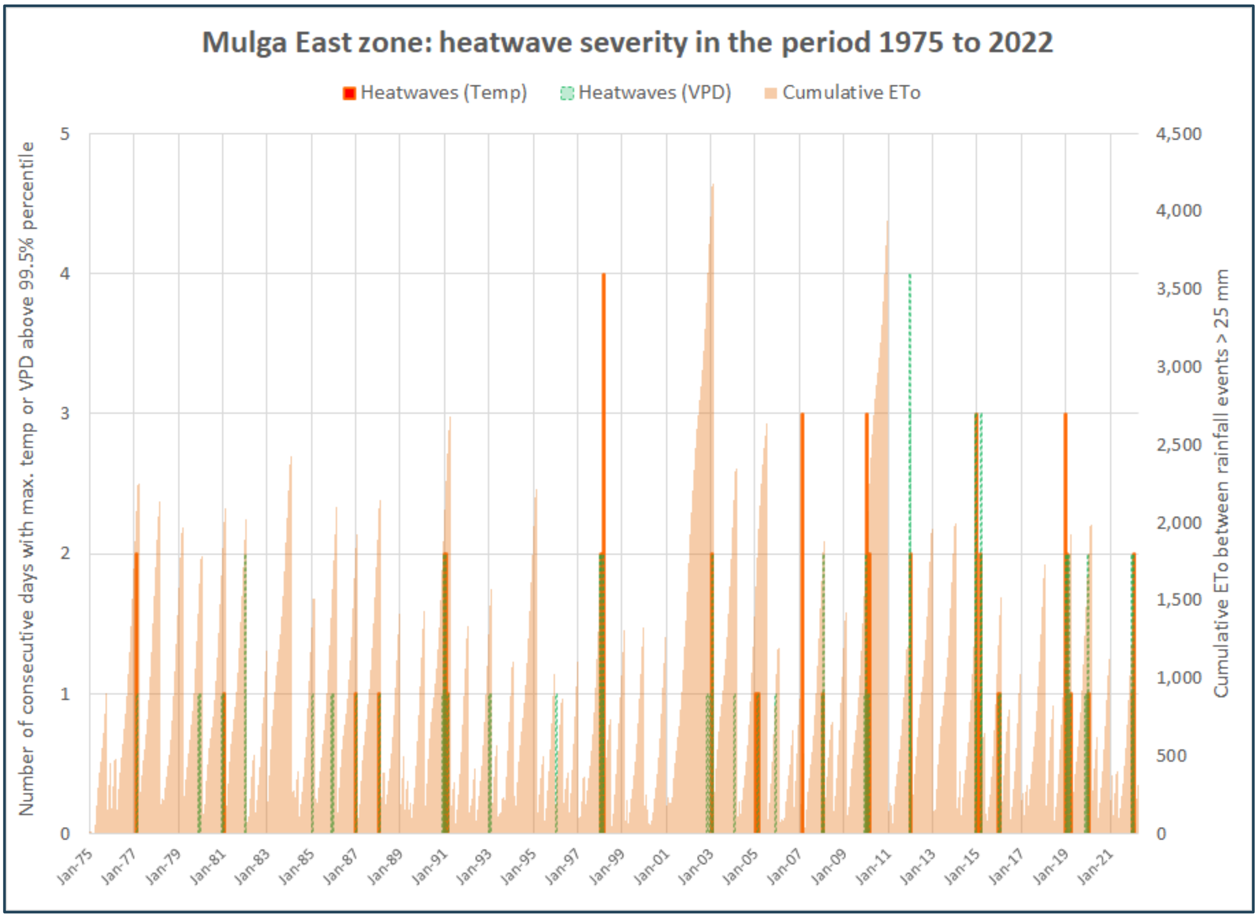


Figure 2.5 Heatwave Severity in the Study Area since 1975

2.4 Climate Change

Climate change projections give the climate response to a set of greenhouse gas, aerosol and land-use scenarios that are consistent with socio-economic assumptions of how the future may evolve. These scenarios are known as the Representative Concentration Pathways (RCPs). The climate projections developed by the CSIRO, Bureau of Meteorology (BoM) and Western Australian Department of Water (DoW) show very high confidence for substantial temperature increases across various emission trajectories (RCPs) to continue in the Pilbara (DoW, 2015; Sudmeyer, 2016). The results indicate that annual average temperature is projected to increase by 0.6–1.5°C by 2030 and by 1.5–3.1°C and 3.1–5.6°C by 2090 for medium (RCP4.5) and high (RCP8.5) emission trajectories respectively. Annual rainfall projections are subject to considerable uncertainty, with the range of projections including both decreases or increases. However, by the end of the 21st century there is high confidence that natural rainfall variability will remain the primary driver of rainfall changes. There is medium confidence that tropical cyclones will become less frequent in future but will increase in intensity. These changes are likely to increase the exposure of vegetation and other biota to water stress. For some species, which are already persisting near their upper limits of climatic extremes and resource limitations, there is a risk of species decline/loss and associated ecosystem destabilisation if climate change intensifies (Lewandrowski et al. 2021).

2.5 Site Collected Data

Across the Mulga Downs region three private rain gauges were installed by HPPL, these include Mulga Downs Exploration Camp (MDEC), Drillers Ridge and Bismark Gorge. In addition, there are a number of BoM run weather stations in proximity to the Project, namely Mulga Downs (ID 5015), Wittenoom (ID 5026) and Karijini North (ID 5098). Of these BoM stations, only Karijini North remains operational. The location of these weather stations is shown in Figure 2.6.

A summary of the available data from these weather stations is summarised in Table 2.2. Note that the data from the HPPL weather station is recorded at varied intervals, most commonly in 30-minute increments but also in hourly increments. There is also a large amount of missing data and some discrepancies in the recordings. As a result of this, and distance from the Project, only the MDEC rainfall recordings have been used in the baseline assessments. Where the MDEC rainfall is missing, data from the BoM weather stations has been used to complete the data set. The order of preference for the use of data is summarised in Table 2.2.

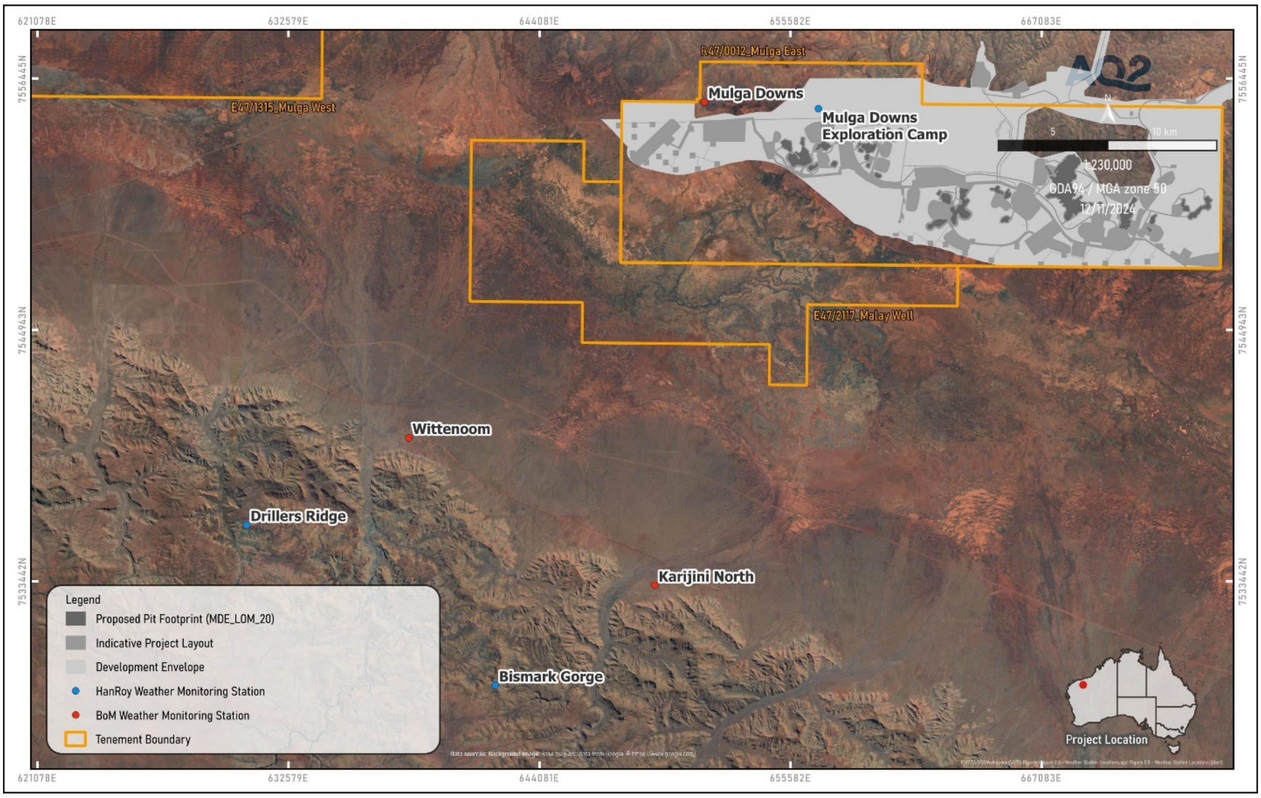


Figure 2.6 Regional Weather Station Locations

Table 2.2 Available Weather Station Data

Weather Station	Owner	Priority	Easting	Northing	Open	Close	Completeness** (%)
Mulga Downs Exploration Camp	Hanroy	1	656864	7555069	*2018	-	45%
Mulga Downs (BoM 5015)	BoM	2	651639	7555371	1897	2019	90%
Karijini North (BoM 5098)	BoM	3	649363	7533248	2018	-	95%
Wittenoom (BoM 5026)	BoM	4	638090	7539995	1949	2019	94%
Drillers Ridge	Hanroy	5	630670	7536006	*2022	-	40%
Bismark	Hanroy	6	642052	7528668	*2023	-	20%

*This corresponds to the first data point in the provided data set.
** Completeness refers to the available data between the first and last datapoint provided.

Within the data collected by the MDEC the largest rainfall event (which also shows a significant response in the monitored creeks) occurred on the 5th of January 2020, where a total of 93 mm fell over 2.5 hours (half hourly rainfall depths shown in Figure 2.7). This rainfall event was used to calibrate the hydrology model to develop estimates of rainfall losses to be used in wider flood study work (discussed further in Section 4).

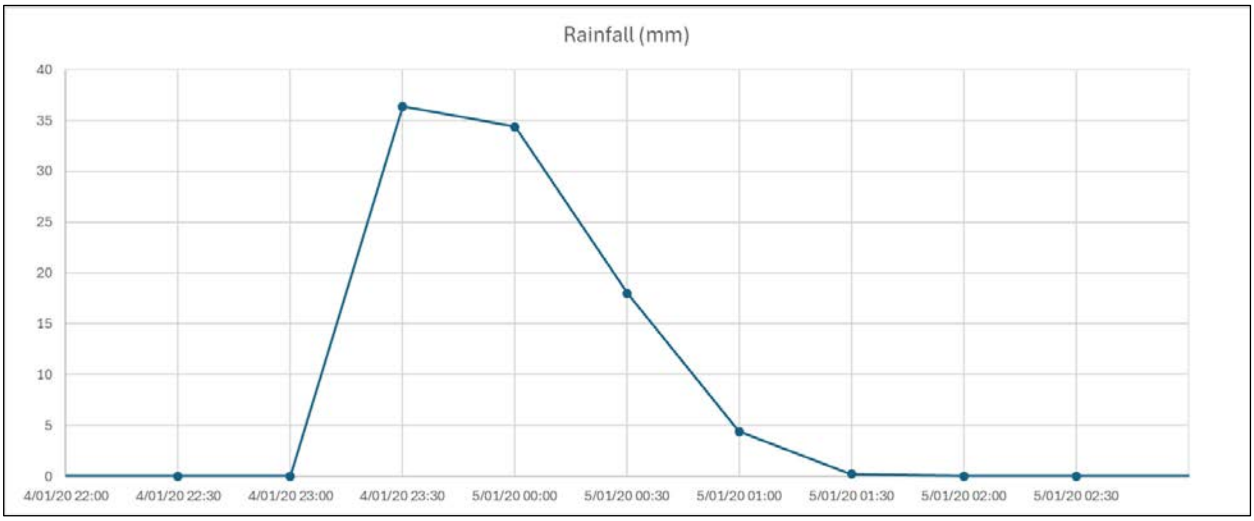


Figure 2.7 Isolated Rainfall Event from MDEC (5/1/2024)

The rainfall within the Pilbara is characterised as having a high degree of spatial variability. Figure 2.8 shows the average annual rainfall totals for three distinct periods in the climate record (as discussed in Section 2.2). The graph shows that the average rainfall recorded at Wittenoom and Mulga Downs BoM weather stations between 1953 and 1998 were relatively similar, however between 1994 and 2018, there is a significant difference in the average rainfall total between the two rain gauges (with Wittenoom being wetter). This period coincides with the wetter period of rainfall as discussed in Section 2.2.

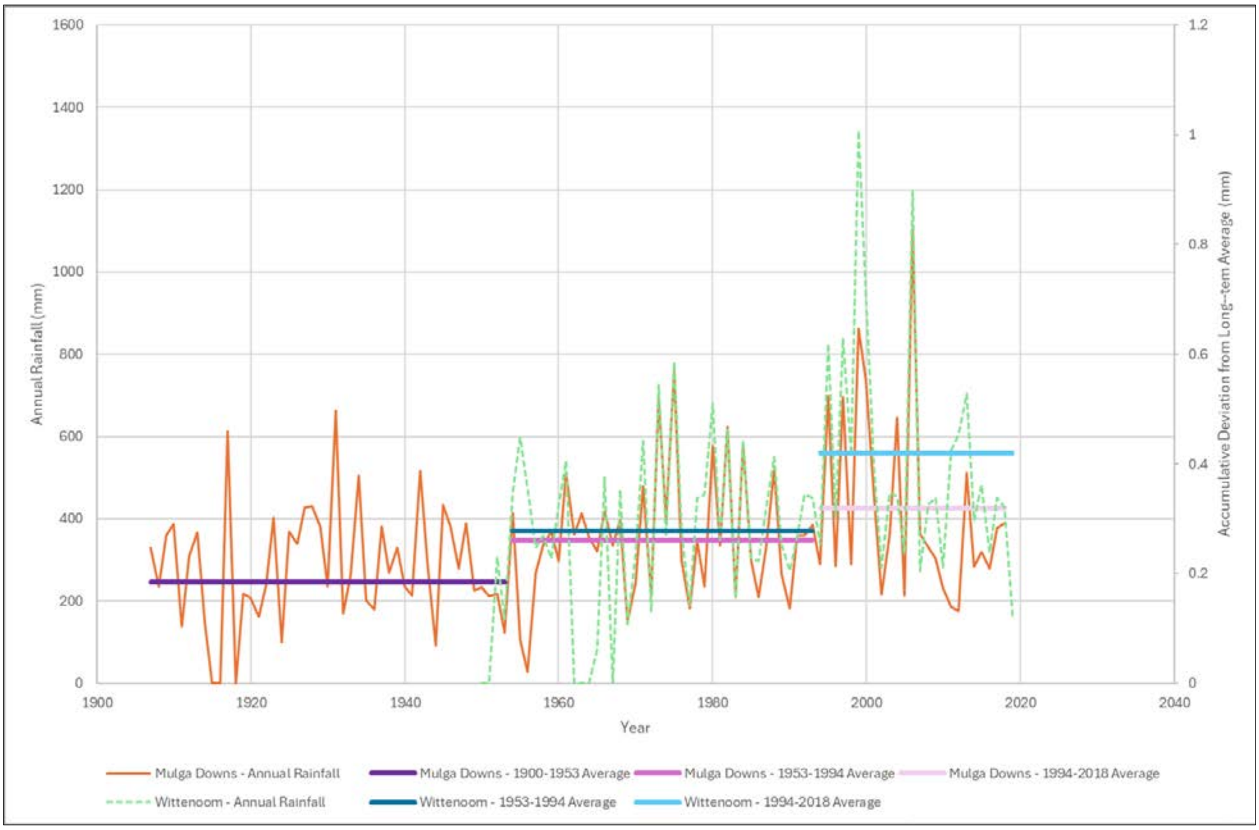


Figure 2.8 Annual Rainfall Comparison (BoM Mulga Downs and Wittenoom Weather Stations)

2.6 Compiled Rainfall Data Sets

Two sets of rainfall data have been created for use in the baseline assessments documented in this report for the following purposes:

- Data Set 1: sub-daily rainfall data, for use in determining runoff parameters for surface water modelling.
- Data Set 2: daily rainfall data, for use in groundwater assessments and claypan water balance modelling.

Data Set 1 was compiled from the HPPL weather stations to create a 30-minute interval rainfall data set. The data set spanned from 2019 to 2023, and used MDEC rainfall where it was available, and Drillers Ridge and Bismark Gorge data to patch missing periods from MDEC. Note that despite having data from all three weather stations, Data Set 1 only covered 49% of the period between 2019 and 2023.

Data Set 2 used the MDEC 30-minute rainfall records (summed to a daily total) for the recent rainfall and the BoM Mulga Downs rainfall station for longer-term rainfall data. Gaps in the record were patched using data from BoM's Wittenoom and Karijini rainfall gauge as per the priorities shown in Table 2.2. A plot of the daily rainfall records is provided in Figure 2.9. Within the data set, 4 daily rainfall events significantly exceeding 150 mm rainfall occur (noting the measurements are fixed 24-hour periods and not a sliding 24-hour duration, such that larger events are likely to have occurred spanning successive records). Daily rainfall events of 324 mm, 167 mm, 207 mm and 189 mm were recorded in 1975, 1997, 1999 and 2003 respectively. Different periods of this data have been sampled depending on the application (as outlined in the following sections).

Note that since baseline surface water data has been collected from the site (October 2018), there has not been a significant daily rainfall event (over 100mm), compared to the long-term record. Note the red line on the figure represents the date that baseline surface water monitoring commenced.

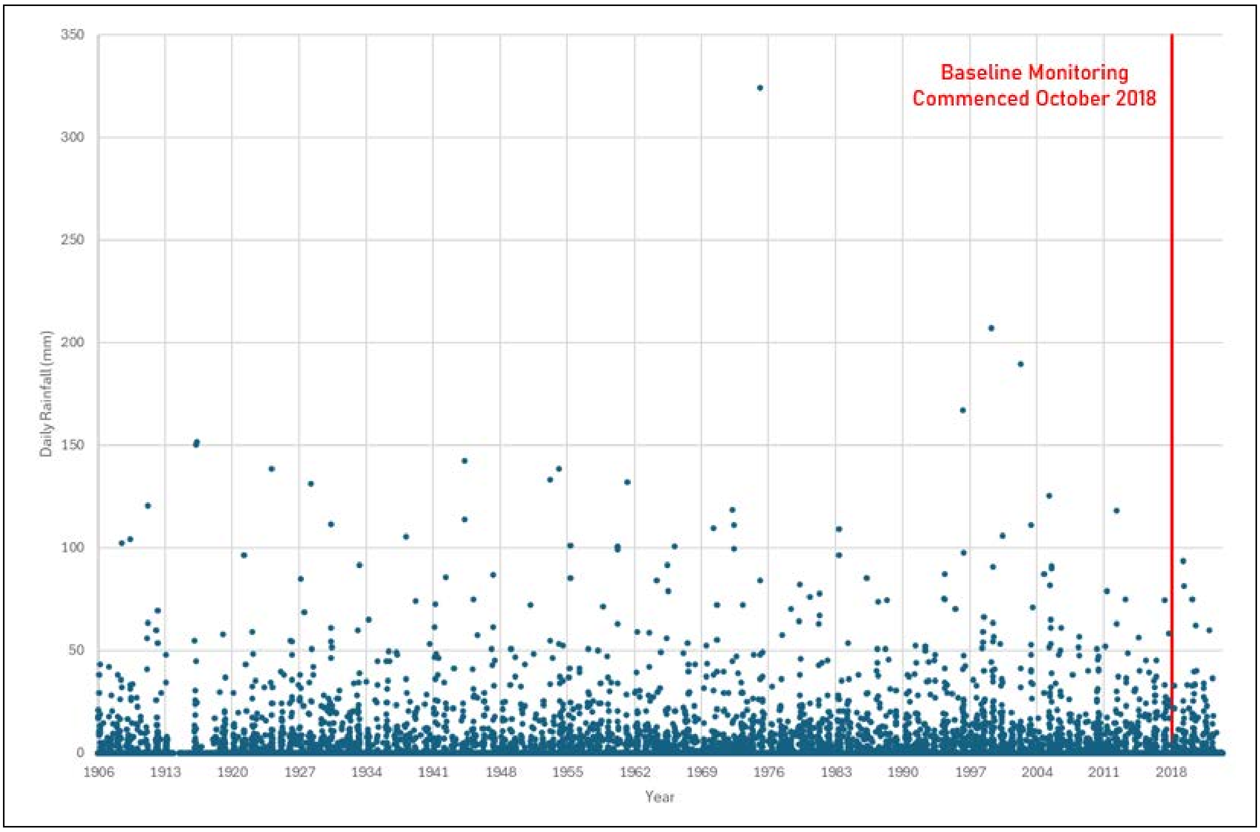


Figure 2.9 Mulga Downs Collated Daily Rainfall

2.7 Intensity Frequency Duration Data

Intensity-Frequency-Duration (IFD) data was extracted from the BoM website for the Project from the 2016 datasets. The 2016 IFD data is presented in Figure 2.10.

Australian Rainfall and Runoff (ARR) (Ball, et. Al, 2019) recommends the use of Annual Exceedance Probability (AEP) when defining flood probability, so this terminology has generally been adopted throughout this report. AEP is defined as the probability or likelihood of an event occurring or being exceeded within any given year, usually expressed as a percentage. This new terminology supersedes the Annual Recurrence Interval (ARI) terminology adopted in the earlier revision of ARR (Institution of Engineers, Australia, 1987). The relationship between ARI and AEP is defined below.

$$AEP = 1 - \exp(\frac{-1}{ARI})$$

For example, a 1 in 100 ARI event would occur on average once every 100 years and has a 1% chance of occurring in any particular year (i.e. 1% AEP), while a 1 in 50 ARI event has a 2% chance of occurring (2% AEP).

Requested coordinate	Latitude: -22.0875	Longitude: 118.4625
Nearest grid cell	Latitude: 22.0875 (S)	Longitude: 118.4625 (E)

IFD Design Rainfall Depth (mm)

Issued: 25 May 2022

Rainfall depth in millimetres for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).

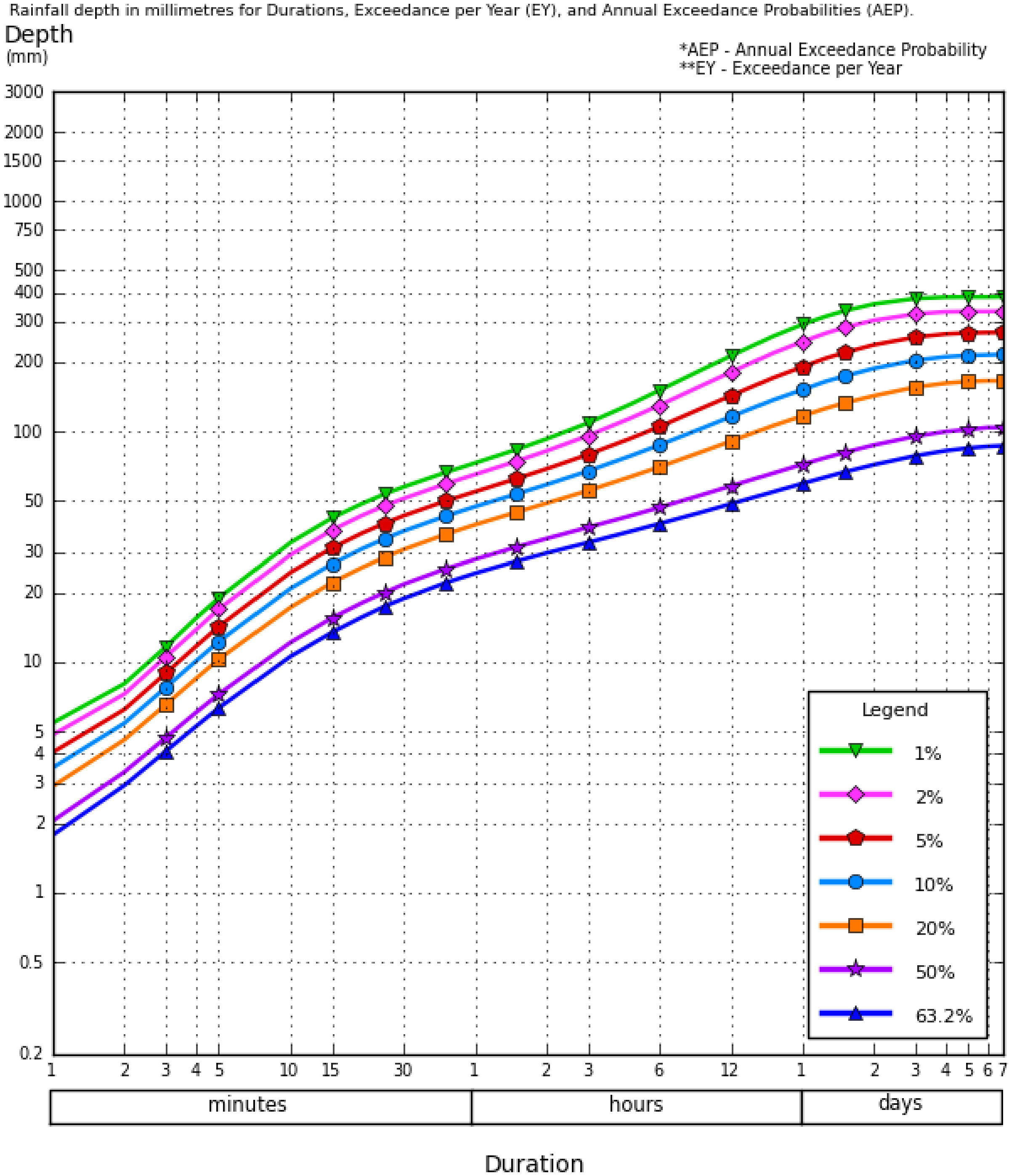


Figure 2.10 BoM IFD Design Rainfall Depths (BoM, 2016)

2.8 Evaporation

Average monthly and annual pan evaporation values were obtained from BoM and the Department of Agriculture (Luke et al., 2003) and are presented in Table 2.3. The BoM pan evaporation rates were measured at the Wittenoom weather station and Department of Agriculture values are based on Class A pan evaporation rates collected at Tom Price. Department of Agriculture also report evaporation losses from small dams (using a pan factor of 65%), which provides an indication of the actual evaporation rates from a shallow water body in the region.

Table 2.3 Potential Evaporation

(mm)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
Wittenoom Mean Evaporation (BoM)	149	189	258	344	372	384	350	274	279	231	177	135	3,143
Tom Price Class A Pan Evaporation (Department of Agriculture)	177	189	274	371	408	460	423	320	318	263	189	169	3562
Tom Prive Dam Evaporation (65%) (Department of Agriculture)	115	123	178	241	265	299	275	208	207	171	123	110	2,315

3. SURFACE WATER FIELD INVESTIGATIONS AND DATA COLLECTED

Site investigations to collect baseline surface water data have been conducted across the Study Area and are continuing. These investigations have included monitoring of the water levels within creeks reporting to the Study Area, monitoring water levels of ponded water within claypans and water quality sampling of creek flows and ponded water in the claypans

3.1 Surface Water Monitoring Stations (Existing)

As part of the baseline hydrological study, eight surface water monitoring locations (SWML) have been established, with six sited on claypan tributaries and two in the claypans (one in each of the Gnalka Gnoona and Koodjeepindarranna Claypans). The six selected tributaries are all located on the northern (Chichester Range) side of the claypans as the HPPL tenements do not cover defined tributaries coming from the south (Hamersley Range) side of the claypans.

Each of the six creek monitoring locations consists of the following:

- Pressure transducer, EC sensor and associated data logger to measure and record water pressure (which is converted to a water depth) and EC.
- Passive sample collection bottle housed within a mounting kit to collect water quality samples after medium to large runoff events.

Each of the two claypan monitoring locations only consists of a pressure transducer, EC sensor and associated data logger (no passive sample collection devices). Instead, the Koodjeepindarranna and Gnalka Gnoona claypans are sampled by 2 transects, with the sample taken at the water's edge where it intersects the transect.

Installation information for each monitoring location, and the associated upstream catchment areas reporting to each monitoring location are provided in Table 3.1 and Table 3.2 for the creeks and claypans, respectively. The maximum potential catchment areas draining to each monitoring location are also shown on Figure 3.1 and Figure 3.2. It should be noted that the catchment areas draining to the claypan monitoring locations are difficult to define given the relative shallow slopes within the Fortescue Valley, the complex behaviour of runoff from incised drainage channels within the ranges once the runoff reaches the alluvial fans and the lack of defined drainage channels (hence a maximum potential catchment area for each claypan has been defined). The results of the baseline 2D hydraulic flood modelling exercise (presented in Section 4.3) were used to assist in refining the effective catchment areas adopted for the claypans. These refined catchment areas are smaller than those reported in Figure 3.2 and are discussed further in Section 4.3.

Table 3.1 Creek Surface Water Monitoring Stations

Logger Serial Number	Location ID	Installation Date	Feature Type	Coordinates (UTM Zone 50)	Record Interval (Minutes)	Catchment Area Estimate* (km^2)
018-1075259	SWML01-A	10/10/18 **	Creek reporting to Koodjeepindarranna Claypan	651241 E, 7556082 S	15	127.5
018-1075259	SWML01	28/07/20	Creek reporting to Koodjeepindarranna Claypan	651075 E, 7555241 S	15	134.6***
018-1075264	SWML02	12/10/18	Creek reporting to Fortescue Valley immediately upstream of Gnalka Gnoona Claypan	667963 E, 7550632 S	15	32.8
018-1075992	SWML05	11/10/18 (06/05/2020)#	Creek reporting to Gnalka Gnoona Claypan	656713 E, 7555960 S	15	6

Logger Serial Number	Location ID	Installation Date	Feature Type	Coordinates (UTM Zone 50)	Record Interval (Minutes)	Catchment Area Estimate* (km^2)
1009302	SWML06	9/05/23	Creek reporting to Fortescue Valley upstream of Gnalka Gnoona Claypan	664587 E, 7553273 S	30	20.9
971457	SWML07	16/11/23	Creek reporting to Fortescue Valley upstream of Gnalka Gnoona Claypan	668999 E, 7554721 S	15	24.5
973240	SWML08	16/11/23	Creek reporting to Fortescue Valley upstream of Gnalka Gnoona Claypan	671812 E, 7551062 S	15	0.8

* Estimated catchment areas delineated using detailed DEM data provided by HPPL. Effective catchment areas may change with the size of the rainfall event.

** SWML01-A replaced by SWML01 in a downstream location.

*** Drainage breakout likely to occur across multiple drainage paths across the alluvial fan. Logger is installed in the main drainage channel through the alluvial fan but may not detect all flow from the upstream catchment area.

Initial SWML05 was damaged and a new one reinstalled at the same location.

Table 3.2 Claypan Surface Water Monitoring Stations

Logger Serial Number	Location ID	Installation Date	Feature Type	Coordinates (UTM Zone 50)	Record Interval (Minutes)	Potential Maximum Catchment Area* (km^2)
018-1075986	SWML03	11/10/18	Koodjeepindarranna Claypan	646369 E, 7550913 S	30	1857**
018-1075250	SWML04	11/10/18	Gnalka Gnoona Claypan	651771 E, 7548466 S	30	

* Estimated maximum catchment areas delineated using detailed DEM data provided by HPPL and SRTM data. Effective catchment areas are likely to change with the size of the rainfall event and preferential flow directions at the alluvial fans. Effective catchment areas adopted in modelling are discussed in Section 4.4.1.

** Maximum potential combined catchment area of the claypans as shown in Figure 3.2; however it is likely the effective catchment area is much smaller. The red flow arrows on Figure 3.2 indicate likely flow directions that report downstream of the claypans.

The initial monitoring installation at SWML05 was destroyed (and logger recovered), most likely after a large rain event in early January 2020. A new monitoring station, with a modified design, was installed at this location on 06/05/2020. In addition, SWML01 was relocated on 28/07/2020, approximately 650 m downstream from the initial location, in the same creek channel.

Solinst Levelogger Edge 3001 pressure transducers were initially installed at each location, with each logger having the capability to monitor water level, temperature and electrical conductivity (EC). Loggers in all locations have now been replaced with In-Situ AquaTROLL (measures EC and level) transducers, due to reliability issues with Solinst Loggers.

Ongoing monitoring comprises the collection of surface water samples following rainfall events (where accessible) and periodic downloading of the loggers during groundwater monitoring rounds.

The monitoring stations were installed in two phases with SWML 1 to 5 installed in 2018 (Phase 1), and SWML 6 to 8 installed in 2023 (Phase 2). Note that data recorded from monitoring locations installed in Phase 2 are not included in this current baseline report because no runoff events had occurred between the installation date (November 2023) and the end of the period reported in this document (December 2023). Additionally, water quality samples collected along the claypan transects have only began during

2024 and are not reported in this study. Previously, water quality samples collected in the claypans (SWML03 and SWML04) were taken in proximity to the location of the SWMLs, however these locations are often inaccessible during surface water sampling runs due to the ponding in the claypans.

Water quality samples have been collected from persistent ponding in channel pools across the site (when ponding is present). The approximate coordinates of the grab sample locations are shown in Table 3.3 and these represent locations where on-going water quality samples will be collected.

Table 3.3 Channel Pool Surface Water Sampling Locations

Sample ID	Feature Type	Coordinates (UTM Zone 50)
SWML09	Channel Pool	643979 E, 7553027 S
SWML13	Channel Pool	653291 E, 7550386 S

Opportunistic samples have been taken at two further locations where ponded surface water has been observed during site visits. These opportunistic sample locations are shown in Figure 3.3 with water quality results included in the water quality sample tables shown in Appendix G. It is not proposed that these locations be sampled on an on-going basis.

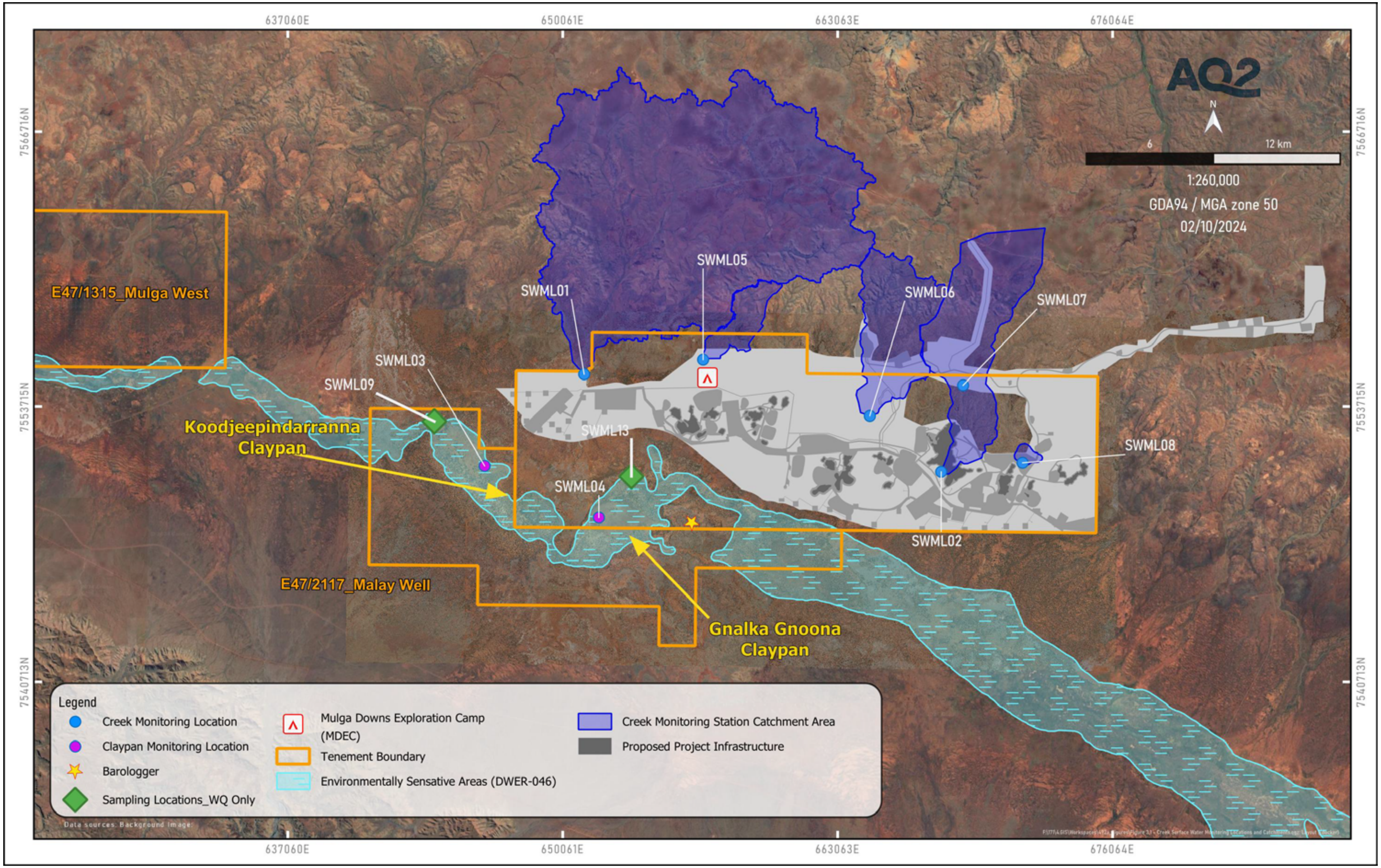


Figure 3.1 Existing Creek Surface Water Monitoring Locations and Catchments

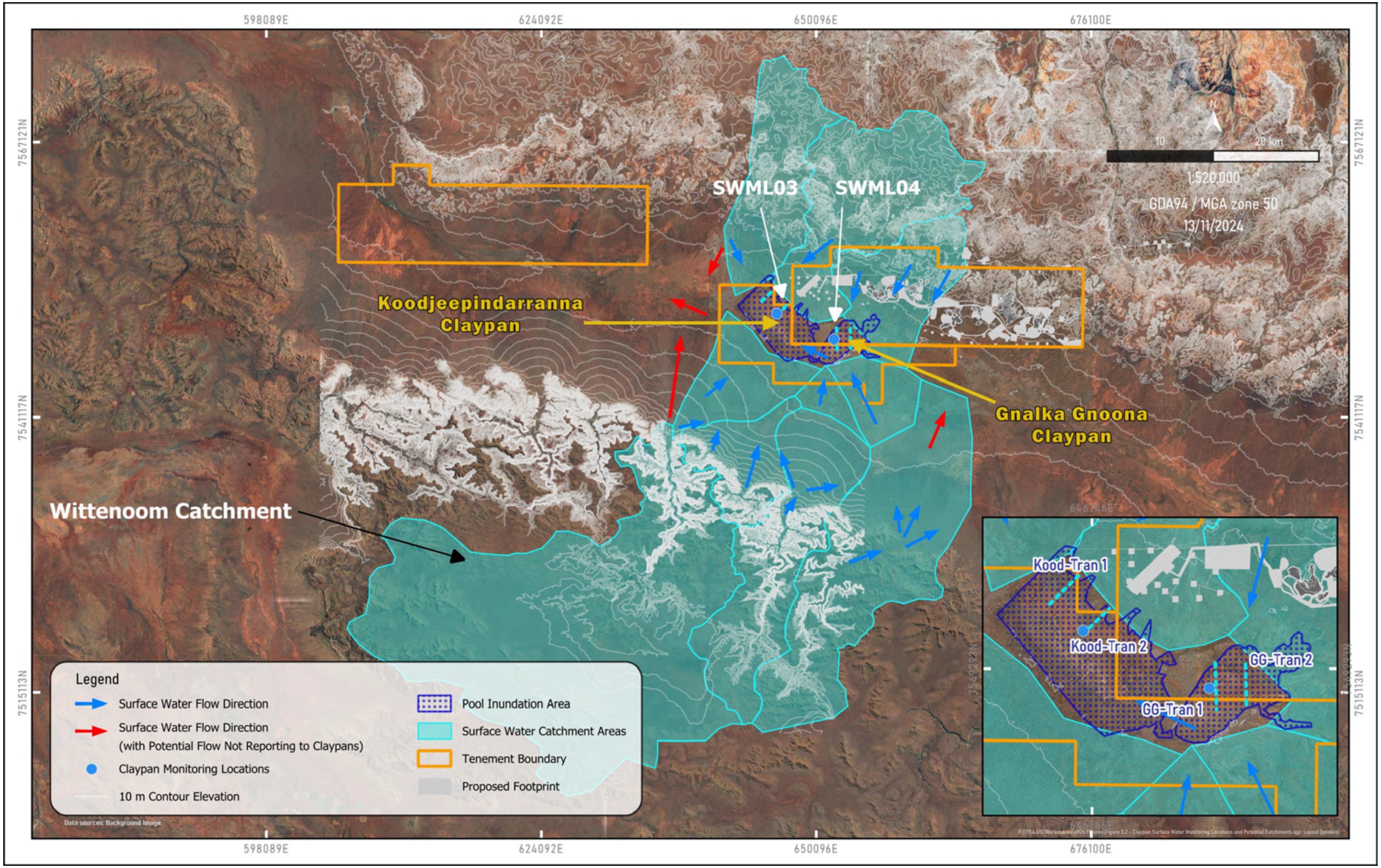


Figure 3.2 Existing Claypan Surface Water Monitoring Locations and Potential Catchments

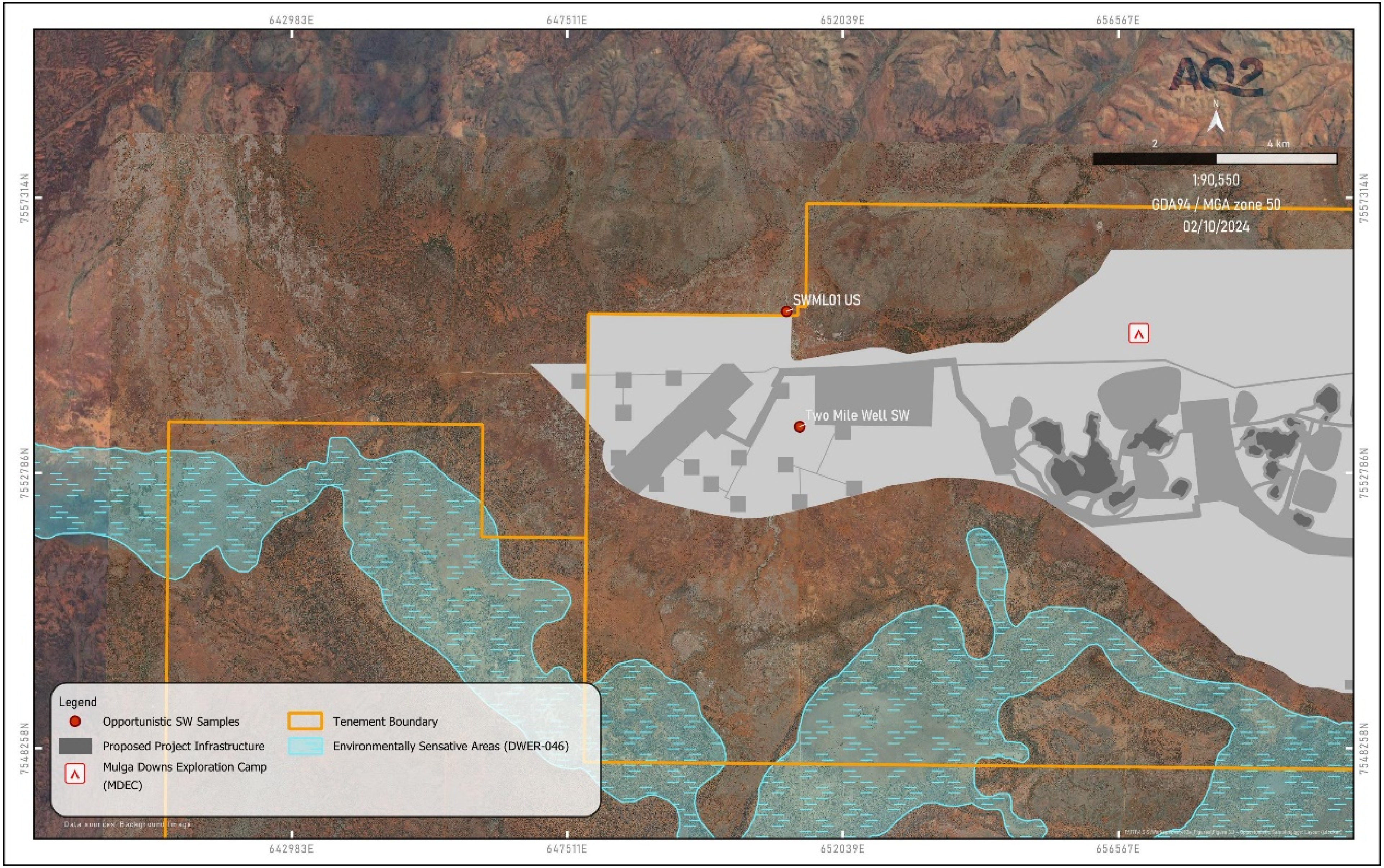


Figure 3.3 Opportunistic Surface Water Sampling Locations

3.2 Ongoing Baseline Monitoring Stations

Additional sites are proposed to be added to the Baseline Monitoring network to increase the spatial distribution of the data collected within the baseline water level and water quality data set. The additional sites are proposed due to:

- The requirement for an increased understanding of the site hydrological conceptual model and environmental assets.
- Updates to the mine development plan which allows consideration of operational monitoring requirements.
- The requirement to provide some robustness for critical monitoring sites by providing multiple reference sites.

The following additional monitoring locations have been proposed to be installed (for both water level and quality) as part of ongoing baseline monitoring but are waiting on heritage approval before they can be installed/sampled:

- At the low point within each of the claypans to provide a backup monitoring location for claypan water levels in the event of a logger failure.
- At two select channel pool location; one upstream of the claypans and one to the north of Gnalka Gnoona Claypan.

Note while there are two existing monitoring locations in the claypans, there were discrepancies identified during data analysis regarding actual elevations. Additional stations will allow for redundancy and likely lead to more reliable results.

Additional locations have been proposed to obtain regular water samples (no logger proposed) where the development has the potential to impact water quality:

- Channel connecting the claypans.
- Channel pool to the northwest of Koodjeepindarranna Claypan.
- Channel pool on the valley floor upstream of the claypans to which runoff from the eastern mining area reports. This location is outside of the mine tenement area.

The locations for these proposed monitoring stations are shown in Figure 3.4, which provides a map of the full baseline monitoring network. Access to the baseline monitoring network is subject to heritage approvals.

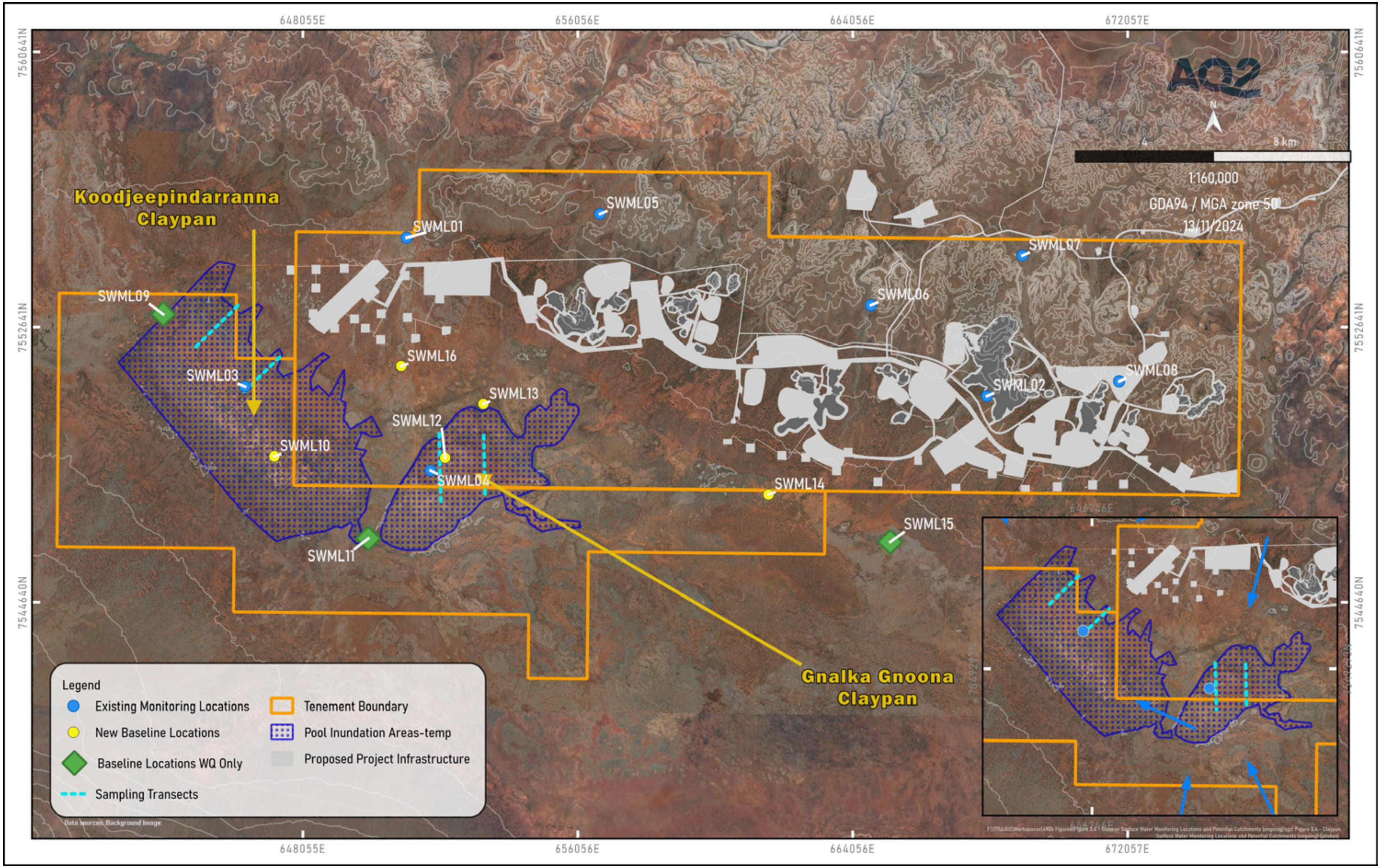


Figure 3.4 Ongoing Claypan Surface Water Monitoring Locations

3.3 Water Quality Data

Surface water samples were collected between 2020 and 2023, both within creek lines, claypans, and channel pools for laboratory analysis. The existing baseline monitoring network is shown in Figure 3.1.

The following number of water quality samples have been collected:

- SWML01 – 5 samples.
- SWML02 – 4 samples.
- SWML03 – 4 samples.
- SWML04 – 5 samples.
- SWML05 – 3 samples.
- SWML09 – 1 sample.
- SWML13 – 1 sample.

Surface water samples have generally been tested for the following parameters:

- General water quality (pH, Conductivity, Na, K, Ca, Mg, S, Si, Hardness, Alkalinity, Sulfate, Chloride, Fluoride, Silica, Nitrate, Nitrite).
- General metals suite (Ag, Al, As, B, Be, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sn, Sr, Ti, Tl, V, Zn).
- Nutrients (Nitrate, Ammonia, FRP as PO4)).
- TDS/TSS.

The water quality data and a discussion of the results is provided in Section 4.5.

4. SURFACE WATER DATA ASSESSMENT

4.1 Approach

The baseline data collected for the Study Area has been analysed to assist with determining the baseline hydrological conditions. It was identified that the hydrological behaviour of flooding within the Study Area is driven by two different mechanisms:

1. Short-duration high runoff rates in response to individual rainfall events across the Chichester Range catchments.
2. Ponding of water within the Fortescue Valley, including within the claypans (Gnalka Gnoona and Koodjeepindarranna), from either a single large or potentially from multiple successive runoff events.

The baseline hydrological conditions of the Study Area have been characterised using 2D flood modelling of catchment runoff (flood mechanism 1) and a water balance model for the claypans (flood mechanism 2). Parameters used within the surface water assessments were guided by analysis of data collected at the site during baseline field studies. Outputs from the 2D flood model were also used to quantify parameters in the water balance model of the claypans.

To model the two flood mechanisms that drive the baseline hydrological behaviour of flooding within the Study Area, a Light Detection and Ranging (LiDAR) Digital Elevation Model (DEM) representing the existing topography (pre-development) was required to simulate rainfall-runoff-storage processes and stage-storage-area relationships for Gnalka Gnoona and Koodjeepindarranna claypans.

Note that the assessments described below have predominantly used the most recent (2023) 0.25 x 0.25 m and 0.5 x 0.5 m LiDAR data sets which cover an extensive region around the Project location, extending across the Fortescue Valley to the base of the Hamersley Range. For some of the modelling and catchment definitions, the 2019 LiDAR DEM (less extensive coverage compared to 2023) and freely available SRTM data was used.

An overview of the 2023 LiDAR data is shown in Figure 4.1.

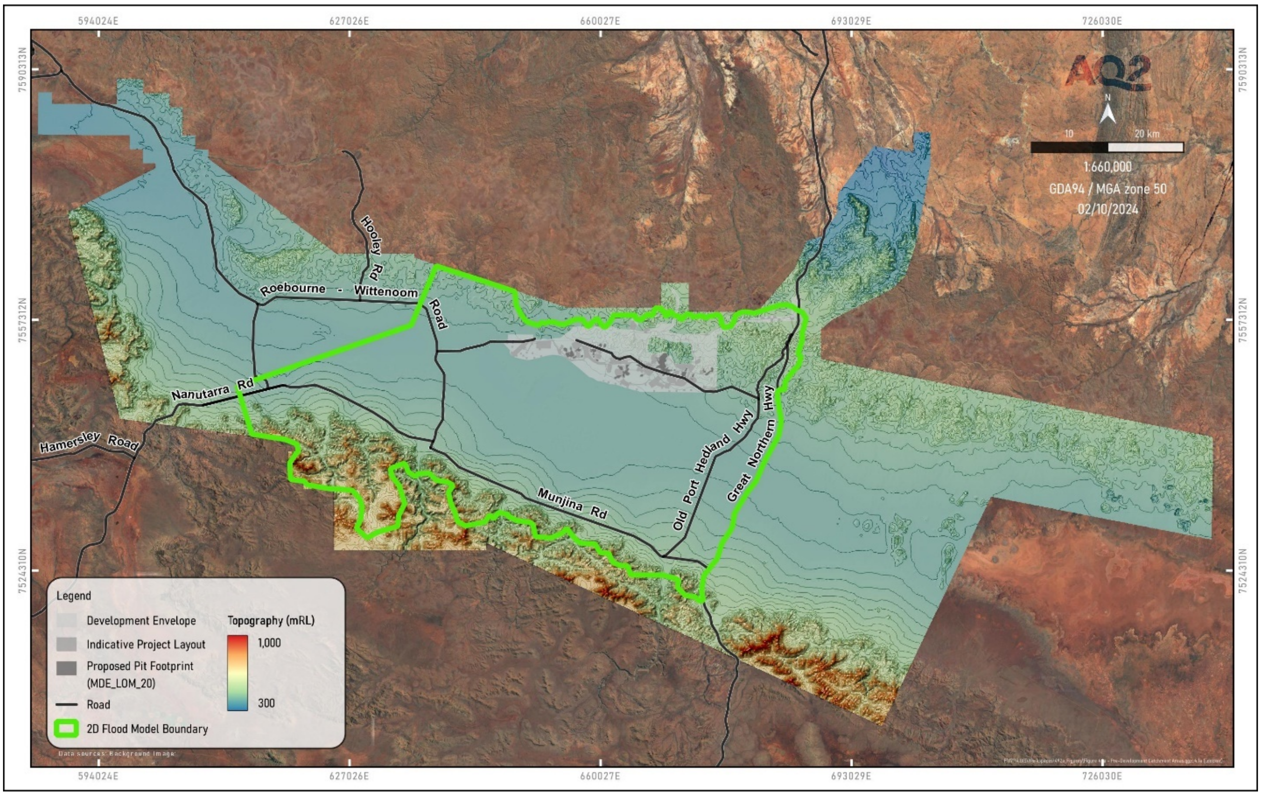


Figure 4.1 Supplied LiDAR Data

4.1.1 Baseline 2D Flood Modelling

The baseline 2D flood modelling was completed for a range of design rainfall events, ranging from 63% to 1% Annual Exceedance Probability (AEP), to simulate surface water flows within the Study Area and Fortescue Valley. The maximum flood depths and velocities predicted by the 2D flood model for baseline (pre-development) conditions are included in Appendix A.

The 2D flood model was developed using the 2023 0.5x0.5 m LiDAR DEM which included detailed terrain for the Study Area, the Chichester Range, and the Fortescue Valley between the Great Northern Highway and downstream of the Fortescue railway (to the west). A comparison of the model boundary to the LiDAR DEM extents are shown in Figure 4.1. The LiDAR DEM resolution and extent was considered appropriate to assess the hydrological behaviour of flooding within the Study Area. The results of the 2D flood model were subsequently used to:

- Assist in defining catchment boundaries (such as for the claypans, broader Goodiadarrie Swamp area and surface water monitoring sites).
- Assist in developing the Conceptual Landscape Model.
- Produce baseline flood maps to be used as a reference to quantify the impact of the mine disturbance areas and any required flood protection measures on the hydrological environment.
- Identify potential environmental impacts of mine infrastructure as a result of changes to the existing surface water regime (as part of the impact assessment report (AQ2 2024)).
- Identify where flood protection measures are required around the mine disturbance areas (pits, waste rock dumps etc.) as part of the Environmental Impact Assessment Report.

4.1.2 Claypan Water Balance

The water balance model of the Gnalka Gnoona and Koodjeepindarranna Claypans was completed to:

- Define the claypans' baseline hydrological regime.
- Predict potential flood levels that may occur due to water storage within the claypans.
- Develop a baseline dataset on surface water quality based on collected water quality data during the pre-mining period.
- Assist in developing the Conceptual Landscape Model.

4.2 Mine Development Catchment Definition

The baseline surface water catchments relative to the proposed mine development area have been delineated to the Fortescue Valley Environmentally Sensitive Area (ESA) as defined by DWER. The following datasets have been used to delineate the baseline catchment areas:

- 2023 LiDAR DEM.
- SRTM datasets.
- Aerial imagery.
- Initial flood model results.

Baseline catchment areas are presented in Figure 4.2, with the size of each catchment area summarised in Table 4.1.

Table 4.1 Mine Development Area Baseline Catchment Area Summary

Catchment	Baseline Area (km^2)
1	23.1
2	164.4
3	39.8
4	28.4
5	33.8
6	13.5
7	29.0
8	11.9
9	43.3
10	53.9
11	65.5
12	1.7
13	6.3
14	2.1
15	4.5
16	7.3

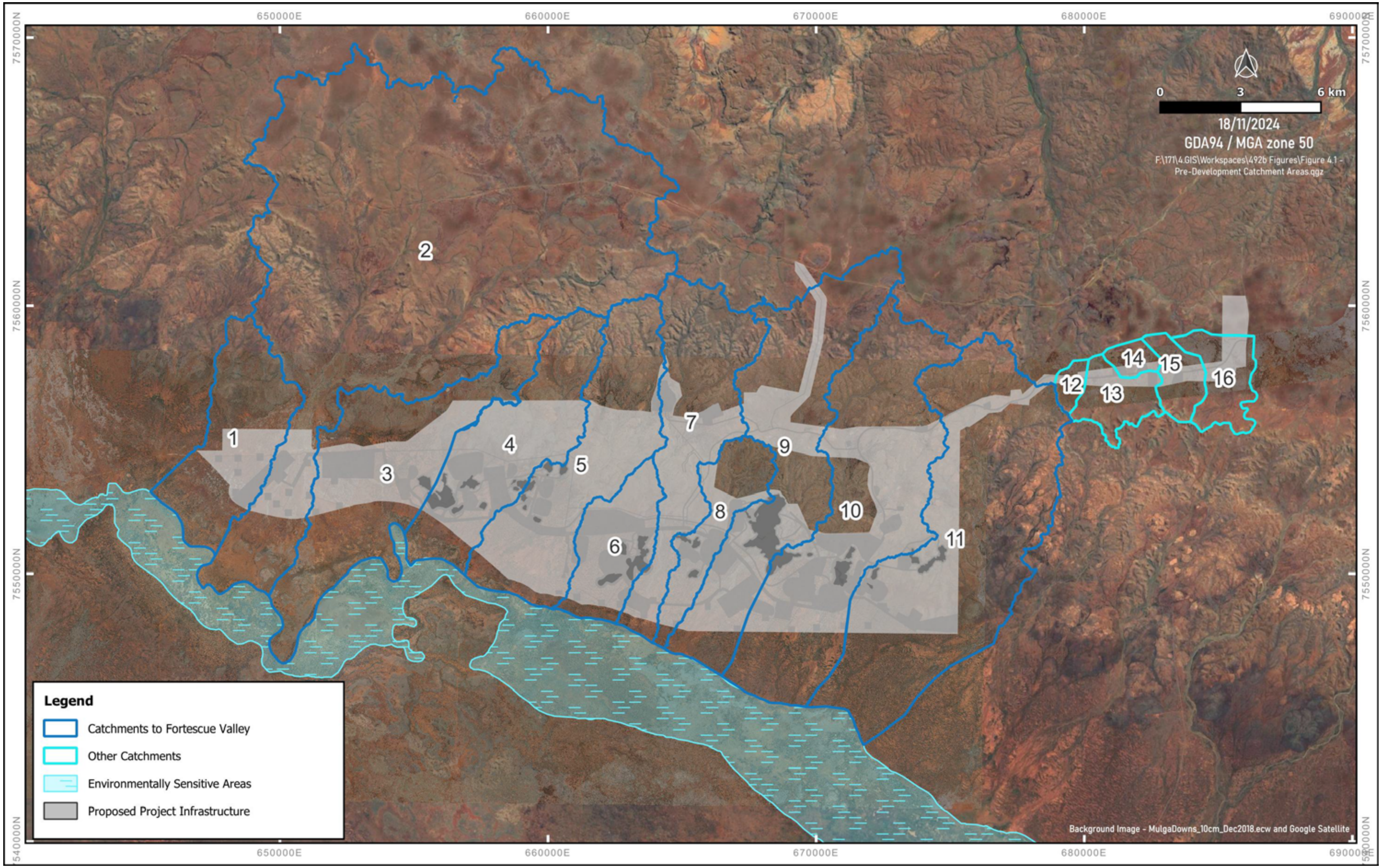


Figure 4.2 Pre-Development Catchment Areas

4.3 Baseline Flood Modelling

The baseline flood characteristics of the Study Area have been mapped by creating a 2D flood model using the Hydrologic Engineering Center's (CEIWR-HEC) River Analysis System (HEC-RAS). The following steps were taken when developing the 2D flood model:

- Analysis of baseline streamflow data collected from monitoring stations to assist in defining catchment rainfall loss parameters.
- Definition of catchment areas reporting to the boundary of the 2D flood model.
- Development of runoff-routing models using RORB (Laurenson et al.,2010) to define inflow hydrographs along the 2D model boundary for the 63%, 50%, 20%, 10%, 5% and 1% AEP runoff events.
- Development of the 2D flood model for the 63%, 50%, 20%, 10%, 5% and 1% AEP runoff events using upstream inflow hydrographs plus rain-on-grid runoff hydrology.
- Mapping of maximum flood depths across the model domain for the design runoff events.
- Mapping of maximum flow velocity across the model domain for select runoff events.

These steps are outlined in the sections below.

4.3.1 Stream Flow Data Analysis

As discussed in Section 3.1, six Surface Water Monitoring Locations (SWML01, SWML02, SWML05, SWML06, SWML07 and SWML08) have been installed in proximity to the Project within drainage lines from the Chichester Range. All of the collected creek data is shown in Appendix B, noting that to date, no baseline data has been collected from SWML06, SWML07 or SWML08.

Data collected during the baseline monitoring phase was reviewed and the following was completed:

- Pressure transducer measurements were converted to a calculated water depth accounting for recorded barometric pressure readings.
- The water depths were converted to a relative level using the surveyed elevation of the monitoring station locations (taking into account dimensions of housing and cable lengths).
- Rating curves defining a flow rate versus flow depth relationship for each of the SWMLs were developed by preparing a localised 2D flood model of the terrain immediately upstream and downstream of the SWML. Note:
  - The 2D flood model used the 2019 LiDAR Digital Elevation Model (DEM) provided by HPPL to define the terrain underpinning the model.
  - Surveyed cross-sections were provided which were used to modify the DEM.
  - There were instances where the surveyed ground elevation at the SWML and the elevation within the DEM differed, leading to uncertainty in the water level monitoring data.
- The measured flow depth data was converted to a flow rate using the developed rating curves.

The measured flow responses were compared with gauged rainfall data from the Mulga Downs Exploration Camp (MDEC) to identify rainfall events that produced a streamflow response. The intent of this step was to identify rainfall events and the corresponding runoff events that could be used to calibrate rainfall losses within a hydrological model. The measured events were therefore filtered to remove those that were unsuitable for calibration.

There have only been a few runoff responses recorded by the SWMLs to date. Commonly across all sites, a large rainfall event in January 2020 triggered responses with a peak flow rate estimated to be almost 500 m^3/s (~3m deep flow) through SWML01 (based on the developed rating curve). The flow occurred as a result of a 24-hr 93mm event with flow only present through SWML01 for a total 26-hour period during and post the event.

A rainfall response event at SWML01a in January 2020, was selected as the only event suitable for use to calibrate the hydrological model. This runoff event was in response to the most significant rainfall event which has been recorded during the baseline period (93 mm over 2.5 hours, refer Section 2.5). The following factors limited the number of events that could be chosen:

- The majority of rainfall events that were measured at the rainfall gauge station were relatively small and therefore the creek flow responses were relatively shallow and occurred over a short-duration.
- The available rainfall records from the MDEC were predominately daily measurements containing significant gaps that could only be filled with rainfall data from the nearest operational BoM weather station, which was Karijini North (005098). Half-hourly rainfall data from the MDEC was only available for approximately half of 2020 and also contained gaps.
- The distance between the SWMLs and the MDEC rainfall gauging station. SWML01a and SWML05 are located relatively close (5.5 km and 2.5 km respectively) to the MDEC and therefore the recorded rainfall data is more likely to be representative of the rainfall that would have fallen over their upstream catchment compared to SWML02, which is located approximately 12 km from the rainfall station.
- The surface water flow regime at the SWMLs is typically characterised by streamflow through a series of braided channels across an alluvial fan. The braided channels have formed at the change in slope as the drainage lines leave the steeper Chichester Range and reach the flatter alluvial fan. Each SWML is only representative of the flow through one of the braided channels and there is inherent uncertainty regarding the manner in which the upstream catchment flow splits across the braided channels. As the braided channels also combine to form wide floodplains under higher flows, it was found that higher flow rates were required to simulate the water surface elevations (WSEs) recorded in the gauges than would be required within a contained channel.
- The streamflow gauge at SWML05 was damaged during the January 2020 runoff event and required subsequent reinstallation resulting in a data gap between January and May 2020 (a period which included the January runoff event).

4.3.2 Rainfall Loss Parameters

A RORB rainfall routing model was developed for the catchment reporting to SWML01a using the January 2020 rainfall event. RORB generates flow hydrographs by subtracting losses from rainfall to produce rainfall-excess hyetographs and routes these hydrographs through catchment storages. The rainfall losses in the model were modified until the estimated discharge rates from the observed flow depths were approximated by the RORB model. This calibration exercise produced the closest fit using an initial rainfall loss of 35 mm and a continuing loss of 5 mm/hr. A comparison of the modelled hydrograph to the gauged discharge rate is presented in Figure 4.3.

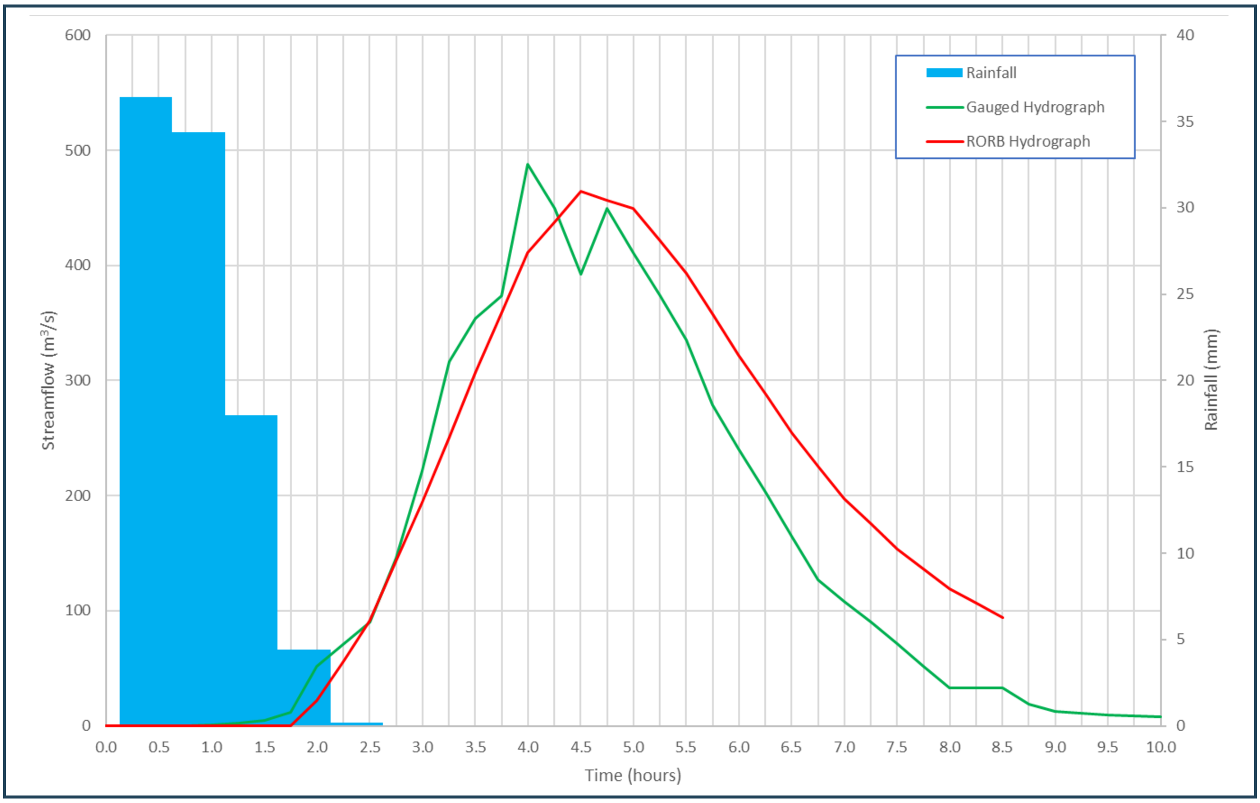


Figure 4.3 RORB Calibration Event at SWML01a from January 2020

The observed rainfall event used for this calibration (a 93.2 mm burst over 2 hours) was estimated to have an AEP of 5% over the 4-hour (approx.) critical duration for the catchment when compared to the site Intensity-Frequency-Duration (IFD) data from BoM (refer above Section 2.6).

Australian Rainfall and Runoff (AR&R) (Ball et al., 2019) flood estimation methodologies encourage the use of site-specific runoff coefficients derived from collected data over the use of regional loss estimates. As such, the loss parameters derived from the calibration exercise as outlined above have been adopted to estimate design flow hydrographs for catchment areas reporting to the boundary of the 2D flood model. [Note that different volumetric rainfall loss coefficients are used when completing water balance modelling of the claypans, as these were calibrated to volumes reporting to the claypans rather than peak flow rates].

The adopted rainfall loss parameters are lower than the regional estimates provided by AR&R and therefore the RORB model produces higher design flow rates when using these parameters compared with regional loss parameters provided by AR&R. A comparison of the peak flow rates estimated by RORB at SWML01 from the January 2020 rainfall event using the calibrated and other published rainfall loss parameters is shown in Table 4.2. The peak flow rate estimated in RORB with the adopted parameters is higher than those produced for the 5% AEP event using the Regional Flood Frequency Procedure (RFFP; Flavell, 2012) and the Regional Flood Frequency Estimate (RFFE, AR&R 2019). The higher runoff rates compared to the regional estimates reflect a degree of conservatism in the calibrated runoff estimates.

Table 4.2 Comparison of RORB Peak Flow Rates Calculated for SWML01a

Method	Peak Flow (m^3/s)
Measured/Gauged	488
Calibrated RORB	464
AR&R (1998) Parameters	342
AR&R (2019) Parameters	160
RFFP (5% AEP Flow Estimate)	232
RFFE (5% AEP Flow Estimate)	246

Rainfall loss parameters were also required to be applied (separately) to the rainfall hyetographs used within the rain-on-grid portions of the 2D flood model. This is discussed in more detail in Section 4.3.5.

4.3.3 Flood Model Catchment Definition

The baseline surface water catchments defined in Section 4.2 report to the boundary of the 2D flood model when LiDAR terrain data is not available for the full catchment area. Rain-on-grid hydrology cannot be simulated in the 2D flood model without the full catchment, instead, inflow hydrographs from RORB hydrological modelling were developed and used as inflows at the model boundary to simulate the relevant catchments inflows to the 2D flood model. Figure 4.4 depicts the catchments reporting to the 2D flood model boundary.

4.3.4 RORB Hydrological Modelling

RORB was used to generate design inflow hydrographs for each AEP event for two catchments in the Chichester Range (C1 and C2) and four catchments in the Hamersley Range (H1-H4) that extended outside of 2D flood model boundary as shown on Figure 4.4. Catchment C2 was considered representative of the remaining smaller Chichester Range catchments reporting to the 2D flood model boundary. The hydrographs for these catchments were derived from the C2 RORB model, with the C2 hydrograph scaled by relative catchment area. The design inflow hydrograph from the C1 RORB model was used for the westernmost Chichester Range catchment as it was of similar size.

The initial and continuing rainfall losses (IL and CL) of 35 mm and 5 mm/hr as calibrated previously was used across all design AEP events within the RORB model. The key parameters used in the RORB models are summarised in Table 4.3. The AR&R (Ball et al., 2019) Kc parameter calculation for the Pilbara was adopted for each catchment.

Table 4.3 RORB Parameters

Catchment	Catchment Area (km^2)	Catchment Equal Area Slope (m/km)	Adopted Kc (AR&R)
C1	147	2.4	9.7
C2	6	7.1	1.5
H1 (Wittenoom Gorge)	687	7.6	13.4
H2	126	10.2	6.3
H3	121	9.0	6.0
H4	641	5.6	19.3

For each of the six catchments which were modelled in RORB, the ensemble of synthetic rainfall hyetographs provided by ARR were run. To determine which hydrographs to include in the updated 2D flood model for each AEP event, box and whisker plots were developed as recommended by AR&R (Ball et al., 2019) for each catchment external to the 2D model domain. The RORB outputs and the box and whisker plots for each catchment were analysed as follows:

- The median, upper and lower peak flow rate outputs from RORB were collated for all durations across all AEP events.
- For each AEP event the highest median peak flow rate was compared to the box and whisker plots to determine a representative critical duration for each model. Note that different AEP events may have resulted in different critical durations for a given catchment.
- To select a single representative critical duration for all AEP events for each catchment, the storm duration that best encompassed the peak flow rates for all AEP events was chosen.
- The corresponding RORB hydrographs for each AEP event were then included as boundary inflows into the 2D flood model.

Note the following points with regards to this approach, which leads to conservatively high runoff rates in the 2D flood model:

- The inflow hydrographs to the 2D flood model are all generated from different storm events (in terms of duration and rainfall distribution through the storm). The likelihood that all of these critical storm events would occur concurrently across these catchments is low.
- An areal reduction factor has been applied within each of the RORB models to account for the fact that the rainfall is unlikely to be consistent across the full catchment area. In practice, a higher aerial reduction factor should be adopted for the full 2D flood model domain to account for the larger total model area and applied to each RORB model catchment.
- Within the 2D model, the inflow hydrographs are all timed to start concurrently. In reality, the timing of the rainfall event is unlikely to occur simultaneously across the full catchment area.

The representative critical durations assessed for Hamersley and Chichester Range catchments are reported in Table 4.4.

Table 4.4 Representative Catchment Critical Durations

Range	Hamersley Range				Chichester Range	
Catchment	H1 (Wittenoom Gorge)	H2	H3	H4	C1	C2
Representative Critical Duration (hours)	36	24	24	36	24	6

The corresponding RORB temporal pattern for the Chichester Range catchment closest to the Project (Catchment C2) for the 5% AEP was used to simulate the different AEP design rain-on-grid depths in the 2D flood model. This temporal pattern was chosen as the 2D flood model domain covers smaller catchment areas (compared to the RORB model) and therefore a shorter duration rainfall event is appropriate.

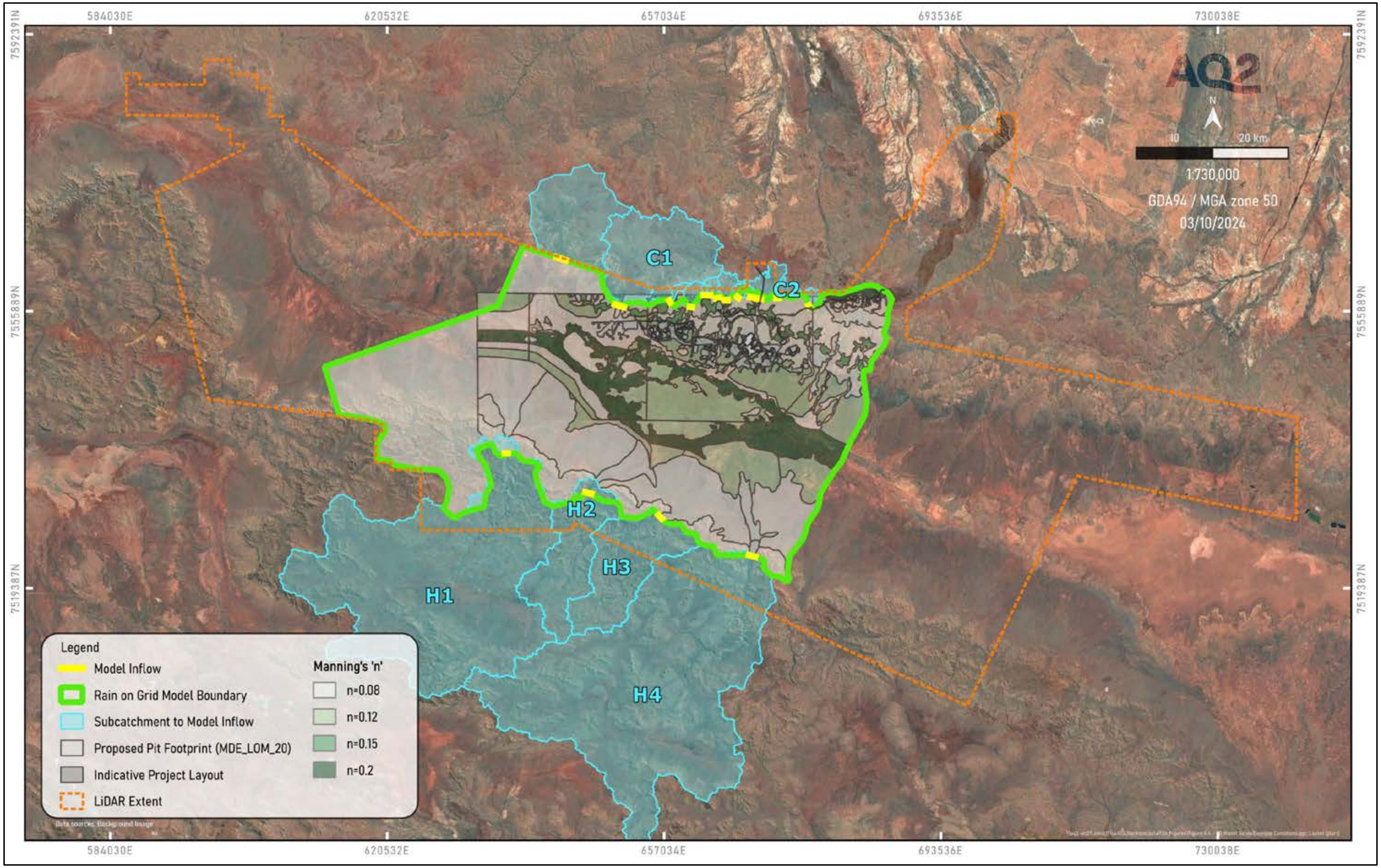


Figure 4.4 2D Model Setup Baseline Conditions

4.3.5 2D Flood Modelling

The 2D flood model was developed using the 2023 0.5x0.5 m LiDAR DEM to predict baseline inundation extents resulting from a range of design events (63%, 50%, 20%, 10%, 5% and 1% AEP). The 2D flood model domain generally falls within the extents of the area covered by the 2023 LiDAR data with some SRTM data used to supplement the upstream portion of smaller catchments that report to the haul road alignment (in the eastern part of the model). A comparison of the available LiDAR DEM data and the 2D flood model domain is shown in Figure 4.1. Inflow hydrographs at the model boundary were developed using RORB for catchments that extended outside the DEM extents within the Chichester and Hamersley Ranges (as discussed in Section 4.3.4).

The intent of the modelling is to provide baseline flood depths and flow velocities in the vicinity of the proposed mine disturbance area so that the impacts of the proposed Project on the surface water regime can be quantified. As such, the model domain was selected to ensure that the hydrological conditions in the vicinity of the disturbance area are appropriately simulated. The floor of the Fortescue Valley adjacent to the Disturbance Area is extremely flat (i.e. 10 m elevation fall over an 80 km total length spanning either side of the claypans which is ~0.01% slope) and contains numerous areas where water ponds. Given this, the eastern and western model boundaries were chosen as follows:

- Eastern model boundary – the Great Northern Highway was chosen as the model boundary to the east of Project. The road represents a local high spot across the valley with very little slope to the natural surface on either side of the road alignment. Any culverts beneath the highway or floodways over the highway would be expected to act more to distribute flows either side of the road rather than to convey large flow rates. As such, it is felt that not much flow will cross the highway and, in the model, no flow is allowed across this boundary (in or out of the model).
- Western model boundary – the western model boundary was chosen to be placed downstream of the Fortescue rail alignment. There is the potential that runoff building up behind the railway may impact the hydrological regime at the claypans such that the model boundary was selected to be positioned sufficiently downstream of rail alignment to allow the effect of this potential hydraulic control to be simulated.

A 2D flow area with a 50 m x 50 m grid was delineated within the model domain. Breaklines with a computational mesh spacing of 10 m by 10 m were applied to natural flow paths and proposed features such as roadways, bunds, embankment slopes, and rail formations. The break lines orient the computational mesh to align cell edges with the features reflected in the terrain surface. In this way, the diversion structures are being picked up in the modelling.

HEC-RAS recognises sub-grid terrain resolution, and the computation of flow transfer between individual grid cells accounts for the geometry of the underlying surface at the terrain resolution of 1 m by 1 m.

The general model build details are as follows:

- A 50 m x 50 m grid applied across the model with a refined grid of 10 m x 10 m applied to key surface water flow paths.
- Inflow hydrographs applied from upstream catchments that were generated using RORB.
- Rain-on-Grid hydrology applied across the model using a 6-hour rainfall event hyetograph generated using the AR&R design rainfall depths and temporal pattern as determined in Section 4.3.4.
- Model simulation duration of 5 days.
    - Note that, as discussed in Section 4.3.4, the critical storm duration of the larger catchments external to the 2D model boundary (which were simulated in RORB) were typically in the range of 24 to 36 hours. At the end of the model, runoff is still reporting to areas where ponding occurs in the Fortescue Valley (such as the claypans).

4.3.5.1 Roughness and Infiltration Parameters

Runoff responses within the Study Area will vary according to different landscape elements. To mimic this, different roughness and infiltration parameters were assigned to the defined ecohydrological units (EHUs) as assessed in Section 8. Each EHU represents a landscape element with broadly consistent and distinctive ecohydrological attributes, for example, (but not limited to) different runoff responses. Refer Table 4.5 for a summary description of each landscape EHU, including their potential roughness and infiltration characteristics, and a schematic locating each EHU within the Study Area. The roughness and infiltration parameters were varied as follows.:

- Manning's 'n' roughness value – higher Manning's 'n' values were applied to EHUs with denser vegetation and undulating microtopography to slow down the transport conveyance of runoff from these EHUs to the next EHU downstream. Flow depths in concentrated flow paths are increased where roughness values are higher. Figure 4.4 shows the spatial distribution of Manning's 'n' simulated in the 2D flood model.
- Infiltration rate – different rainfall infiltration losses were applied to the rainfall hyetograph within the model by assigning different infiltration models to each EHU. This allowed some EHUs to contribute a higher portion of the runoff to receptors (such as the Gnalka Gnoona and Koodjeepindarranna claypans) and for others to contribute less runoff (i.e. simulating increased local scale water storages, such as within the Fortescue Valley where loamy soils are present).

Infiltration losses within the 2D model domain were simulated using the Deficit and Constant Loss method. Table 4.4 shows the adopted Initial Loss and Continuing Loss values, which were applied in the model as Initial Deficit and Potential Percolation Rates, respectively for each of the EHU areas. A Maximum Deficit of 60 mm was applied to all areas (i.e. the maximum total rainfall loss in the model was 60 mm). Note that the initial losses shown in Table 4.4 are generally lower than those adopted in the RORB. This is because the initial loss used in the RORB model needs to account for both the initial soil infiltration loss and the storage losses (low points in the terrain), whereas the DEM used in the 2D flood model means the storage losses are accounted for within the model.

Spatially varying Mannings roughness coefficients were applied to each area as shown in Table 4.4.

Table 4.5 Summary of landscape ecohydrological units and 2D model parameters

EHU	Description	Relative rainfall storage	Initial Loss (mm)	Continuing Loss (mm/hr)	Mannings 'n'
Upland Rises	Peaks and upper hillslopes; shallow or skeletal soils overlying basement rocks.	Low	15	4	0.08
Upland Valleys	Broader depressions in the Chichester Range where sediments have accumulated, enabling runoff capture/storage and denser vegetation	High	20	6	0.15
Upland and Alluvial Fan Drainages	Channels that exit the Chichester Range and transmit across the gently sloping alluvial plains to the south of the range. Progressive loss of flow energy on exiting the range. Alluvial Fan Drainages support relatively dense mulga shrubland.	Moderate	20	6	0.08
Alluvial Fan Washplains	Banded vegetation on a gently sloping stony plain. Runoff is mostly generated locally and captured in the downgradient grove.	High	20	6	0.12
Valley Calcrete Plains	Broad unit of the valley floor. Variably dissected and overprinted by alluvium, giving rise to a subtle mosaic of rises and depressions.	Moderate (greater around the periphery of outcrops; less where local depressions prevent any spillover to adjacent areas)	15	4	0.12
Valley Stony Flats	Stony plains abutting the valley where slope (and hence runoff) is insufficient to support banded vegetation.	Low/Moderate	15	4	0.08
Valley Loamy Flats	Areas below the Stony Flats, where accumulated sediment and organic matter underpin better topsoil structure and high infiltration rates. These support dense patches of woodland and grassland vegetation; as determined by subtle changes in physical and chemical soil properties.	High	30	10	0.2
Valley Ponding Flats	The lowest depressions where water ponds; typified by high clay content topsoil that impedes infiltration.	Low	10	2	0.08
Basaltic Tablelands	Stony gilgai plains and grasslands with underlying vertisol clays soils that form deep wide cracks vertically from the surface once dried out. These cracks allow for high infiltration rates and minimal runoff until closed.	High	50	10	0.2

4.3.5.2 Modelling Approach

The modelling approach adopted is focused on providing baseline hydrological flood characteristics within local drainage lines immediately surrounding the proposed development during design storm events, but may not fully represent flooding within the full Fortescue Valley area (including the claypans) for the following reasons:

- The critical duration storm to cause flooding of the claypans is likely to be different to that being modelled for flooding of the local small catchments.
- No initial storage of water in the Fortescue Valley has been accounted for.
- The cumulative effects of a sequence of rainfall events have not been considered.
- The model has not been run until all runoff from the catchments has reported to the claypans.
- Evaporative or infiltration losses within the Fortescue Valley have not been allowed for.

Flood levels within the claypans have been addressed separately using a water balance approach (refer Section 4.4).

For the ponded water within the Fortescue Valley ESA (refer Section 1.7), the environmental impact assessments informed by the flood model are considered valid as the full catchment area reporting to the ponding area is being simulated within the flood model domain. Any changes to the ponded water level regime as a result of mine development are considered to be realistic. It is unlikely runoff within the Fortescue Valley from the east of the Study Area would contribute to the ponding in small rainfall events. If these events did contribute runoff then the impact of the Project on hydrological changes would be reduced and hence the approach taken is suitably precautionary.

4.3.6 2D Flood Modelling Results

The baseline maximum flood depths and flow velocities predicted by the 2D flood model for the design rainfall events are presented in Appendix A. Note the 2D flood model maps are screened to only show predicted flood depths that exceed 0.05 m.

Key observations from the 1% AEP flood predictions for baseline conditions are:

- The majority of the proposed mine infrastructure is located along the Chichester Range and alluvial fans to the north of the Fortescue Valley. Across the alluvial fans, infrastructure would be exposed to extensive shallow sheetflow across the floodplain and braided channels branching over the fans.
- A number of upstream catchments drain towards the Fortescue Valley from the north and flow through the Study Area as defined watercourses. Flood depths in these channels can exceed 1.5 m. The proposed Fridge Central / Horseshoe West mining infrastructure areas appear more susceptible to these flows given its proximity and relatively compact layout.
- Extensive flooding across the claypans is predicted, with areas of widespread ponding occurring. The flood maps also show the claypan inundation extents as predicted from the water balance model for the 1% AEP rainfall event. This flood level is unlikely to occur simultaneously with the predicted 1% AEP flood depths from the 2D flood model as they may be driven by different flood mechanisms, for example, storm duration or consecutive runoff events. The 2D flood model does not simulate these flood mechanisms and thus the predicted depths within the claypan are limited and likely underestimated. For flood depth predictions specific to the claypans refer to Section 4.4.7.

The extent of inundation and predicted flood depths are reduced for the smaller AEP events. The maximum predicted flood depths for the 10% AEP event show the flow primarily confined to defined drainage channels with less flow across the floodplains. For the 20%, 50% and 63% AEP events, the maximum predicted flood depths are contained within the channels and discrete areas of ponding within the valley are observed, generally, only interconnected by very shallow flood depths.

In the 63% AEP event, interplay of different EHUs on water movement in the landscape can be observed. For example, Figure 4.5 shows a relatively large ponding area (Point A) that occurs at the termini of two coalescing drainage tracts exiting the alluvial fans. The flood model results (which use EHU specific Manning's n and infiltration parameters) predict the following observed flood behaviour:

- Water accumulating on the low infiltration Stony Flats EHU with resultant fine sediment deposition.
- Water shedding onto the adjacent Loamy Flats EHU and then rapidly infiltrating; these areas support denser vegetation.
- Further ingress of flood water into the valley as influenced by microtopography and ultimately prevented by the Calcrete Plain barrier area to the southwest.

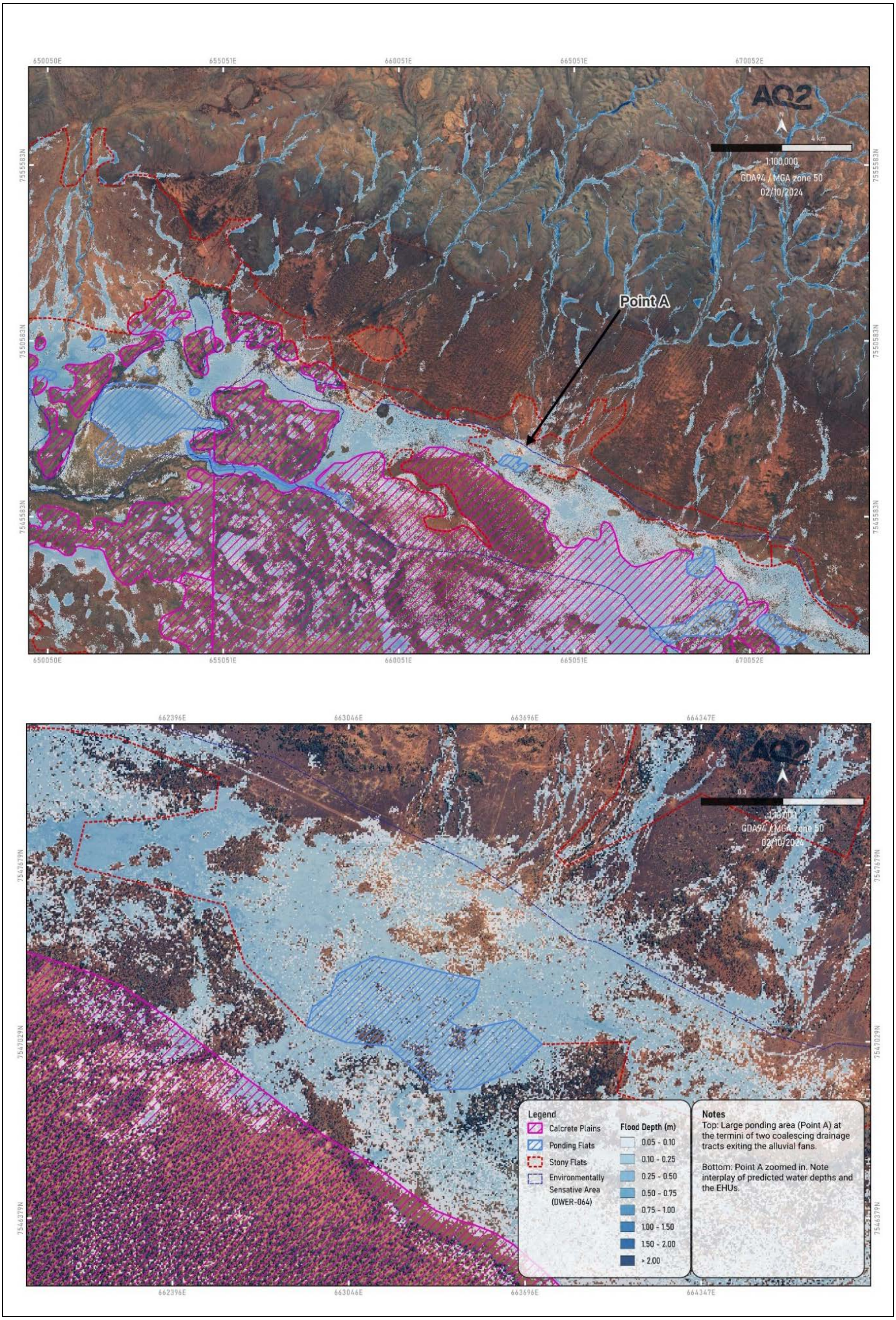


Figure 4.5 2D Model Predicted 63% AEP Maximum Flood Depths and EHUs

Outputs from the 2D flood model were used to quantify parameters in the water balance model of the Gnalka Gnoona and Koodjeepindarranna claypans. With reference to the claypan catchments discussed further in Section 4.4.1 and shown in Figure 4.6, the potential for runoff contribution to Koodjeepindarranna Claypan from the Chichester and Hamersley ranges was quantified from the 2D flood model results across various AEP events. Runoff from (refer Figure 4.6) Catchment E and Catchment L (Wittenoom Gorge) was simulated in the 2D flood model using the peak inflow hydrographs from RORB as discussed in Section 4.3.4. For entire catchment responses to the various AEP events, it was predicted that, on average, 68% of runoff from Catchment E and 15% of runoff from Catchment L contributed to Koodjeepindarranna Claypan and the remaining runoff reports to the Fortescue Valley downstream of the Koodjeepindarranna Claypan. These predicted flow splits were used to quantify the approximate runoff volumes reporting to Koodjeepindarranna Claypan as described further in Section 4.4.1.

The 2D flood model results also predicted some runoff from Catchment K and J can contribute to Gnalka Gnoona Claypan in large AEP events (1% AEP), however flood flows predominantly report further downstream to Koodjeepindarranna claypan. In the water balance of the claypans, catchments K and J were assumed to report to Koodjeepindarranna Claypan.

Inflows from two Hamersley Range catchments that were simulated in the 2D flood model (H3 and H4 in Figure 4.4) were excluded from the water balance of the claypans upon inspection of the 2D flood model results, 2023 LiDAR DEM and aerial imagery. Between the catchment termini into the Fortescue Valley and Gnalka Gnoona claypan, drainage is poorly defined and throughflow is impeded by local depressions and calcrete barriers. Preferential flow paths from catchment H3 and H4 were primarily predicted to contribute to the loamy and ponding flats upstream of the calcrete barrier.

4.4 Claypan Water Balance

A water balance of the Gnalka Gnoona and Koodjeepindarranna claypans was completed to define the baseline hydrological regime of the claypans and to predict potential flood levels that may occur due to water storage within the claypans. To complete the water balance, the following steps were taken:

- Definition of catchment boundaries reporting to each of the claypans based on interpretation of elevation data, aerial photography and the 2D flood model results.
- Analysis of collected water level data.
- Development of a water balance model.
- Run a short-term calibration model to match modelled water levels to recorded data.
- Run a longer-term calibration model to match modelled water levels with observations from historic satellite imagery.
- Flood frequency analysis of the modelled water levels from the longer-term calibration model.

4.4.1 Claypan Catchment Boundaries

The maximum potential catchment areas which may report to the claypans are discussed in Section 2 and are nominally shown in Figure 4.6. There is uncertainty when defining the boundaries of the surface water catchments draining to the claypans due to the following reasons:

- The Fortescue Valley floor in proximity to the Study Area is extremely flat (i.e. 10 m elevation fall over an 80 km total length spanning either side of the claypans which is ~0.01% slope) and drainage channels along the floor of the valley are poorly defined. There is also evidence of ponding due to the valley floors microtopography, which would prevent runoff from contributing to downstream flow until available storages are full. This makes it difficult to define the extent of the Fortescue Valley floor which would contribute runoff to the claypans from the south and east as it may vary depending on the size of the rainfall event and antecedent conditions. It has been assumed that the effective claypan catchments extend only a limited distance upslope along the Fortescue Valley floor.

- Where drainage lines exit from the Chichester and Hamersley Ranges, extensive alluvial fans have formed with braided preferential flow channels that distribute runoff across them. Some of the fans are positioned such that runoff from the upstream catchment may or may not report to the claypans depending on the position of the preferential flow channel for a particular event.

Effective catchment areas reporting to the claypans were adopted to account for the microtopography in the Fortescue Valley and preferential drainage paths on the alluvial fans as defined in the 2023 LiDAR DEM. The results of the 2D flood modelling exercise (discussed in Section 4.3) were used to assist in defining the effective catchment areas for the claypans, which are shown on Figure 4.6 and detailed in Table 4.6. The catchments were split into “Chichester” catchments, “Hamersley” catchments and “Valley” catchments as the rainfall loss parameters applied to the steeper, rocky Chichester and Hamersley Ranges would be different to those applied to the flat, vegetated Fortescue Valley area.

The following should be noted:

- Discharge from catchment area E has nominally been split to be 68% to Koodjeepindarranna and the remainder to discharge downstream of the claypans, based on the 2D flood model results.
- Discharge from catchment area F has nominally been split to be 90% to Koodjeepindarranna and 10% to Gnalka Gnoona, based on inspection of aerial imagery.
- It has been assumed that only catchments L and K from the Hamersley Range drain to the claypans. Runoff from the other potential Hamersley Range catchments (refer Figure 3.4) have been assumed to collect within the Fortescue River Valley and not reach the claypans.
- Discharge from catchment L (Wittenoom Gorge), has been split such that 15% reports to Koodjeepindarranna Claypan and the remainder is assumed to discharge downstream of the claypans, based on the 2D flood model results.
- It has been assumed that existing linear infrastructure development within the claypan catchment areas (such as the rail lines and roads) have not altered the contributing catchment areas to the claypans. These features have been picked up in the 2023 LiDAR data and were included in the 2D model domain, with gaps in the linear infrastructure landforms made in the model surface to simulate culverts where these are apparent in aerial photography. The 2D model simulated the impact of these features on the natural runoff which was used to define claypan catchment areas.
- The total effective claypan catchment areas which have been adopted in the water balance model are 817 km^2 (Koodjeepindarranna) and 215 km^2 (Gnalka Gnoona).

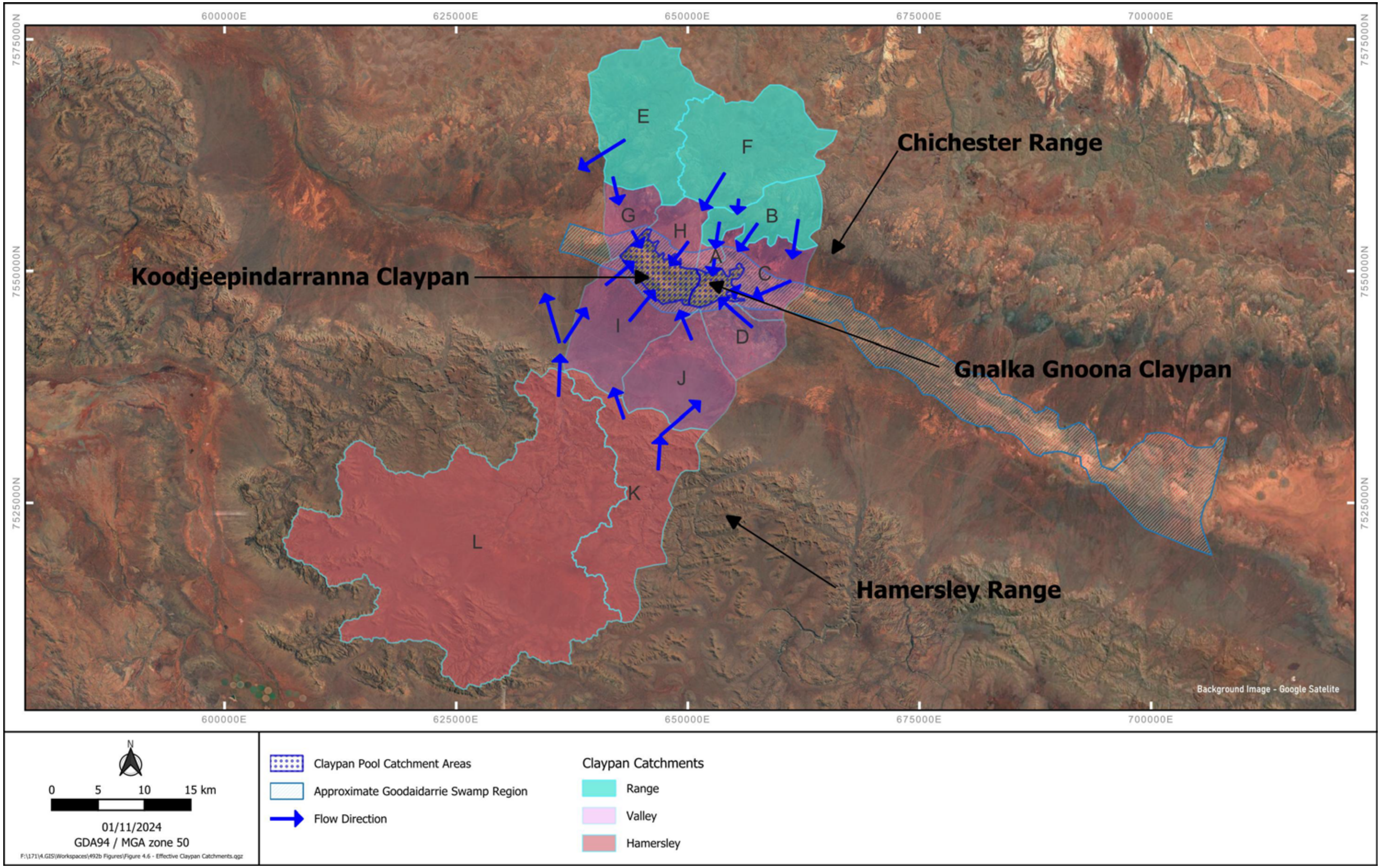


Figure 4.6 Effective Claypan Catchments

Table 4.6 Effective Claypan Catchments (Pre-Development)

Catchment ID	Reporting to Koodjeepindarranna Claypan (km²)	Reporting to Gnalka Gnoona Claypan (km²)	Reporting Downstream of Claypan (km²)	Catchment Type
A	-	6	-	Valley
B	-	63	-	Range
C	-	65	-	Valley
D	-	49	-	Valley
E	101 (68% of Catchment)	-	48 (32% of Catchment)	Range
F	140 (90% of Catchment)	16 (10% of Catchment)	-	Range
G	35	-	-	Valley
H	34	-	-	Valley
I	106	-	-	Valley
J	99	-	-	Valley
K	165	-	-	Hamersley#
L	103 (15% of catchment)	-	586 (85% of catchment)	Hamersley#
Koodjeepindarranna Claypan Footprint	34	-	-	Valley
Gnalka Gnoona Claypan Footprint	-	16	-	Valley
Total	817	215	634	

Note that within the model, the rainfall losses for Valley catchments were applied to the Hamersley catchments, K and L.

4.4.2 Water Level Data Assessment

As discussed in Section3.1, the baseline surface water monitoring network included pressure transducers installed within the claypans; specifically, SWML03 installed in Koodjeepindarranna Claypan and SWML04 installed in Gnalka Gnoona Claypan. The baseline data was assessed as follows:

- Pressure transducer measurements were converted to a calculated water depth accounting for recorded barometric pressure readings.
  - Note barometric pressure data is not available for the period between January 2022 to February 2023. As a result, corrections of the water level data during this period were not completed, resulting in additional uncertainty in the observed data during this period (such as the claypan inundation event in early 2020).
- The water depths were converted to a relative level using surveyed elevations of the installation locations and measurements of cable lengths which support the pressure transducers.
  - Note that there was a significant discrepancy (0.29 m) between the surveyed ground level at SWML03 (Koodjeepindarranna Claypan) compared to the DEM elevation at the SWML. The surveyed elevation has been discarded as it is not consistent with the distribution of ponded water within the claypans shown in historic imagery, which indicated that the elevation of the SWML is similar to the lowest elevation within the claypan, consistent with the DEM but not the survey data. The DEM elevation was therefore used. However, if the DEM at the SWML03 location

is not representative of the actual elevation of the logger, the calibration of the claypan water balance model will be affected.

- Stage vs storage curves for each of the claypans were developed using the latest (2023) LiDAR DEM to convert the measured water levels into stored volumes within the claypans. The following observations are made:
    - It appears that vegetation may be picked up within the DEM, rather than the ground surface. Particularly in Koodjeepindarranna Claypan, which is more heavily vegetated, the conversion of measured water levels would therefore result in reduced estimates of stored volume within the claypan when the stage vs volume curve is applied.
    - A drainage channel links the Koodjeepindarranna and Gnalka Gnoona Claypans with a high point that needs to be overtopped before water can flow between them. The elevation of this high point is 402.9 mRL based on the DEM, which was used as part of the boundary between the claypans when defining the stage vs storage curves.
    - Based on the DEM, the Koodjeepindarranna Claypan appears to overflow further downstream when lake water levels exceed 403.5 mRL. This overflow point has been used as part of the boundary when defining the stage vs storage volume curve.
- The measured water level elevations were converted to storage volumes using the stage vs volume curves.

4.4.3 Water Quality (TDS) Data Assessment

The baseline surface water monitoring network included monitoring stations within the two claypans, which recorded electrical conductivity (EC) readings at 15-minute increments. These readings have been converted to approximate salinity (as TDS) to provide data on how the salinity of the claypans changes following runoff events.

Timeseries plots of the recorded salinity within the claypans are shown on Figure 4.7 and Figure 4.8. Key observations from the recorded data are as follows:

- When runoff first reports to the claypans, the salinity of the ponded water is typically low (<100 mg/L).
- As the water in the claypans evaporates and the salts are left behind, the salinity of the claypans increases.
- Maximum TDS values from the observed data are less than 900 mg/L.

Further water quality analysis is discussed in Section 4.5.

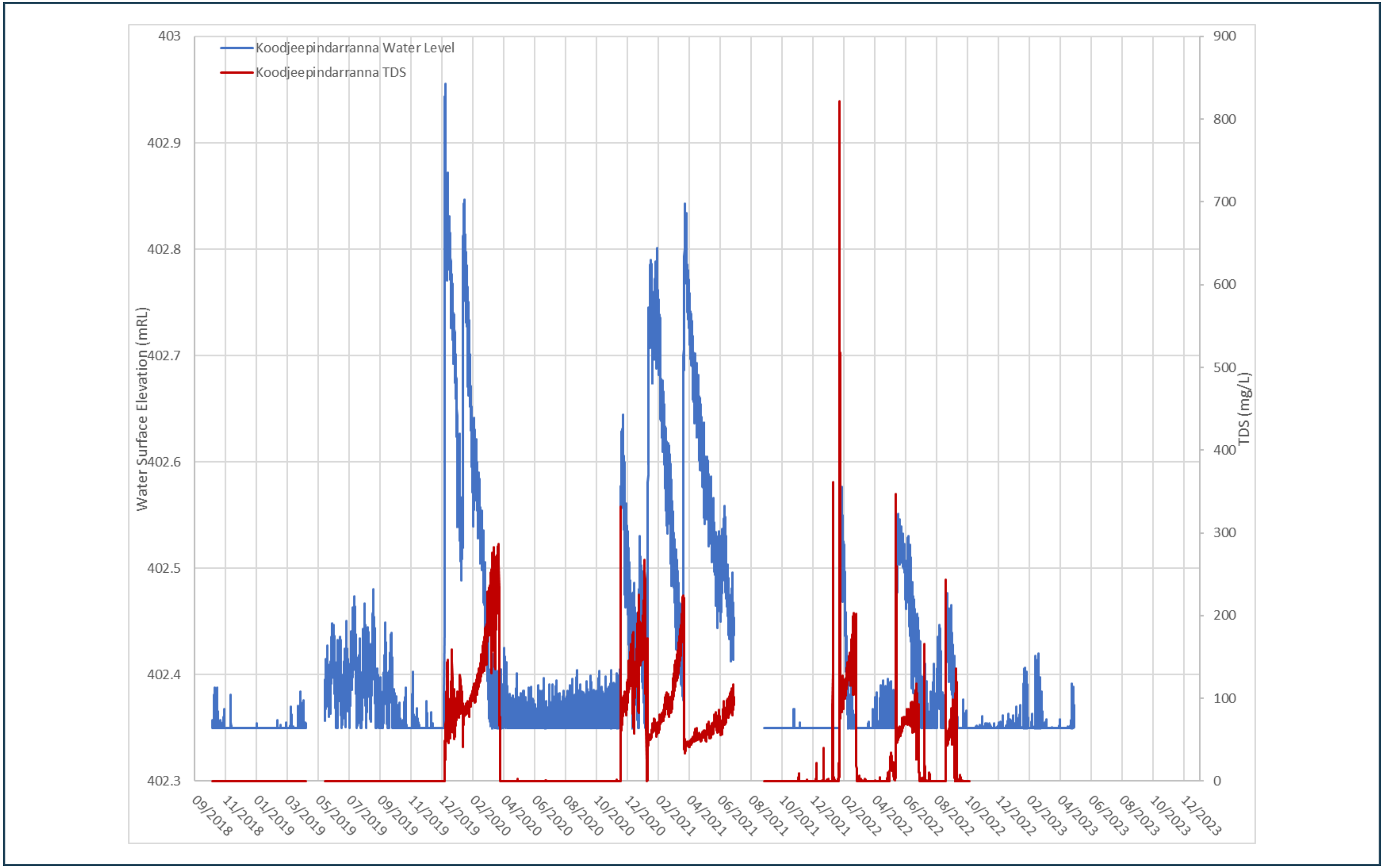


Figure 4.7 Koodjeepindarranna Claypan Salinity Measurements

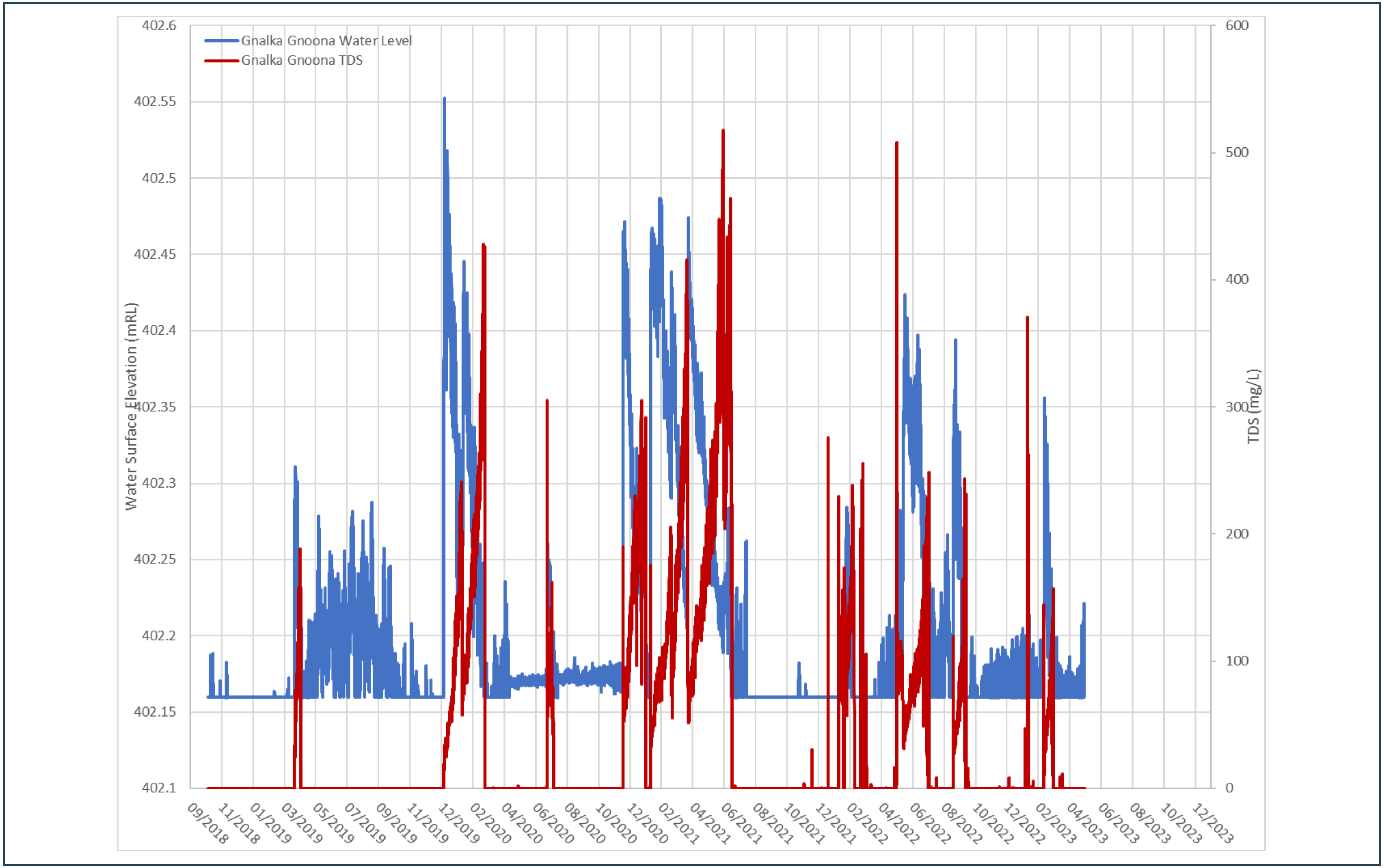


Figure 4.8 Gnalka Gnoona Claypan Salinity Measurements

4.4.4 Water Balance Model Development

A water balance for each claypan was created in GoldSim and completes water balance calculations on a daily timestep, consistent with the recorded rainfall data. The stored water volume is calculated at each time step by adding new inflow volumes to the storage volume from the previous time step and subtracting the outflow volume:

$$Storage\ Volume = Storage\ Volume_{Previous} + Inflows - Outflows$$

The water balance model which has been developed covers both claypans using similar calculation logic, but different inputs based on observed behaviour. Inflows to the claypans include runoff from the defined effective catchments and rainfall directly onto the surface of water ponded in the claypan. Water losses from the models are via evaporation from the ponded water surface area, and infiltration/seepage to groundwater from across the ponded surface area.

The following input parameters were used:

- Claypan effective catchment areas (as shown in Figure 4.6).
- Stage/area/volume relationships for each claypan at 0.1 m elevation increments derived from the DEM data developed by Aerometrex Ltd for the Project and surrounding areas and provided to AQ2 by HPPL.
- An extract of the baseline daily rainfall data set was used (1922 onwards) as many data records were missing pre-1922 (refer Section 2). The extract consisted of:
    - Mulga Downs (BoM) rainfall data from 1922 to 2018;
    - Mulga Downs Exploration Camp (MDEC) rainfall data from 2018 to December 2023;
    - Karijini North (BoM) data between 2018 and January 2023 where MDEC data was not available.
- Average monthly dam evaporation loss rates sourced from Department of Agriculture for Mt. Tom Price (Luke *et al.*, 2003).
- Calibrated rainfall loss coefficients Initial Loss (IL) and a Proportional Loss (PL) function as discussed further in Section 4.4.5.1.
- Lake infiltration/seepage loss rate as calibrated in the model (refer Section 4.4.5).
- The elevation of the high point separating Koodjeepindarranna and Gnalka Gnoona claypans is 402.9 mRL. The model includes the following logic:
    - When the water level in only one of the claypans exceeds the interconnecting overflow level, 40% of the stored water volume above the overflow elevation is transferred to the other claypan.
    - When the water level in both claypans exceeds the interconnecting overflow level, 40% of water from the claypan with the higher water level is transferred to the claypan with the lower water level. Over a few days, the water levels in the two claypans typically equalises.
    - The factor of 40% is a nominal number to prevent model instabilities which may occur from water overflowing back and forth between the claypans if a high percentage was adopted.
- Water surface elevation and flow rate predictions extracted from the 2D flood model were used to develop a rating curve to define the outflow rate from Koodjeepindarranna claypan when predicted water levels in the claypan exceed 403.5 mRL (the elevation at which the Koodjeepindarranna claypan overflows downstream through the Fortescue Valley).
- A function to nominally transfer water between the Gnalka Gnoona and Koodjeepindarranna claypans when the water level in either claypan is above the high point separating the claypans was also adopted to balance (over time) the water levels within the claypans following large rainfall events. The purpose of the function is to achieve similar water levels in the two claypans following a large rainfall event when the two claypans are in hydraulic connection. The function transfers (nominally) 7% of the volume that represents the difference in claypan water levels each day, noting that larger rates of water transfer led to risks of numerical instabilities occurring in the model results.

4.4.4.1 Rainfall Losses

Modelled runoff to the claypan catchments within the water balance model responds to historic daily rainfall records, which are measured over a fixed 24-hr period, and centred 7-day rainfall totals (R_7) that account for past and upcoming rainfall days. Centred rainfall totals were used as the magnitude of these events were found to correlate to the largest observed inundation events in the claypans as assessed from historical satellite imagery. Runoff to the claypans results from excess rainfall across the upstream catchments after accounting for the following conceptual losses:

- Initial Loss (IL) at the start of a storm event that must be exceeded before any runoff can occur (considering storage within the valley and range catchments). For example, an IL of 100 mm effectively means that no runoff is generated into the claypan for any daily rainfall events which do not exceed 100 mm.
- Subsequent continuing runoff co-efficient (ROC), as a function of the centred 7-day rainfall total (R_7). This is applied to any remaining rainfall within the event that exceeds the IL. The ROC is calculated with a function based on the R_7 value and is used for all the catchment types. The result of the function is a ROC which increases the percent of rainfall that runs off as the size of the event increases. This was required when calibrating the model to approximate the claypan response to both small and large rainfall events.

The rainfall losses adopted were determined during a calibration exercise as discussed in Section 4.3.4, with losses due to evaporation and seepage from the claypan water volume accounted for separately in the model.

The modelling assumes 100% of rainfall falling on the ponded claypan surface water area reports to the pond storage volume (no losses).

Antecedent moisture conditions were simulated in the model by considering that rainfall recorded during previous days reduces the IL applied to a subsequent day's rainfall. This running IL value fluctuates between the full IL value and zero throughout the simulation period depending on the sequence of daily rainfall totals. The way the antecedent moisture conditions within the model are simulated to predict runoff volumes is summarised as follows:

- A running IL value varies between the full IL value and a loss of 0 mm throughout the model depending on the rainfall sequence.
- At the start of the model, the full IL is applied as the running IL until the first day of rainfall occurs.
- If the day's rainfall total is higher than the IL value, the IL value is removed from the total and the ROC applied to the excess rainfall. The IL that will apply to the following day's rainfall (if any) will be zero and the ROC will be applied.
- If the daily rainfall total is less than the IL value, no runoff occurs and the running IL value which would apply to the following time step is reduced by the rainfall depth. For example, for a nominal IL value of 100 mm, a daily rainfall total of 60 mm will reduce the running IL value for the next time step to 40 mm.
- If the rainfall total for the following day is less than the running IL value, the running IL value is further reduced by that day's rainfall depth. For example, a rainfall total of 20 mm would further reduce the running IL value from 40 mm to 20 mm.
- For days with no rainfall, the running IL value increases by a set amount (refer Section 4.4.5.1).
- The full IL is enforced again following sufficient successive days of no rainfall to increase the running IL value back to the full value.

4.4.4.2 Water Storage Volume

As outlined above, the claypan storage volume at the start of a timestep is defined as the stored volume from the start of the previous timestep plus (or minus) the difference between inflows and outflows over the timestep. The calculated storage volume is subsequently used to define the lake surface area, depth and relative level using lookup tables derived from the DEM. Note that the elevation at which the water levels were measured within the claypans was not at the lowest elevation as per the DEM, but the volume of water stored below the measurement point is relatively small.

4.4.4.3 Water Quality

In parallel to the water balance model operation, a salt mass balance model has been run within the GoldSim model. Each water flux within the model has an assigned TDS concentration which allows the mass of salt to be balanced in each of the claypans. A TDS in the claypans is calculated at each timestep by dividing the mass of salt (from the salt balance) by the volume of water in the claypan (from the water balance).

The assigned TDS concentration for each flux in the model is summarised as follows:

- Direct rainfall on the claypan lake surface: 1 mg/L (nominal).
- Runoff from the catchments: 50 mg/L (typical value to approximate salinity monitoring results).
- Evaporation loss from the claypans: 0 mg/L.
- Seepage loss to the groundwater: calculated TDS concentration for the claypan.
- Overflow from the claypan: calculated TDS concentration for the Koodjeepindarranna claypan.
- Overflow between the claypans: calculated TDS concentration for the claypan which is overflowing.

4.4.5 Calibration Runs

The following calibrations were completed for the water balance model:

- A short-term calibration to determine rainfall loss coefficients by matching model predictions to the observed water levels from the claypan surface water monitoring stations as detailed in the Section 3.
- A longer-term calibration to confirm the rainfall loss coefficients derived from the short-term calibration also predicted appropriate responses to significant rainfall events, based on reviewing historic aerial imagery, as these were limited in the short-term calibration period.

4.4.5.1 Short-Term Calibration Run

The purpose of the short-term calibration was to define IL and ROC parameters such that the model's peak water level predictions for the claypans closely approximated measured water levels. The same rainfall losses were applied to both claypans for the different types of catchments (refer Table 4.7) but the seepage loss rates were modified individually to allow the modelled water levels to approximate the observed recession following a runoff event. A seepage loss of 2 mm/day was applied to Koodjeepindarranna (SWML03) and 5 mm/day to Gnalka Gnoona (SWML04). The calibration was completed against data collected between late 2018 and mid-2023.

Table 4.7 Water Balance Rainfall Loss Parameters

Parameter	Catchment		
	Chichester	Valley	Hamersley#
Initial Loss	90 mm	120 mm	120 mm
Runoff Coefficient (%)	$0.15R_7 + 7.5$	$0.15R_7 + 7.5$	$0.15R_7 + 7.5$
Initial Loss Recovery	15 mm/d	10 mm/d	10 mm/d

Note that within the model, the rainfall losses for Valley catchments were applied to the Hamersley catchments, K and L.

A comparison of the calibrated model results to the observed water levels in the claypans is shown in Figure 4.9 and Figure 4.10. The following observations are made, noting that other combinations of rainfall loss parameters could have been chosen which would allow the model to replicate the observed claypan water levels:

- The SWMLs in each claypan were not positioned at the lowest point. The modelled and observed water levels could therefore not be compared once the modelled levels fell below the surveyed elevation of the sensor at the SWML.
- A rainfall event of close to 100 mm was measured in January 2019 without any water volume in the claypans recorded above the pressure transducers. This served as the basis for the IL parameters adopted in the water balance model.
    - It is noted that this rainfall event may have only occurred over part of the claypan catchment and was the first rainfall event following a prolonged drought (refer Section 2). As such, it is possible that the IL adopted in the model may be over-estimated. However, when lower IL were used in the model, the model predicted the claypans to be inundated more frequently and at greater depths than the observations suggested.
- To achieve a reasonable model approximation of observed claypan water level responses, the runoff responses to the claypan were spread over a few days following the rainfall event, which mimics the time taken for runoff to report to the claypans from the upstream catchment areas. The effect of spreading out runoff reporting to the claypans was that the claypan ponded water surface area (where 100% of runoff reports to the claypan) was smaller in the days following a rainfall event, when the likelihood of additional rainfall is likely. The following percentage of runoff in each day from the recorded rainfall event was as follows:
    - Day zero – 20%
    - Day one - 50%
    - Day two – 15%
    - Day three – 10%
    - Day four - 5%
- Within the baseline data collection period, significant rainfall events occurred during the 2019/2020 and 2020/2021 wet seasons. Observed data from the claypan surface water monitoring stations for the 2019/2020 wet season showed the highest water level responses in the claypans in January 2020 (maximum values of 402.95 mRL in Koodjeepindarranna Claypan and 402.65 mRL in the Gnalka Gnoona claypan). This response is inconsistent with the baseline rainfall dataset extract as greater rainfall depths appeared to have occurred in the 2020/2021 wet season compared to the 2019/2020 wet season. Note that the 2019/2020 wet season followed a prolonged period of soil water depletion and drought stress between June 2018 and February 2020 (as discussed in Section 2).
- The 2020/2021 wet season predicted water levels in Koodjeepindarranna are relatively higher than those in Gnalka Gnoona and they exceed the overflow elevation between claypans. Within the water balance model, this results in the transfer of water from Koodjeepindarranna to Gnalka Gnoona and causes the predicted water levels in Gnalka Gnoona Claypan to be higher what would be predicted from rainfall/runoff from Gnalka Gnoona's direct catchments.
- The water balance model could not be configured to simulate the peak water levels across all events in the short-term calibration period as the magnitude of the observed runoff response did not match the magnitude of the rainfall in all instances.

- The recorded rainfall data is a measurement of rainfall at a single point and may not be representative of rainfall across the full claypan catchment areas. It is assumed that the rainfall records for the 2019/2020 wet season were more representative of rainfall over the entire catchment than the 2020/2021 and 2021/2022 wet season and therefore the rainfall loss parameters were calibrated predominantly for this data set. As a result, the water balance model overpredicts the 2020/2021 and 2021/2022 wet season claypan water levels and underpredicts events mid-2022.

The adopted IL for the Valley catchments are higher than for the Chichester catchments. The higher losses within the Valley catchments were applied given the lack of defined drainage shown on the LiDAR DEM within the Fortescue Valley, which indicates relatively slow runoff responses and large catchment storages that need to be filled before runoff to the claypans occurs. The steeper Chichester catchments will be more responsive to runoff and have less catchment storage losses and therefore a higher rate of runoff is expected. Further:

- The IL in the Chichester catchments (90 mm) is the equivalent of less than a 24-hr 20% AEP event (refer Figure 2.10, in Section 4.3 for IFD). The applied running IL recovery of 15 mm/d means that, following a runoff event, the running IL value in the model returns to the full value of 90 mm after 6 consecutive no-rain days.
- The IL in the Valley catchments (120 mm) is the equivalent of a 24-hr 20% AEP event. The IL recovery of 10 mm/d means that, following a runoff event, the running IL value returns to the full value of 120 mm with 12 consecutive no-rain days, reflecting the ponding storage that is likely to occur within the Valley area.
- There is greater uncertainty in the definition of the catchment areas within the Valley area than in the Chichester Range (both temporally and spatially). The higher rainfall losses applied to the Valley catchments reduces the impact of this uncertainty on the model calibration.

The rainfall losses from the Valley Catchments were also applied to the Hamersley Catchments, K and L, even though the runoff generation characteristics within the Hamersley Range are likely to be similar to the Chichester catchments. The higher rainfall loss parameters were applied given the distance the runoff from the catchments needs to flow through before reaching the claypans. This is attributed to the microtopography and limited slope throughout the Fortescue Valley as discussed in previous sections.

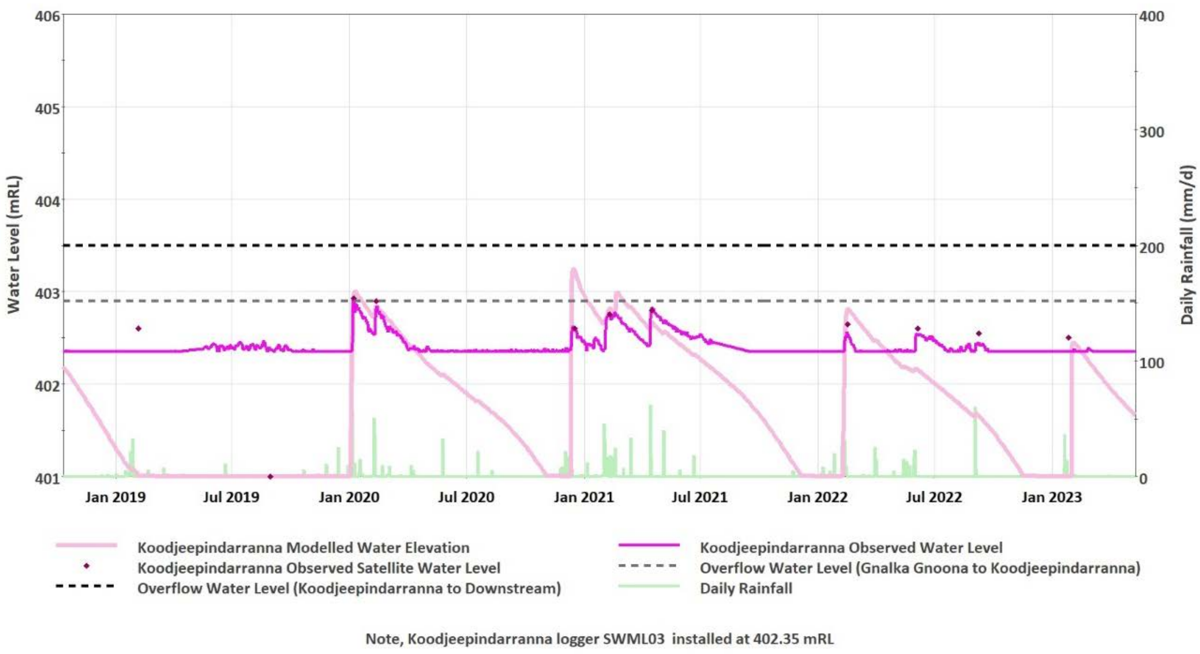


Figure 4.9 Short-Term Calibration – Koodjeepindarranna Claypan Water Levels

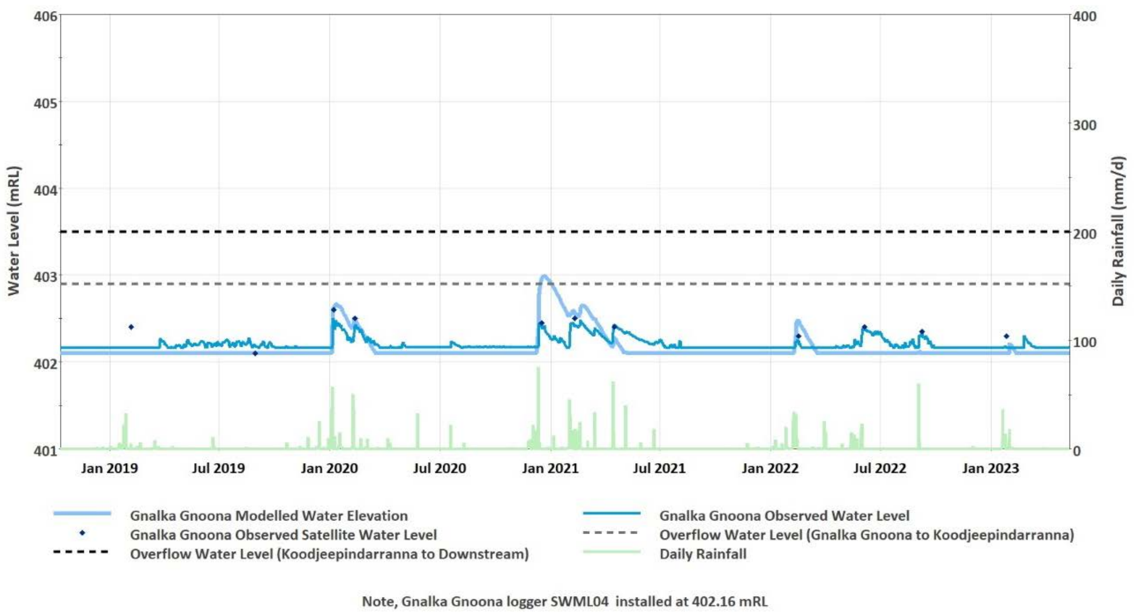


Figure 4.10 Short-Term Calibration – Gnalka Gnoona Claypan Water Levels

As well as the calibration against water levels, TDS concentration predictions from the model were compared against the observed values in the claypan (although the model wasn't calibrated to achieve the salinity results). A comparison of the observed and modelled salinity is shown in Figure 4.11 and Figure 4.12. The following should be noted with respect to the salinity predictions:

- Observed salinity in the claypans is typically below 500 mg/L, with the exception of "first flush" spikes in salinity prior to large inflows of runoff into the claypan.

- The modelled salinity approximates the timing and magnitude of the observed salinity levels reasonably well in both claypans, with the exception of matching the peak values at the end of a ponding event. The reasons for this discrepancy are discussed below.
- Within the GoldSim water/salt balance, the calculated salinity becomes extremely high as the volume of water within the claypan reduces, due to the TDS being calculated by dividing the mass of salt by an increasingly smaller volume. The logic within the model has been programmed to overwrite the salinity to 0 mg/L when the storage volume becomes (nominally) less than 0.1% of the maximum storage volume (to the overflow point) in each of the claypans.
  - Note that TDS concentration is set to 0 mg/L for plotting purposes, however the mass of salt within the claypan is preserved for the next runoff inflow event.
  - The 0.1% volume cut-off was nominally selected to keep the modelling salinity within the same order of magnitude as the observed salinity so that the comparison could be viewed.
  - The 0.1% volume cut-off also generally coincides with the point at which the water level in the claypans falls below the salinity sensor elevation.
- The data logger in the claypans is not located in the lowest point of the claypans. Hence the salinity in the claypans could increase above the values shown below as the lake surface area further reduces.

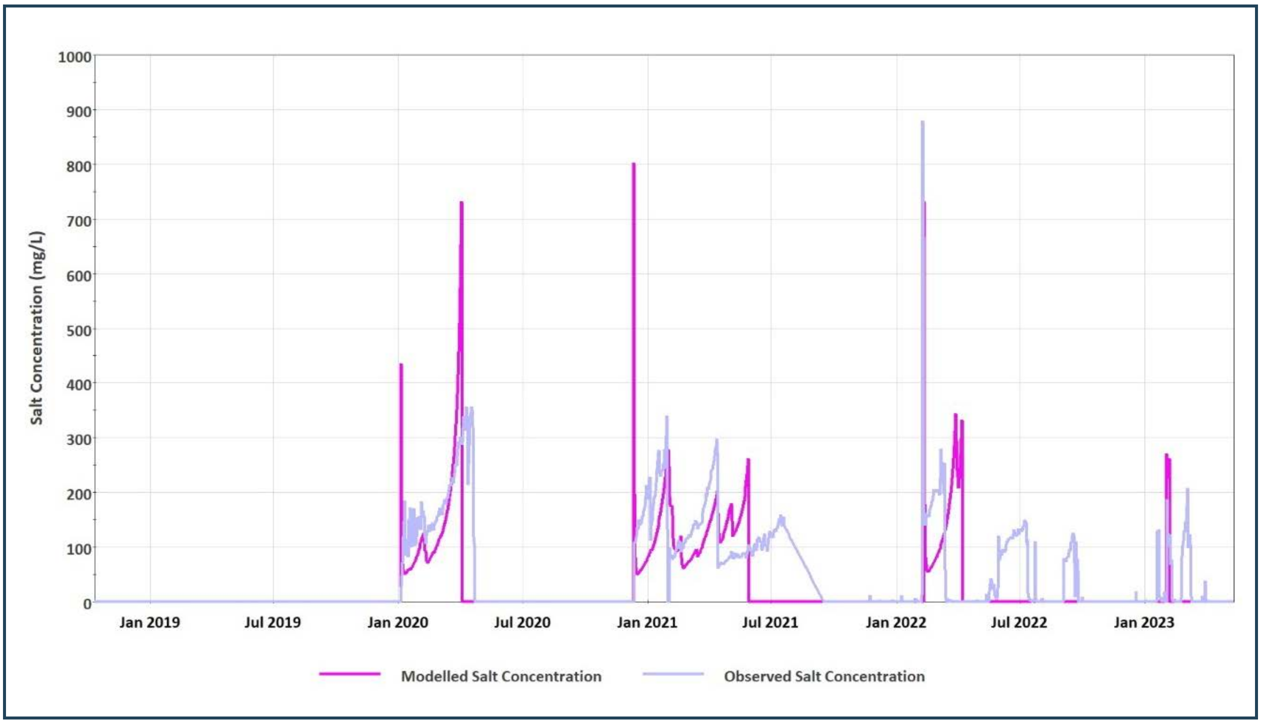


Figure 4.11 Short-Term Calibration – Koodjeepindarranna Claypan Salinity

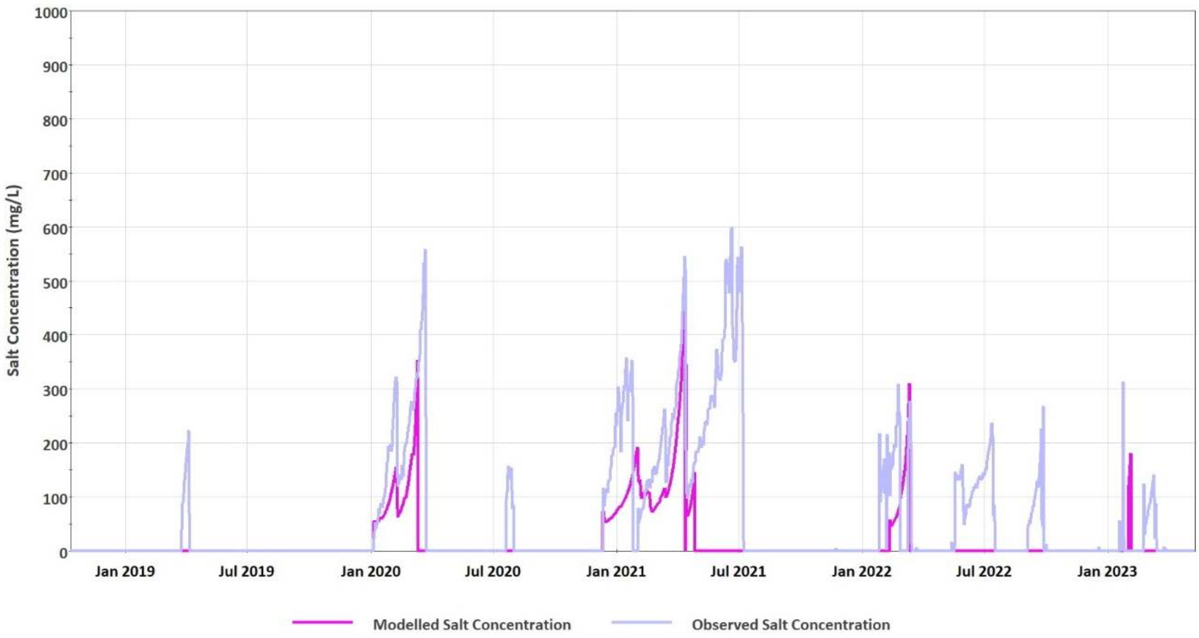


Figure 4.12 Short-Term Calibration – Gnalka Gnoona Claypan Salinity

4.4.5.2 Longer-Term Calibration Run

The Short-Term Calibration model parameters produced model predictions which approximate measured claypan water levels from the baseline data collection period, but the magnitude of rainfall events during this period were relatively small. The model was run for an extended duration (from 1988) to test the loss parameters identified in the short-term calibration exercise during a period which contained larger rainfall events, with model predictions compared to inundation extents from aerial images of the claypans obtained from Sentinel, Landsat and Google Earth satellites. The inundation events are plotted against the model predictions in Figure 4.13 and Figure 4.14.

The water balance assumes the full claypan catchment contributes runoff from the applied excess rainfall depths (after accounting for losses). This may lead to an overestimation of runoff to the claypans as rainfall events are unlikely to occur with the same intensity across the large catchment.

As catchments E and L have the potential to contribute large runoff volumes (refer Table 4.6), it was found varying the ROC in proportion to the size of the rainfall event was required to calibrate the model to predict both the small and large inundation events observed within the claypans. The adopted ROC's and this approach are documented in more detail in Section 4.4.5.1.

There is a varying level of confidence in the estimated inundated extents from observed satellite imagery and whether available imagery coincides with the actual peak inundation extent. The level of confidence is lower for imagery pre-2014 as there is missing imagery for extended periods, some images do not cover the full claypan extents and imagery capture was less frequent.

When comparing the observed inundation depths and the model predictions, the following was noted:

- The water levels observed in the 1988 events may potentially be underestimated due to the infrequent imagery captures from Landsat 4-5 at this time.

- Between 2008 and 2012 small inundation events were observed but not predicted by the water balance. It is possible the baseline rainfall dataset extract throughout this period was less representative of the actual rainfall that fell on the effective claypan catchments or that the IL parameter adopted in the model was lower during this period because of the wetter climate sequence.
- It is likely a large inundation event occurred in early 1999, although it was only sighted within the Fortescue Valley upstream of the Great Northern Highway (and thus not plotted) as aerial imagery of the claypans was missed or obscured by clouds. This would match the water balance model predictions.
- Only limited Google Earth imagery was available between December 1999 to May 2003 and September 2011 to March 2013. This imagery was sparsely taken and overlaid in places by multiple images such that it was difficult to ascertain when images were taken. Notably, there is limited confidence in the 2012 and 2013 wet season as discussed below:
  - The baseline rainfall dataset extract suggests large claypan responses should be prevalent for both years, with the 2013 rainfall event larger than the 2012 rainfall event.
  - Imagery taken approximately 6 months after the 2012 rainfall event appears to show large levels of ponding persisting in the claypan. From the aerial image, the peak water level in the claypan which was likely to have occurred immediately following rainfall was inferred from signs of potential ponding.
  - Imagery in 2013, similarly available 6 months post rainfall event only shows a small amount of remnant ponding in the claypans.
  - The water balance predictions appear to underpredict and overpredict the 2012 and 2013 wet season events respectively, however the water balance results are consistent with the observed rainfall records.

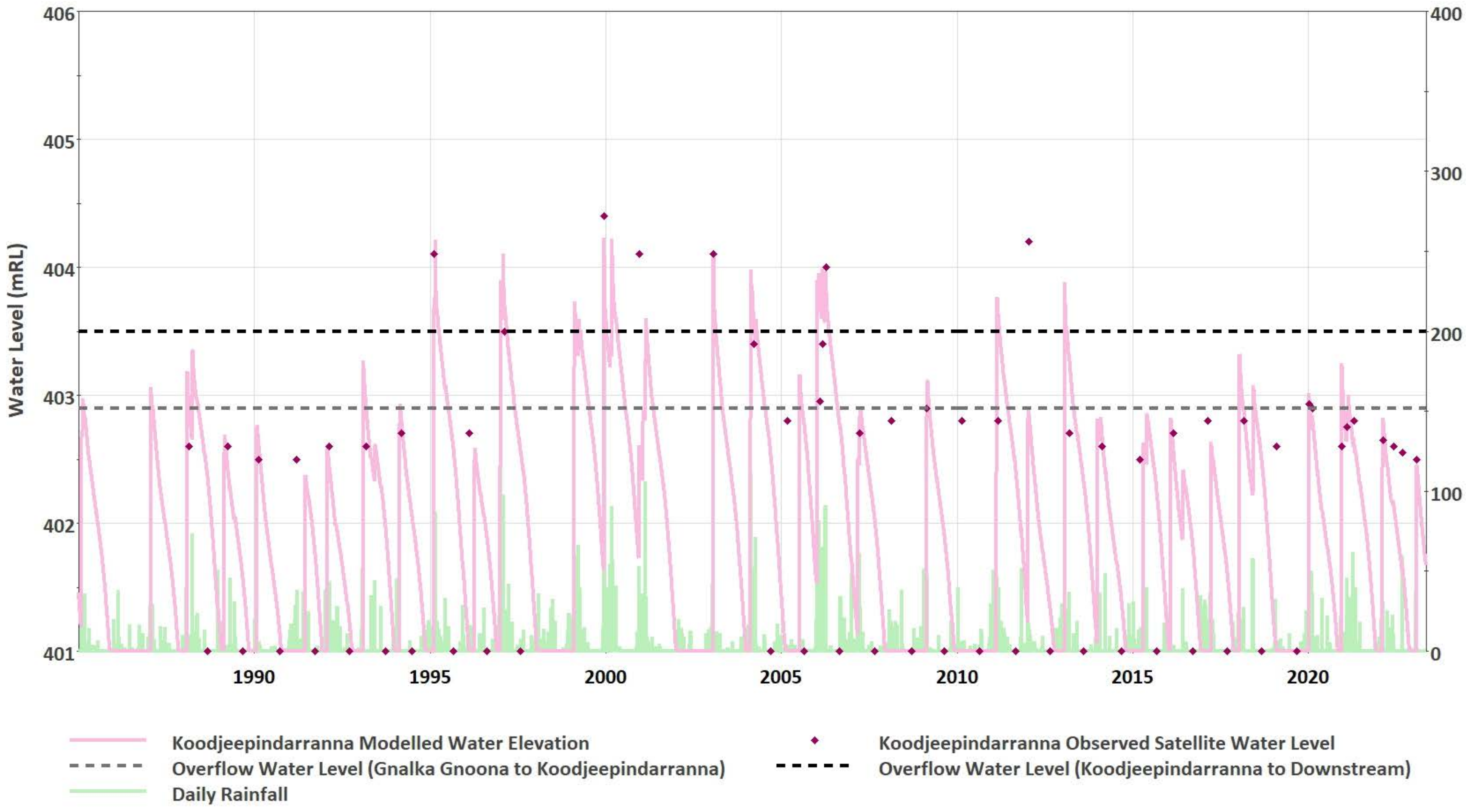


Figure 4.13 Longer-Term Calibration Results – Koodjeepindarranna Claypan

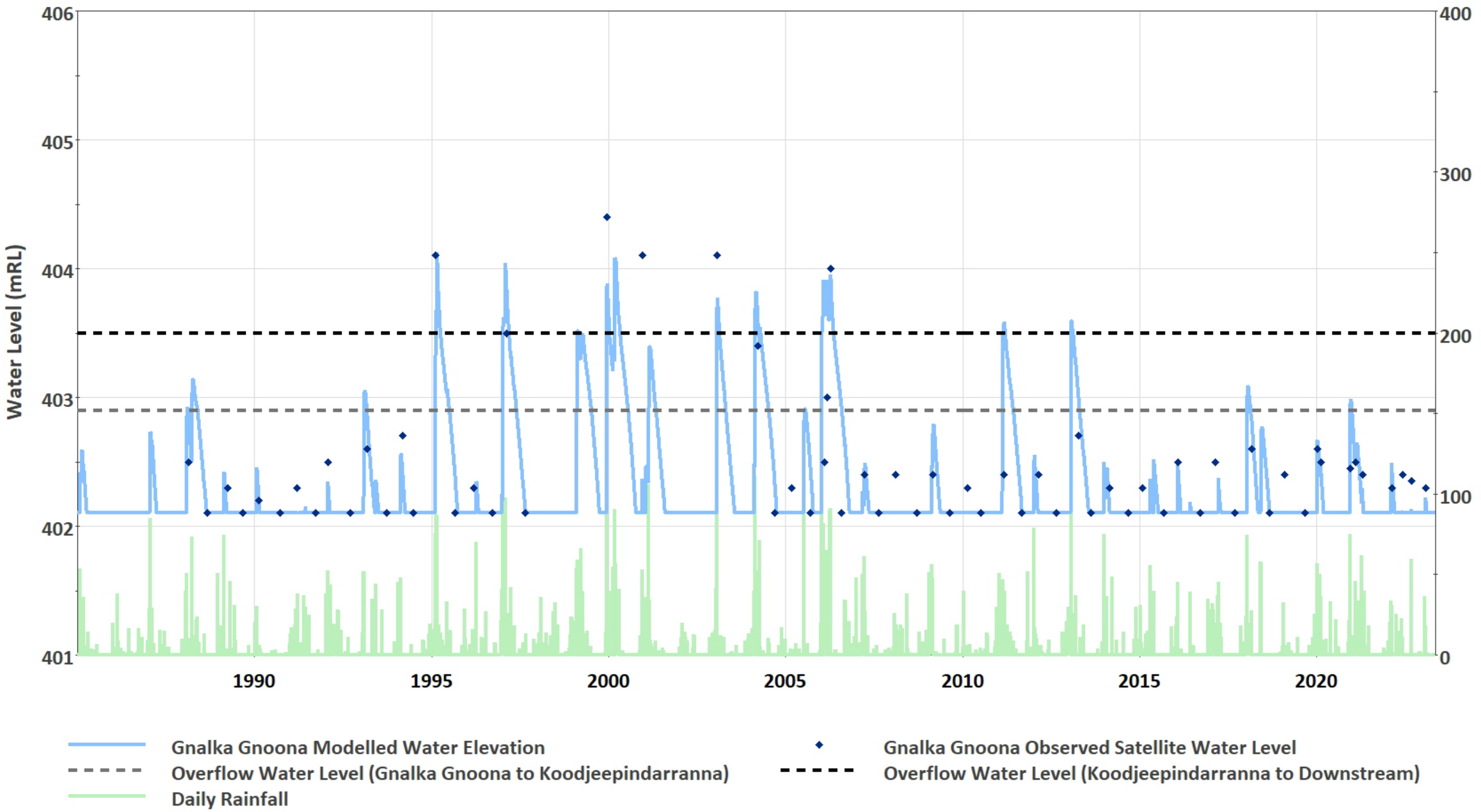


Figure 4.14 Long-Term Calibration Results – Gnalka Gnoona Claypan

4.4.5.3 Calibration Summary

The following observations were made from these results:

- The rainfall loss and seepage loss parameters adopted in the Short-Term Calibration also resulted in the Longer-Term Calibration approximating the observed claypan levels over the longer (satellite based) observation period.
- The long-term calibration run suggests large inundation events in the claypans may occur as a result of large runoff volumes from the Hamersley and/or Chichester Range catchments.
- The rate of overflow from the Koodjeepindarranna claypan downstream impacts the duration of ponding in the claypan and therefore the pond recession curve. To define the outflow rate from Koodjeepindarranna claypan a rating curve developed from the 2D flood model results was used.
- The water depth in the claypans from the base to the downstream overflow elevation is 1.5 m (Gnalka Gnoona) and 2 m (Koodjeepindarranna) in each of the claypans. Comparison with the annual average evaporation depth of 2.4 m, indicates that flooding from a single rainfall event is unlikely to sustain water levels in the claypans for a full year. This is simulated in the water balance model, where surface water ponding typically does not persist for the full year.
- There are differences between the predicted water levels in the claypans and the observed water levels in the satellite imagery, however the model provides a reasonable overall approximation of the observed data. There is inherent uncertainty in the model predictions due to the following main factors:
  - During the period that claypan water levels have been measured (short-term calibration), there has only been relatively small flood events.
  - The model simplifies relatively complicated rainfall-runoff-storage processes to predict claypan responses. Although the rainfall loss parameters within the model have been calibrated to observed claypan water levels, different combinations of loss parameters and different loss models may also have been able to produce results which approximate the observed data.
  - Uncertainty within the definition of the catchment areas which report to the claypans and changes in the effective catchment areas reporting to the claypans depending on the size of the rainfall event. This uncertainty has been reduced by the development of the large-scale baseline flood model, which has allowed flow paths to be identified and the spread of water across the alluvial fans to be predicted.
  - Overflow processes between the claypans and downstream to the Fortescue Valley. Note that these overflow processes have a large impact on what the defined flood level in the claypans would be for different recurrence intervals, such that the defined flood levels of the claypans have a large degree of uncertainty related to them. Again, analysis of the 2D flood model predictions has been used to better estimate the stage vs overflow relationship of the claypans.
  - Uncertainty in the stage-storage-area curve, particularly related to the impact that vegetation may have on the data.
  - Uncertainty in the relative level of the pressure transducer compared to the DEM elevations, and therefore how the observed water depths were converted into observed water levels and storage volumes.
  - How representative the baseline rainfall dataset extract is of the actual rainfall depths which fell over the entire claypan catchment areas.

The objective of the water balance modelling was to provide baseline predictions of the claypans which can be compared to catchment conditions when proposed mine development occurs. Despite the uncertainty in the input parameters, the model provides a reasonable approximation of the hydrological behaviour of the claypans which can be used for this purpose.

A secondary objective of the water balance modelling was to produce an annual maxima series of peak water levels within the claypans for input into a Flood Frequency Analysis (FFA). It should be noted that the limitations within the water balance model simulation also impact the definition of the annual maxima series, and therefore the FFA.

4.4.6 Long-Term Water Balance Predictions

Using the water balance parameters that were defined by the calibration runs, a model was developed for the full duration of the baseline rainfall dataset extract.

The predicted water levels within the claypans are shown on Figure 4.15 and Figure 4.16 and represent the Baseline claypan water level predictions. These results were used to complete a FFA on the predicted claypan flood levels. Some observations from the long-term model include:

- The largest predicted water level in the claypans occurred in the 1974/1975 wet season when 320 mm of rainfall was recorded over 24 hours.
- The 1994/1995 wet season event produced the second largest predicted water level in the claypans.
- Large inundation events were predicted in the claypans between 1995 and 2010 with a greater frequency than other periods of time. As shown in Figure 4.15, the 1995-2010 period was wetter on average, and included a number a large rainfall events, such as:
  - 6 rainfall events exceeding 80 mm of rain in 24 hours, with 3 of these exceeding 160 mm of rainfall.
  - 895 mm of rainfall falling over a 3-month period.
  - 990 mm of rainfall falling over a 6-month period.
- The longest period of continuous claypan inundation predicted to be stored above the elevation of the installed Claypan Surface Water Monitoring Stations (~403.2 mRL) is in the order of 300 days (i.e. the claypan hydroperiod). There were 19 occasions (within the 72-year model duration) where the hydroperiod of the claypans was predicted to exceed 200 days above 403.2 mRL.
- The results indicate that flooding within the claypans can be driven by both a single rare (very large) rainfall event, or by multiple consecutive large rainfall events. Ponding in the claypans would rarely exceed a year's duration.

Other observations from the Baseline claypan water balance model are:

- Claypan water levels are predicted to exceed the overflow linking the two claypans (402.9 mRL), on average, every 2 years.
- Claypan water levels are predicted to exceed the downstream overflow level (403.5 mRL), on average, once every 3-4 years.
- The claypans are predicted to typically dry-out during the dry season in most years.
- The highest claypan water level predicted by the model was 405.4 mRL.

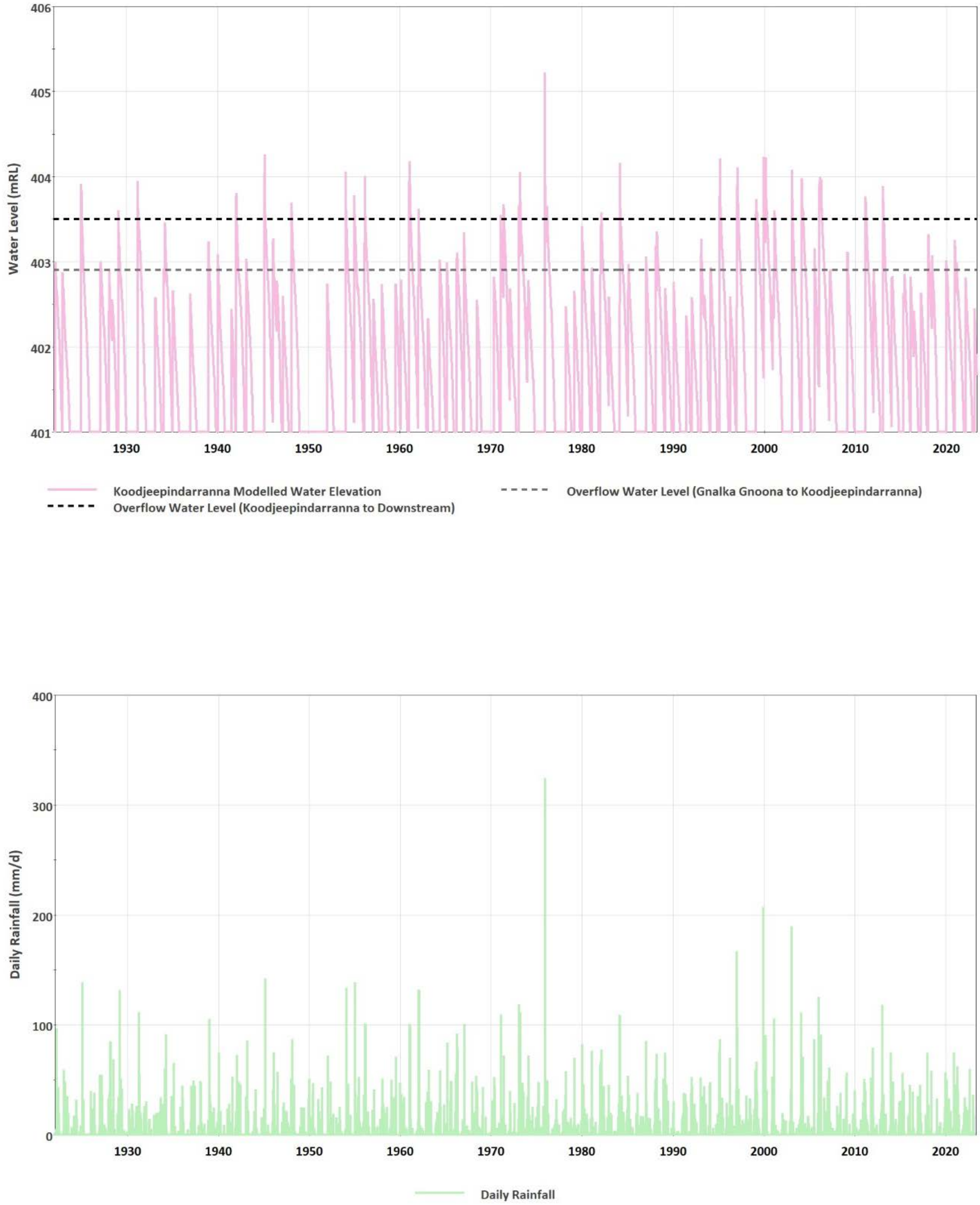


Figure 4.15 Baseline Water Balance Model Predictions – Koodjeepindarranna Claypan

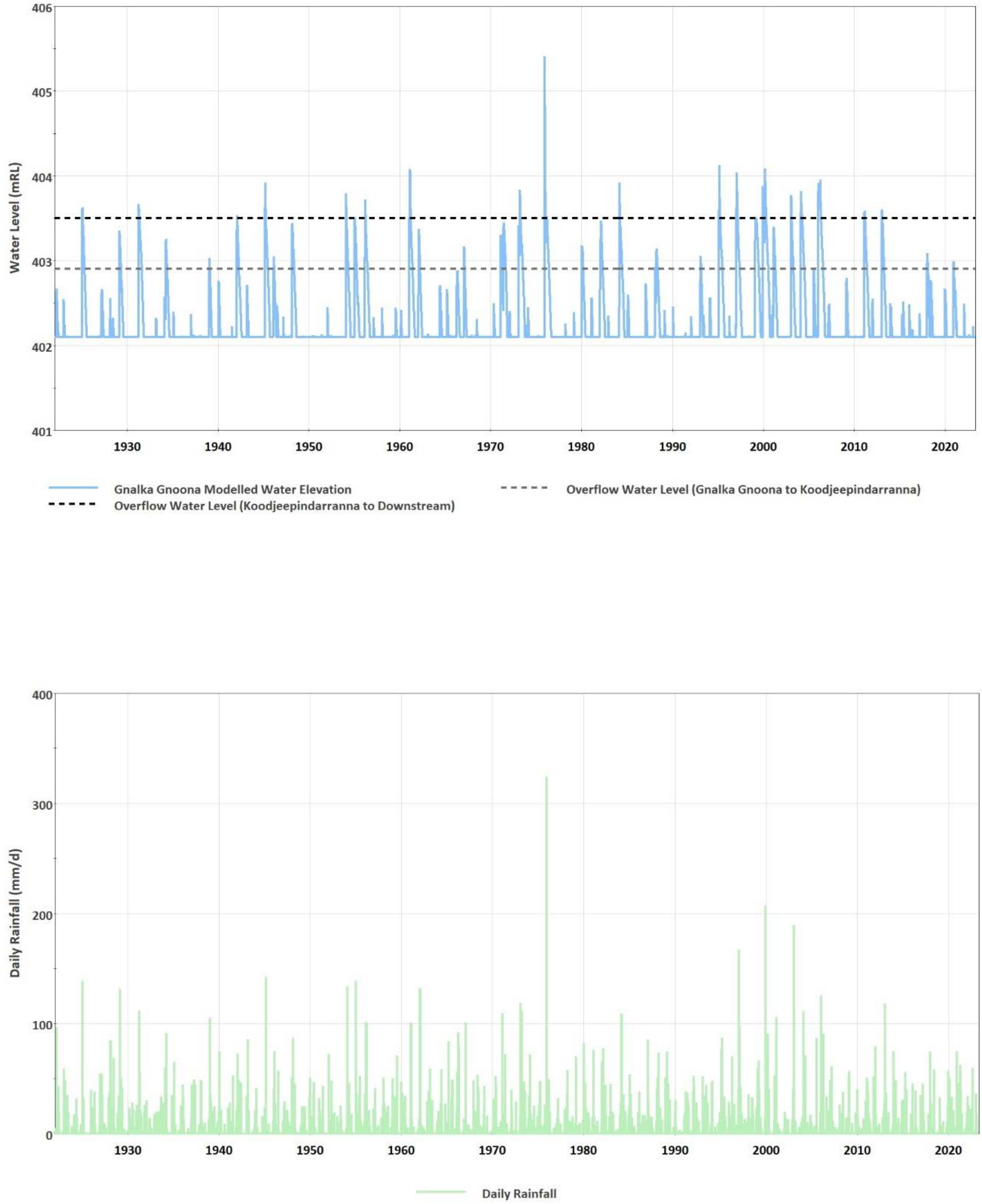


Figure 4.16 Baseline Water Balance Model Predictions – Gnalka Gnoona Claypan

4.4.7 Updated Flood Frequency Analysis

An annual maxima series was developed for the Gnalka Gnoona claypan water levels using the Long-Term Water Balance model predictions discussed in Section 4.4.6. The annual maxima series consisted of 102 years of data and was imported into the software package TUFLOW Flike and a Flood Frequency Analysis (FFA) completed by fitting the series to a number of different probability distributions to determine the flood level for different recurrence interval events.

The annual maxima series was censored to remove years where the model does not predict any ponding of water in the claypan. Comparing the different curves available for fitting the annual maxima series, it was found that the Generalised Pareto was the most appropriate fit for the data. The results of the regression analysis are provided in Table 4.8. It is assumed that the same flood levels are experienced in both claypans.

Table 4.8 FFA Results – Claypan Peak Water Levels

ARI (1 in Y)	% AEP	Peak Water Level (mRL)
5	20	403.4
10	10	403.9
20	5	404.3
50	2	404.8
100	1	405.0

Based on the FFA, the peak water level within the claypan area is estimated to be 405.0mRL for a 1% AEP event. For reference, the largest flood event predicted in the Long-Term Water Balance Model was 405.4mRL (in 1975), which was estimated to be a 1 in 170-year storm event by the FFA.

The limitations within the FFA are mostly related to the limitations in the claypan water balance. However, if the FFA is used to estimate flood rates significantly greater than the 1975 flood event (the largest event in the water balance model), a further limitation is that the FFA does not take into account any physical limitations to the depth of flooding which may occur. In this instance, the stage/volume curve for the claypans and the rate at which water can overflow from the Koodjeepindarranna Claypan at larger inflow rates would not be considered within the FFA.

A plot of the FFA result is shown in Figure 4.17.

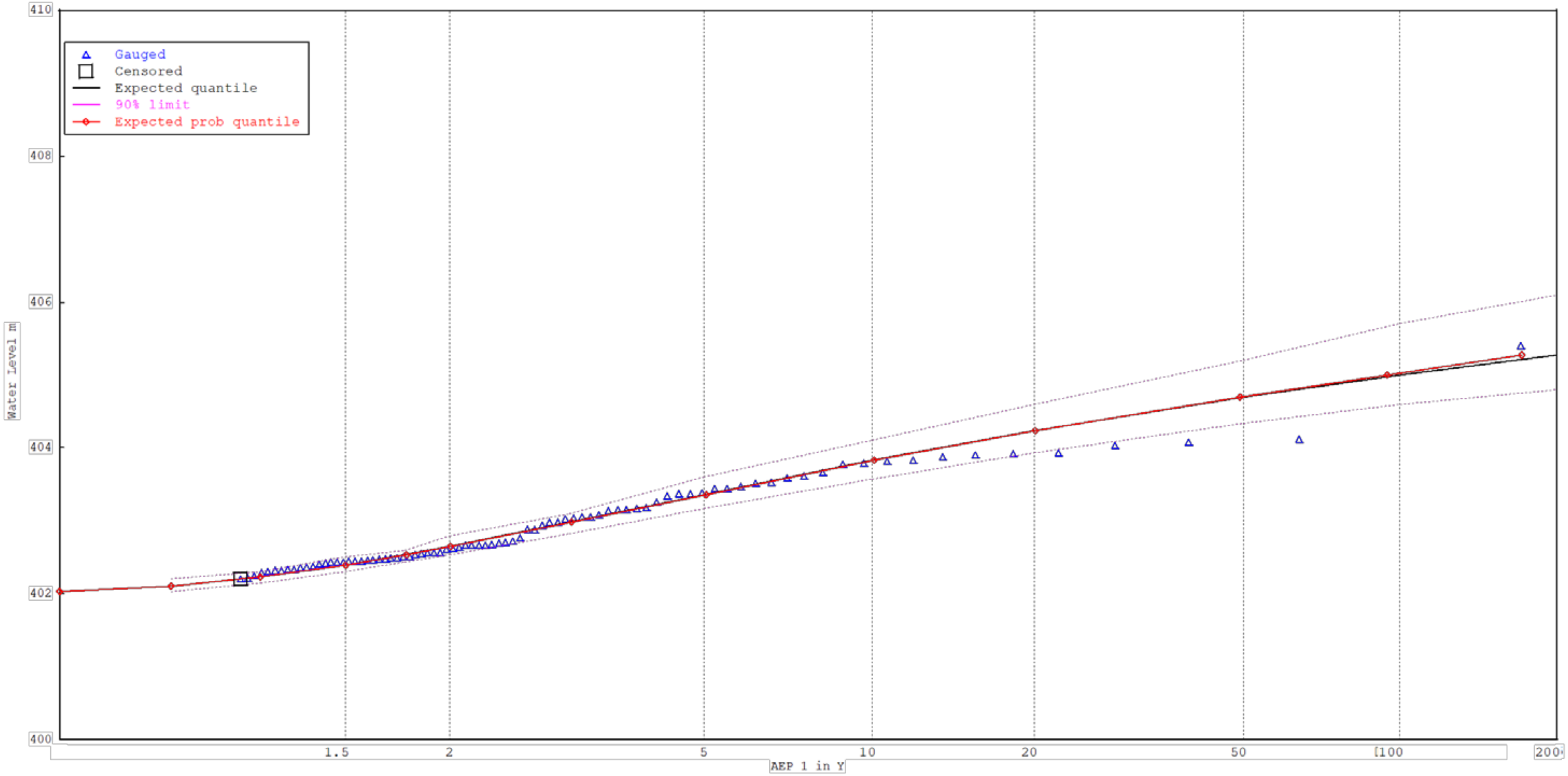


Figure 4.17 Gnalka Gnoona Claypan Flood Depth FFA Result

4.5 Surface Water Quality Measurements

The collected water quality samples provide some baseline water quality data and can be found in Appendix G. The locations of where these samples were collected are shown in Figure 3.4. Given the naturally large variability in the runoff data, additional samples are required to be collected with time to provide a more robust baseline dataset which could be used to characterise the surface water quality for the Project. The water quality within the claypans will also vary with time as the runoff evapo-concentrates.

In general, water quality sample results indicate that surface water runoff within the Study Area is fresh and generally pH neutral. There is the potential that the natural runoff can have high levels of suspended sediment. The salinity in the claypans tends to be fresh immediately following a runoff event, but salinity increases with time as the ponded water evapo-concentrates.

The collected baseline water quality data have been compared with the ANZECC Freshwater Aquatic Ecosystem guideline values to show where the runoff from the existing catchments exceeds them. With reference to the Aquatic Ecosystem Guidelines, note the following:

- Samples collected from the creeks and channel pools are classified as being from an 'Upland River' sub-system for comparison to physical stressor trigger values.
- Samples collected from the claypans would be classified as being from a 'Fresh Water Lakes' sub-system for comparison to physical stressor trigger values.
- The site would be classified as slightly to moderately disturbed due to the historic and continuing cattle farming practices that occur through the catchment. However, the site is considered to have a high conservation value (refer Section 1.7).
- As such, sampled results have been compared against ANZECC Tropical Fresh Water trigger levels for physical stressors for Upland River and Freshwater Lakes ecosystems (refer Appendix G), as well as toxicant trigger values for both ecosystem types associated with 95% species protection.

The water quality analysis results are shown Appendix G, with a summary provided in Table 4.9 of the key parameters which have been analysed. With reference to the tables shown in Appendix G:

- Red cells indicate values where ANZECC 95% Species Trigger Level values have been exceeded.
- Blank cells indicate where samples were not analysis for the associated analyte.
- "<" indicates observed analyte level is below the laboratory detection limit.

The key observations made from the water quality data collected to date are as follows:

- Aluminium, Zinc, Phosphorus, Sulfate concentrations measured are consistently above the trigger levels.
- The measured TDS concentrations of the samples taken from the claypans (SWML03 and SWML04) are variable (as expected) depending on the timing of the sample collection relative to the date of the inundation event.
- In general, claypan samples have a higher conductivity, TDS and alkalinity.

Table 4.9 Summary of Key Baseline Surface Water Quality Results (mg/L)

	Drainage Line Samples		Claypan Samples	
	Range	Typical	Range	Typical
TDS#	18 to 240	100	120 to 19,000	~4,000
Calcium	1.6 -21	10	3.9 - 35	5
pH (pH Units)	3.7 - 8	6.4	7 – 8.3	7.2
Bicarbonate	<5 - 47	20	50 - 130	100
Carbonate	<5	<5	<5	<5
Ammonia - N	<0.02 – 9.5	1	<0.02 - 6	1
Nitrate-N	0.02 - 28	2	<0.01 – 1.6	1
Filterable Reactive Phosphorus	<0.01 – 1.8	0.1	<0.01 – 0.44	0.1
Magnesium	0.4 – 5.6	4	1.2 - 180	3
Sulfate	2 – 43	5	<1 to 230	40
Sodium	0.8 – 15	5	22 - 950	40
Chloride	2 – 17	<5	11 – 1,600	50
Aluminium (dissolved)	0.015 – 1.6	0.1	1.8 – 7.4	5
Iron (dissolved)	0.02 – 0.85	0.08	0.06 - 14	8

Notes

Samples from drainage lines in 2019 have not been included in this summary, as these were collected using a different methodology which likely resulted in abnormally high TDS water quality results.

Variable water quality in the claypans reflects evapo-concentration of water stored in the claypans following runoff events.

5. GROUNDWATER FIELD INVESTIGATIONS

5.1 Introduction

Early hydrogeological field investigations at Mulga Downs were undertaken by MWH, with two drilling and testing programmes conducted in 2009 and 2012. Thereafter, AQ2 has undertaken three phases field investigations in (2018/19, 2021 and 2023) and introduced a comprehensive programme of baseline monitoring, commencing in early 2019. As data from each of these programmes has been used to develop the conceptual hydrogeological model, each programme is detailed in the sections below.

All completed bores have been named using the HPPL naming convention, as summarised below:

- Production bores have a prefix “MDPB”.
- Monitoring bores (piezometers) have a prefix “MDPZ”.
- At paired or cluster monitoring bore sites, the same bore name/number is used with a suffix to indicate the relative depth:
    - For paired bores, “D” for the deep and “S” for shallow.
    - For cluster bores sites, “A” for the deepest, “B” for the next deepest and “C” for the shallowest.

5.2 Preliminary Hydrogeological Investigations

As part of the early hydrogeological investigations undertaken by MWH (2009; 2012; 2014), a number of HPPL mineral exploration bores were retrofitted as monitoring bores. The monitoring bore construction comprised casing these holes with predominantly 25 mm ND PVC casing, with no gravel pack or annular seals. Some of these bores were then equipped with In-Situ Troll water level data loggers. Additionally, several production bores (MDPB001 to MDPB0010) were installed, with pumping tests conducted on selected bores. The locations of these monitoring and production bores are shown in Figure 5.1 with bore and pumping test details tabulated in Appendix C, together with available bore completion logs. Early investigations were predominantly focused on the northern flanks of the valley, within the Mulga East tenement (R47/12). A summary of the reports associated with the previous hydrogeological studies is given below:

- March 2009 – Murray’s Hill Groundwater investigation: test pumping and hydrochemistry of MDPB001 (Murray’s Bore) and MDPB002 (East Wooley Bore), salinity profiling of MD0173, MD0572, MD0573, MD0574, MD0551 and MDPB002.
- October 2012 – Assessment of Fenceline Borefield Area (Mulga East): test pumping and hydrochemistry of MDPB004, MDPB005 and MDPB006.
- March 2014 – Conceptualisation of Hydrogeology of the Mulga East Deposit, based on existing data for MDPB004, MDPB005 and MDPB006 plus salinity profiles for MDPZ0704, MDPZ0708, MDPZ0745, MDPZ0757.

5.3 AQ2 Field Investigations

Summaries of the three phases of investigations are presented in Sections 5.3.1 to 5.3.3, with further details thereafter.

5.3.1 Baseline Study 2018/2019

AQ2 undertook a baseline study under contract to JBS&G (for HPPL). The objectives of the 2018/2019 hydrogeological field investigations were to:

- Further develop the hydrogeological understanding of the Study Area, particularly to the south of the deposit where previous data were limited and conservation areas associated with ecological communities exist.

- Install a groundwater monitoring network to provide a means of collecting baseline hydrogeological data.
- Collect a hydrogeological data set against which the potential impacts of mining could be identified.

Bore locations were selected following an initial desktop study and conceptualisation process (AQ2 2018); locations were limited to the HPPL tenements and were sited along existing tracks, outside of conservation areas. Production bore locations were identified based on the results of the exploration drilling / monitoring bore installation and the spatial distribution of geological units.

The 2018/2019 hydrogeological drilling and bore construction were undertaken by Ausdrill Northwest (now Pentium Hydro) under direct contract to HPPL, using a Foremost DR24 HD rig. Drilling commenced on 10th November 2018 and was completed on 10th August 2019, with a 6-week break over the Christmas / New Year period, a 1-week hiatus due to weather (Cyclone Veronica) and a ~2-month hiatus (from May to July 2019) awaiting native vegetation clearances.

A total of 51 monitoring bores were installed at 23 locations (MDPZ7449 to MDPZ7471) comprising 8 single monitoring bores and 15 cluster monitoring bores (14 sets of three cluster bores and one deep cluster bore (MDPZ7465A) adjacent to an existing shallow bore (MDPZ0757)). In addition, 5 test production bores (MDPB0011 to MDPB0015) were installed. Locations of the bores installed during the 2018/2019 field programme are presented in Figure 5.2.

Test pumping of the five production bores was conducted between the 3rd September and 9th October 2019 by McArthur Drilling and Pumping Pty Ltd (MDP), under contract to Strategen-JBS&G.

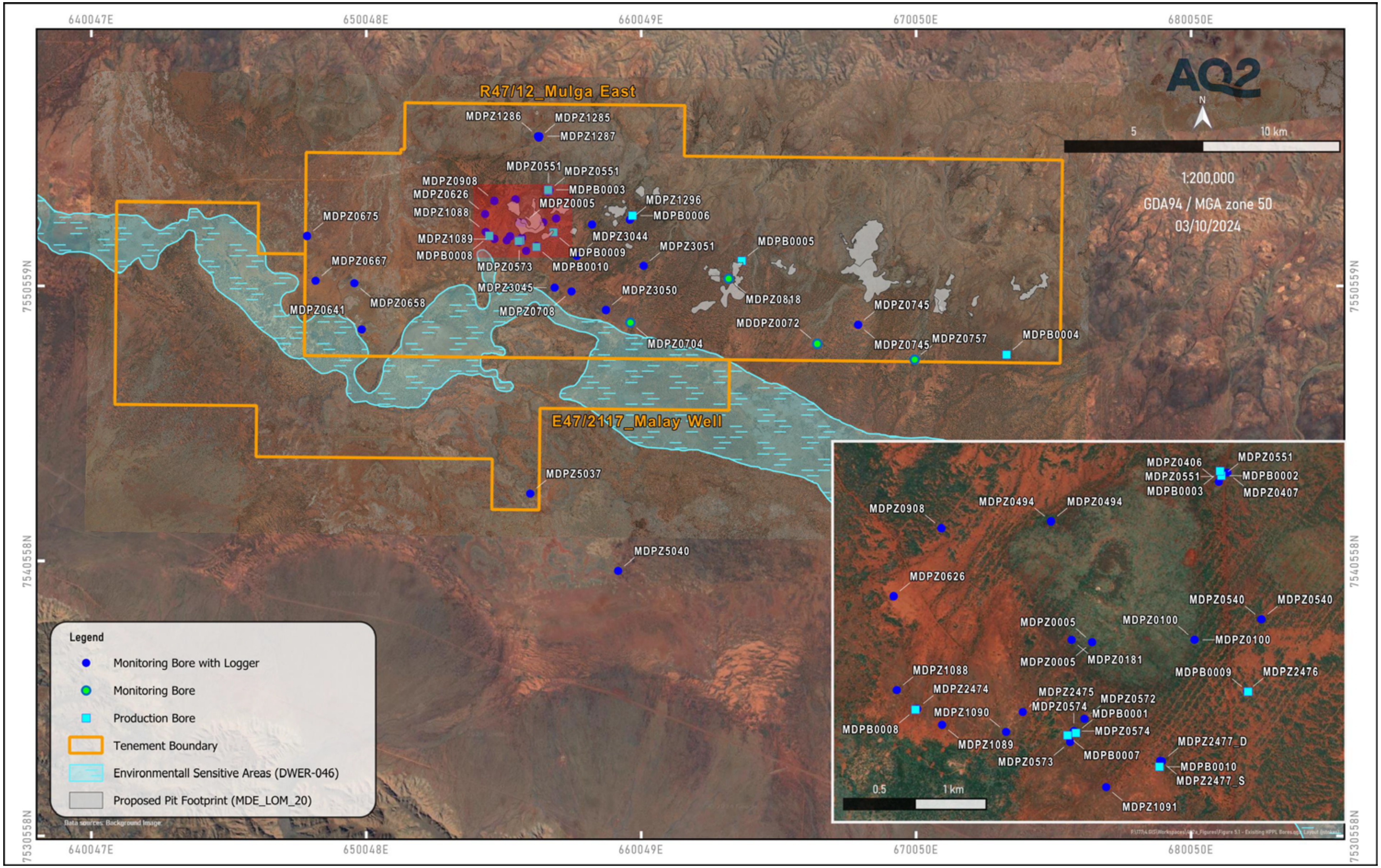


Figure 5.1 Historic Existing HPPL Bore Location

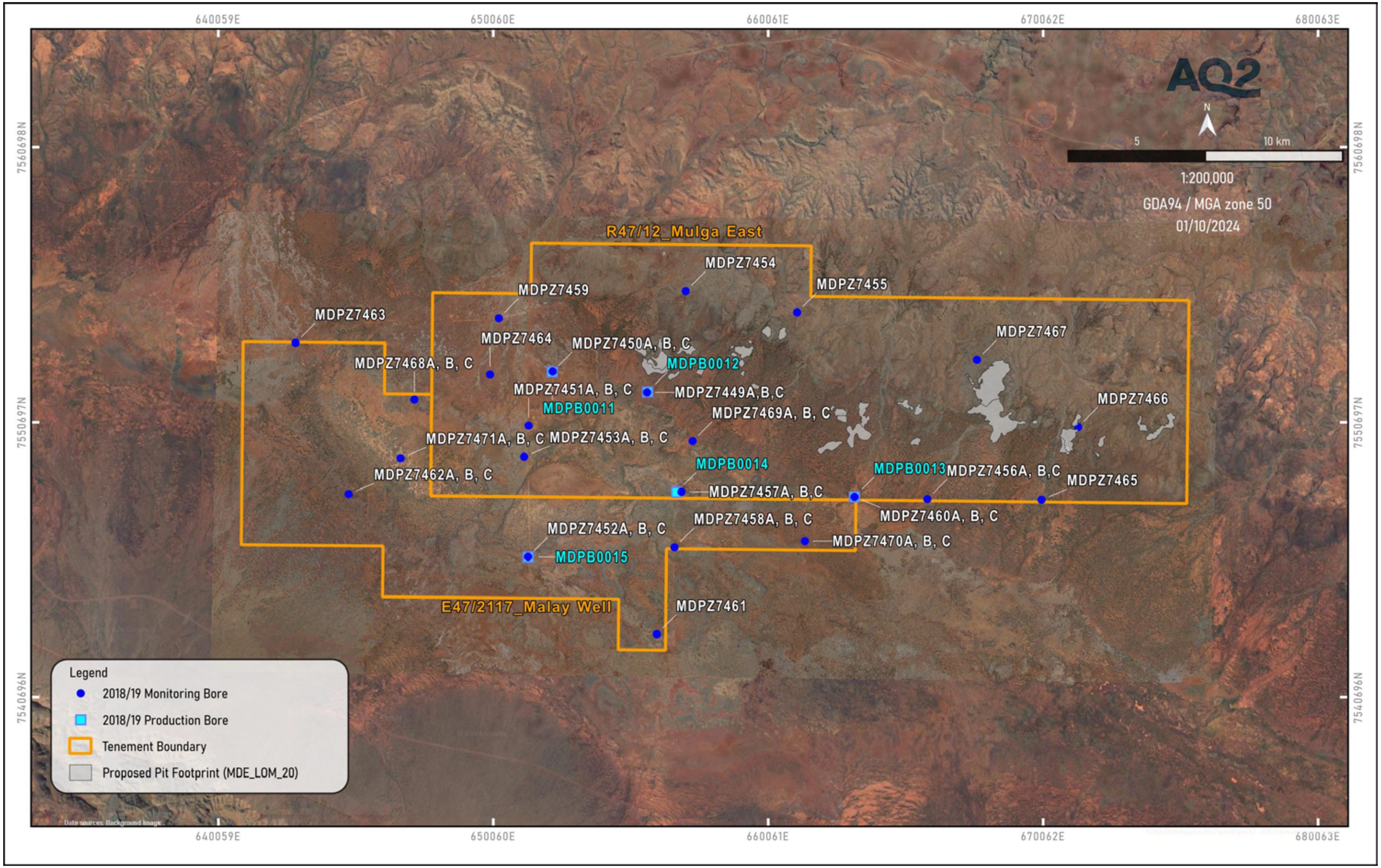


Figure 5.2 2018/2019 Bore Locations

5.3.2 2021 Investigations

The 2021 investigations were undertaken under contract to Roy Hill. The objectives were to address risks associated with mine dewatering, water supply and excess water disposal (through managed aquifer recharge (MAR)), in addition to extending the existing hydrogeological understanding and baseline monitoring network to incorporate the Mulga West tenement area.

Drilling sites were selected as part of a preliminary desktop study (AQ2 2021). Water supply drill sites in the orebody area were restricted to areas of low salinity groundwater, on the assumption that water for processing would need to have a salinity of less than ~5,000 mg/L TDS. Whilst MAR drill sites were in areas where groundwater salinity was anticipated to be higher. Investigations were focused on the disposal of high salinity water as this carries increased risk, i.e. it has more potential to have a detrimental impact on other users and / or the environment. Drill sites were selected based on an assessment of data from existing reverse circulation (RC) drilled mineral holes within the identified areas of interest. All 2021 drill sites were near to an existing RC hole, outside of the identified conservation and heritage areas, with access along existing station / exploration tracks.

Aside from the predetermined locations of the two production bores for dewatering investigations, all other production bore locations were identified based on the observed hydrogeological data from the exploration drilling / monitoring bore installation.

The 2021 drilling and bore construction were undertaken by Pentium Hydro under direct contract to Roy Hill, using a Foremost DR24 HD rig. Drilling commenced on 7th July 2021 and was completed on 13th December 2021.

A total of 23 monitoring bores were installed at 21 locations (MDPZ9201 to MDPZ9221) comprising 14 single unsealed monitoring bores, five single sealed monitoring bores and four paired monitoring bores (two paired bores at two sites). In addition, five test production bores (MDPB0016 to MDPB0020) were installed. The locations of the 2021 bores are shown Figure 5.3 (for the Mulga East and Malay Well tenements) and Figure 5.4 (for the Mulga West tenement).

Hydraulic testing via test pumping of the five production bores and mini testing of six monitoring bores (MDPZ9205, 9206, 9208, 9209, 9210 and 9213) was conducted by MDP, under contract to Roy Hill. This work was conducted in two stages between the 21st September and 21st October 2021 and between 25th November and 18th December 2021.

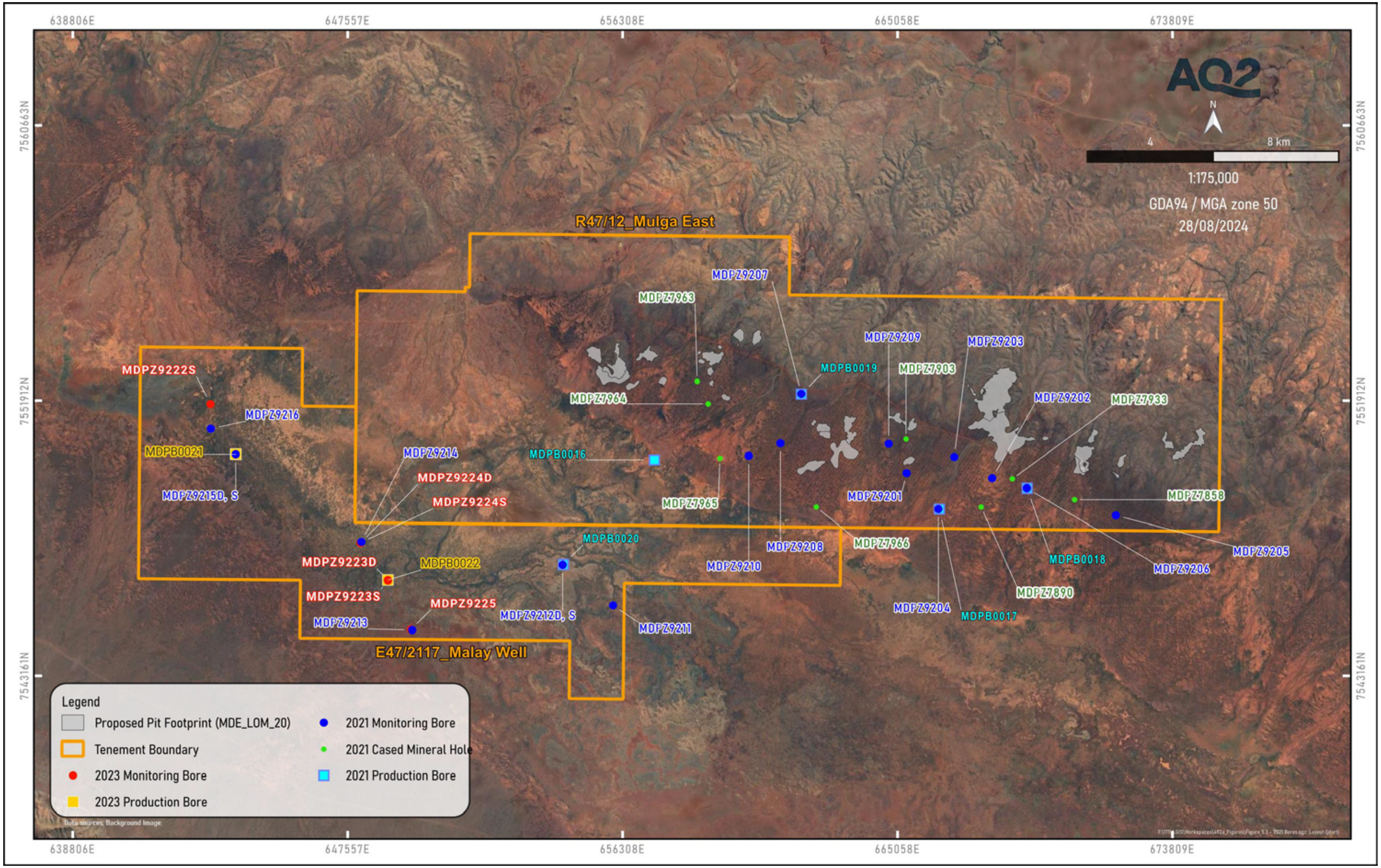


Figure 5.3 2021 and 2023 Bore Locations - Mulga East & Malay Well Tenements

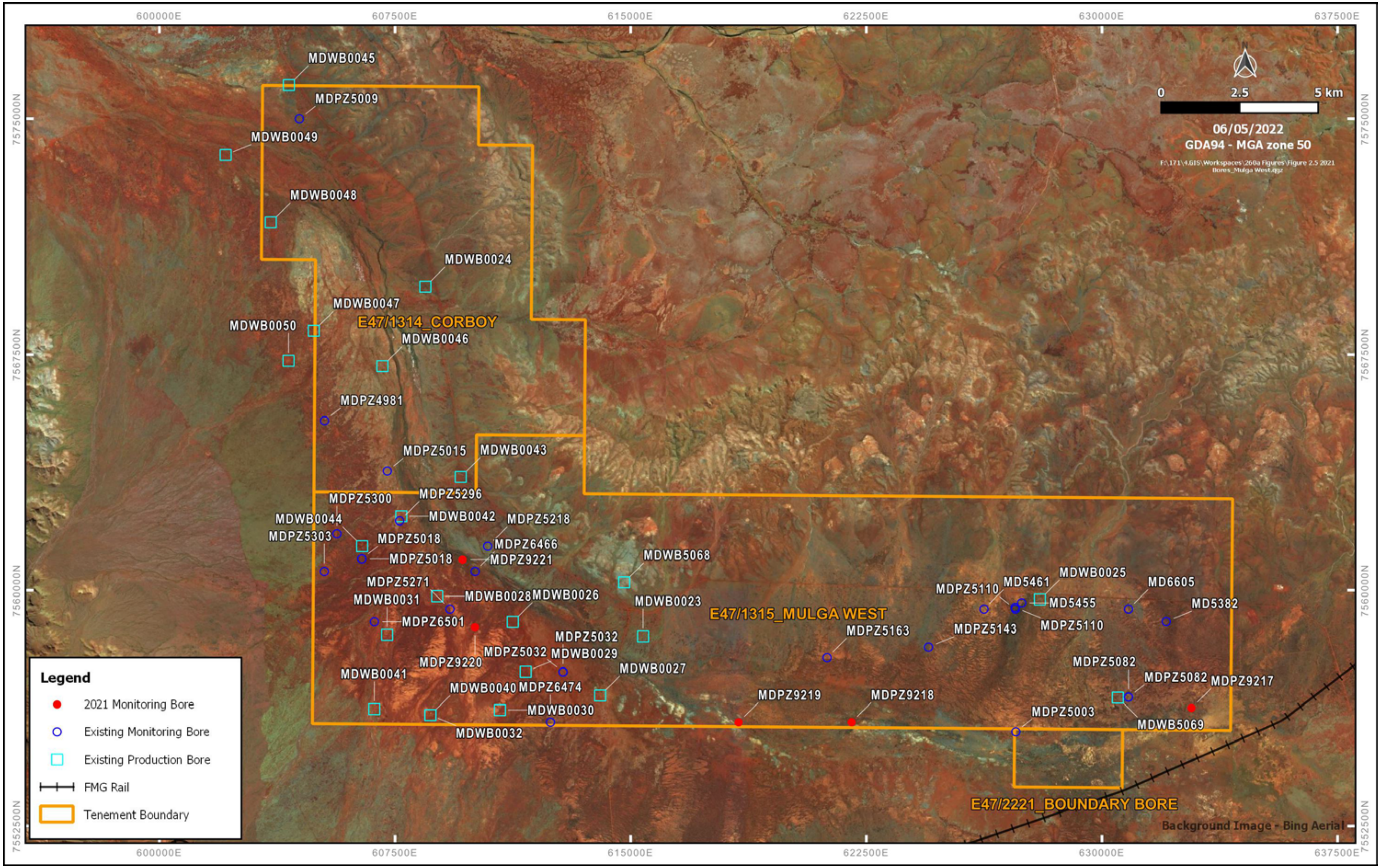


Figure 5.4 2021 Bore Locations – Mulga West

5.3.3 2023 Investigations

The 2023 investigations were undertaken under contract to Roy Hill. The objectives were to install test production / re-injection bores and undertake further hydrogeological exploration over the proposed re-injection area within the Malay Well tenement. However, drilling sites were restricted to existing drill pads as further clearing within Mungurrdu (although not officially registered at the time) was not permitted. In an effort to reduce the detrimental impact on shallow groundwater quality, if the upper 40 to 50 m of groundwater was found to be <10,000 uS/cm EC, the screened intervals of production re-injection bores were installed below 40 m depth (with the upper 40 m grouted off), such that, if used for re-injection purposes, direct injection would only be into the deeper, more saline interval.

The drilling and bore installation were undertaken by Pentium Hydro under contract to Roy Hill between 4th August and 11th October 2023, using a Schramm T130 drill rig.

A total of six monitoring bores were installed at four locations (MDPZ922 to MDPZ9225) comprising two single monitoring bores and four paired monitoring bores (i.e. deep and shallow) at two sites. In addition, two production / re-injection bores (MDPB0021 and MDPB0022) were installed. The locations of these bores are shown in Figure 5.3.

Although test pumping / re-injection trials were proposed, this work has been deferred, initially due to wet season access restrictions and subsequently due to the requirement for further approvals for work within Mungurrdu.

5.3.4 Drilling and Bore Construction

Between 2018 and 2023 a total of 80 monitoring bores and 12 test production bores have been installed across the Mulga East, Malay Well and Mulga West tenements. Drilling was undertaken using dual-rotary (DR) techniques through unconsolidated ground and conventional down-the-hole hammer (DTH) techniques through competent bedrock. Bore locations are presented in Figure 5.4 and Figure 5.5, with the drilling and bore installation methodology summarised below. Monitoring bore details are presented in Table 5.2 to Table 5.3, with production bore details in Table 5.4. Hydrogeological / bore completion logs for all bores are provided in Appendix D.

Monitoring Bores

The monitoring bores were drilled at 9" (DR) and 7.5" (DTH) diameters, with all DR (conductor) casing retrieved during bore completion. At each paired or clustered bore location, the deepest bore was installed first, such that the lithology / hydrostratigraphic units could be identified and the target units / bore completion designs determined. One hole in 2021 (MDPZ9207(L)) was declared lost at 46 m due to a break in the conductor casing string; the hole was subsequently redrilled to total depth on the same pad. Whilst in 2023, at hole MDPZ9222, the drill rods snagged on the DR casing when pulling out of the hole, such that the DR casing had to be retrieved with the rods, before bore completion. Due to the subsequent collapse of the hole, only a shallow bore completion could be achieved.

For all holes, drill cuttings were collected at 2 m intervals and logged by the site hydrogeologist. Airlift yields were recorded at the end of each rod during drilling, together with measurements of EC, pH and temperature for the discharge water.

The 2018/19 monitoring bores (MDPZ7449 to MDPZ7471) were completed with 50 mm ND Class 18 PVC casing, with 2 mm machine-slotted casing installed against the targeted aquifer unit; the 2 mm slot size was used for the purposes of stygofauna monitoring. The first four 2021 monitoring bores (MDPZ9201 to MDPZ9204) were completed with Class 12, 50mm ND bell-end PVC (1 mm slots), thereafter all subsequent monitoring bores (MDPZ9205 to MDPZ9225) were completed with Class 18, 100 mm ND threaded PVC (1 mm slots).

For all monitoring bores, the annulus was packed with graded gravel (3.2-6.4 mm) to 2 m (in 2018/19) to 6 m (in 2021 and 2023) above the slotted section, above which a bentonite seal was placed, with the remaining annulus (above the seal) backfilled with a cement grout. All monitoring bores were airlift-developed for between one and two hours, until the discharged water was free from sediment. Discharge rates during airlifting were measured and water samples collected for chemical analysis. Bore headworks comprised a heavy-duty steel standpipe with lockable cap and a small concrete surface plinth.

Production Bores

The 2018/19 and 2021 production bores were drilled at 16" (DR) and 14.5" (DTH) diameters, while the 2023 production / test reinjection bores were drilled at ~18" (DR) and 16.5" (DTH). All DR casing was retrieved during production bore completion. Bore MDPB0020 could not be drilled to the targeted depth, despite the mobilisation of an auxiliary compressor, due to excessive yields (~140 L/s).

As for the monitoring bores, drill cuttings were collected at 2 m intervals and logged by the site hydrogeologist. Airlift yields were recorded at the end of each rod during drilling, together with measurements of EC, pH and temperature for the discharge water.

Production bores MDPB0011 to MDPB0019 were completed with 250 mm ND Class 12 PVC, with 1 mm slotted casing. Bore MDPB0020, in the Malay Well MAR investigation area, was completed with 250 mm ND, Class 18 PVC blank casing, with 250 mm ND wire-wound stainless-steel screens (1 mm slot) whilst subsequent test re-injection bores in the Malay Well MAR investigation area (MDPB0021 and MDPB0022) were completed with 300 mm ND, Class 18 PVC blank casing, with 300 mm ND wire-wound stainless-steel screens (1 mm slot). As shallow groundwater at MDPB0021 and MDPB0022 was found to be <10,000 uS/cm EC, the screened intervals were installed below 40 m depth (with the upper 40 m grouted off), such that, if used for re-injection purposes, direct injection would only be into the deeper, more saline interval.

The annulus of all production bores was packed with graded gravel (3.2–6.4 mm). Bores MDPB0016 to MDPB0019 were gravel packed to 2 mbgl, above which a bentonite 'surface seal' was placed. All other production bores were gravel packed to 2 m (in 2018/19) to 6 m (in 2021 and 2023) above the slotted section, above which a bentonite seal was placed, with the remaining annulus (above the seal) backfilled with cement grout.

All production bores were airlift-developed for between 4 and 12 hours, until the discharged water was free from sediment. Discharge rates during airlifting were measured and water samples collected for chemical analysis. Bore headworks comprised a heavy-duty steel standpipe with lockable cap and a concrete surface plinth.

Discharge

To avoid environmental harm (as required under the *Environmental Protection Act 1986*), drilling-discharge during each field investigation campaign was contained in line with the requirements at that time. For the 2018/19 investigations, DWER advised that all drilling-discharge water exceeding 10,000 µS/cm required containment; whilst in 2021 all water exceeding 7,300 µS/cm EC required containment, as per Roy Hill's Water Discharge Management Procedure. In 2023, in line with the requirements of the Banjima People, for working with in Mungurrdu (although not officially registered at that time), all discharge water was contained in sumps.

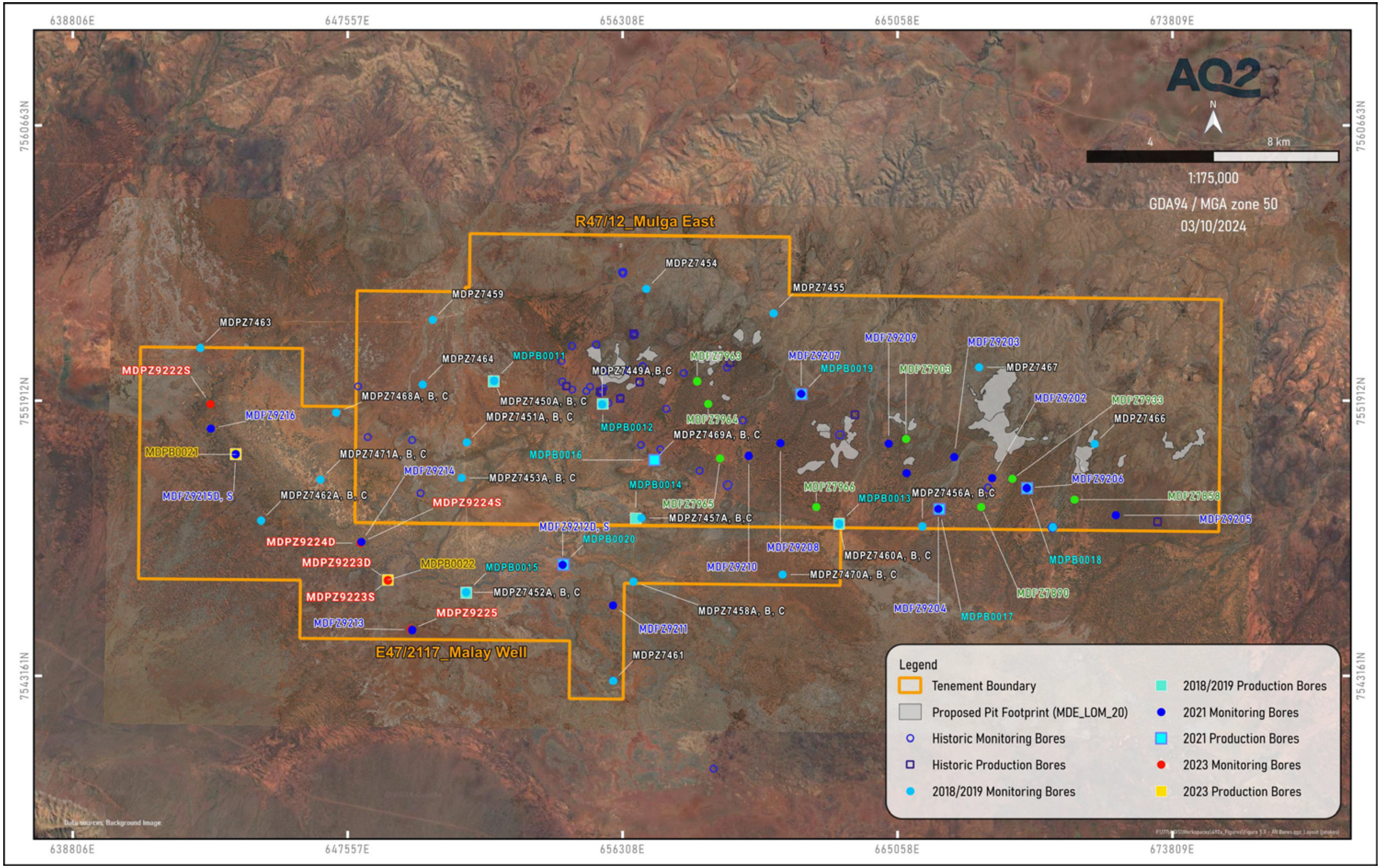


Figure 5.5 2018 to 2023 Bore Locations – Mulga East & Malay Well

AQ2

Table 5.1 2018/9 Monitoring Bore Details

Hole ID	Easting MGA_50	Northing MGA_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilled Airlift (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Depth (m)	Unit Monitored	Completed	SWL (mbTOC)	SWL (mRL)	Date of SWL
MDPZ7449A	655656.40	7551784.82	405.93	0.54	DR / DTH	0-52 / 52-82	241/191	15	82	CL18 PVC	50	52-82	Marra Mamba	14/11/2018	4.92	401.01	8/09/2019
MDPZ7449B	655656.95	7551794.50	405.99	0.56	DR / DTH	0-46 / 46-52	241/191	15	47	CL18 PVC	50	11-47	CID/Pisolite	16/11/2018	5.25	400.74	8/09/2019
MDPZ7449C	655656.84	7551804.66	405.98	0.54	DR	0-11	241	0.1	10.65	CL18 PVC	50	4.65-10.65	Upper Silcrete (+ Pisolititic Clay)	17/11/2018	5.25	400.73	8/09/2019
MDPZ7450A	652212.74	7552518.04	406.86	0.59	DR / DTH	0-52 / 52-102	241/191	35	102	CL18 PVC	50	48-102	Marra Mamba	20/11/2018	6.43	400.43	8/09/2019
MDPZ7450B	652202.67	7552512.35	406.69	0.61	DR / DTH	0-40 / 40-42	241/191	5	42	CL18 PVC	50	22-42	CID/Pisolite	22/11/2018	6.33	400.36	8/09/2019
MDPZ7450C	652197.73	7552504.43	406.77	0.58	DR	0-22	241	5	22	CL18 PVC	50	10-22	Undiff. Tertiary	23/11/2018	6.36	400.41	8/09/2019
MDPZ7451A	651328.49	7550564.57	404.46	0.53	DR / DTH	0-118/118-120	241/191	25	120	CL18 PVC	50	94-120	Marra Mamba	27/11/2018	5.37	399.09	8/09/2019
MDPZ7451B	651335.19	7550574.10	404.58	0.54	DR	0-64	241	10	62	CL18 PVC	50	52-62	Basal Calcrete	1/12/2018	5.21	399.37	8/09/2019
MDPZ7451C	651343.79	7550577.11	404.54	0.53	DR / DTH	0-40/40-44	241/191	5	44	CL18 PVC	50	14-44	Undiff. Tertiary	3/12/2018	4.87	399.67	8/09/2019
MDPZ7452A	651326.77	7545805.52	404.45	0.60	DR / DTH	0-58 / 58-72	241/191	45	72	CL18 PVC	50	53-72	Basal Calcite & Dolomite	5/12/2018	4.29	400.16	26/02/2019
MDPZ7452B	651336.38	7545806.11	404.35	0.61	DR	0-53	241	30	51.5	CL18 PVC	50	32.5-51.5	Undiff. Tertiary	7/12/2018	4.24	400.11	26/02/2019
MDPZ7452C	651345.87	7545807.09	404.44	0.60	DR / DTH	0-28/28-32	241/191	7	32	CL18 PVC	50	8-32	Upper Calcrete	8/12/2018	4.35	400.09	26/02/2019
MDPZ7453A	651179.71	7549447.05	405.44	0.47	DR / DTH	0-64 / 64-72.5	241/191	25	72.5	CL18 PVC	50	52.5-72.5	Basal Calcrete	11/12/2018	6.38	399.06	8/09/2019
MDPZ7453B	651188.93	7549447.07	405.42	0.49	DR / DTH	0-46 / 46-48	241/191	22	48	CL18 PVC	50	30-48	CID/Pisolite & Undiff. Tertiary	12/12/2018	6.24	399.18	8/09/2019
MDPZ7453C	651198.83	7549447.51	405.30	0.49	DR	0-17	241	5	17	CL18 PVC	50	9-17	Upper Calcrete	13/12/2018	6.13	399.17	8/09/2019
MDPZ7454	657054.03	7555455.52	436.49	0.57	DR / DTH	0-4/4-58	241/191	0.3	58	CL18 PVC	50	16-58	Jeerinah	29/01/2019	26.62	409.87	8/09/2019
MDPZ7455	661107.77	7554688.42	448.71	0.59	DR / DTH	0-4/4-61.5	241/191	1.25	60	CL18 PVC	50	14-60	Jeerinah	1/02/2019	31.63	417.08	8/09/2019
MDPZ7456A	665850.76	7547906.10	410.67	0.49	DR / DTH	0-52/52-120.5	241/191	20	120	CL18 PVC	50	62-120	Marra Mamba (lower)	8/02/2019	8.33	402.34	8/09/2019
MDPZ7456B	665865.23	7547917.74	410.77	0.55	DR / DTH	0-52/52-62	241/191	20	62	CL18 PVC	50	46-62	Marra Mamba (upper)	3/02/2019	8.44	402.33	8/09/2019
MDPZ7456C	665858.43	7547912.29	410.72	0.53	DR / DTH	0-40/40-42	241/191	10	41	CL18 PVC	50	6-41	CID/Pisolite & Undiff. Tertiary	4/02/2019	8.44	402.28	8/09/2019
MDPZ7457A	656707.00	7548167.60	405.02	0.55	DR / DTH	0-70/70-100	241/191	20	100	CL18 PVC	50	76-100	Marra Mamba (incl Hardcap)	11/02/2019	4.79	400.23	8/09/2019

Hole ID	Easting MGA_50	Northing MGA_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilled Airlift (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Depth (m)	Unit Monitored	Completed	SWL (mbTOC)	SWL (mRL)	Date of SWL
MDPZ7457B	656716.47	7548166.77	405.07	0.54	DR	0-59	241	20	59	CL18 PVC	50	41-59	CID/Pisolite & Basal Calcrete	12/02/2019	4.71	400.36	8/09/2019
MDPZ7457C	656725.70	7548165.99	405.14	0.57	DR	0-35	241	14	35	CL18 PVC	50	19-35	Upper Calcrete	13/02/2019	4.73	400.41	8/09/2019
MDPZ7458A	656645.81	7546145.78	404.73	0.58	DR	0-71	241	30	71	CL18 PVC	50	54-71	CID/Pisolite, Basal Calcrete, Dolomite	18/02/2019	4.33	400.40	8/09/2019
MDPZ7458B	656655.16	7546145.38	404.81	0.56	DR	0-52	241	20	52	CL18 PVC	50	45-52	CID/Pisolites	20/02/2019	4.40	400.41	8/09/2019
MDPZ7458C	656664.79	7546144.68	404.88	0.63	DR	0-41	241	20	41	CL18 PVC	50	5-41	Upper Calcrete	25/02/2019	4.44	400.44	8/09/2019
MDPZ7459	650261.72	7554484.42	410.73	0.54	DR	0-28	241	3.5	28	CL18 PVC	50	5-28	Alluvial Fan Gravel (Undiff Tert)	27/02/2019	11.21	399.52	7/09/2019
MDPZ7460A	663200.83	7547990.12	406.66	0.46	DR / DTH	0-58 / 58-112	241/191	25	112	CL18 PVC	50	70-112	Marra Mamba	3/03/2019	5.02	401.64	8/09/2019
MDPZ7460B	663194.31	7547981.81	406.67	0.52	DR	0-53.4	241	8.5	53.4	CL18 PVC	50	45.4-51.4	CID/Pisolite	5/03/2019	5.21	401.46	8/09/2019
MDPZ7460C	663189.48	7547975.65	406.74	0.65	DR	0-29.3	241	3.7	29.3	CL18 PVC	50	17.3-29.3	Undiff Tertiary	6/03/2019	5.33	401.41	8/09/2019
MDPZ7461	656011.19	7542996.40	405.74	0.47	DR / DTH	0-54 / 54-119.2	241/191	15	119.2	CL18 PVC	50	5.2-119.2	Upper Calcrete/CID/Basal Calcite/Dolomite	9/03/2019	4.88	400.86	10/03/2019
MDPZ7462A	644800.00	7548090.09	404.41	0.58	DR / DTH	0-58 / 58-120	241/191	12.5	120	CL18 PVC	50	63-120	Basal Silcrete / Dolomite	17/03/2019	4.96	399.45	7/09/2019
MDPZ7462B	644799.50	7548099.81	404.46	0.52	DR	0-58.5	241	12	58.5	CL18 PVC	50	39.5-58.5	CID/Pisolite & Undiff Tertiary	21/03/2019	5.11	399.35	7/09/2019
MDPZ7462C	644798.52	7548109.80	404.50	0.58	DR	0-35	241	12.2	35	CL18 PVC	50	21-35	Upper Calcrete	22/03/2019	5.25	399.25	7/09/2019
MDPZ7463	642862.56	7553586.81	404.37	0.28	DR / DTH	0-82 / 82-88	241/191	35	85.5	CL18 PVC	50	10.5-85.5	Upper Calcrete/Undiff Tertiary/CID/Basal Calcrete/Wittenoom	1/04/2019	5.64	398.73	7/09/2019
MDPZ7464	649944.40	7552426.04	406.18	0.28	DR	0-88	241	25	88	CL18 PVC	50	6-88	Upper Calcrete/Undiff Tertiary/CID/Marra Mamba	6/04/2019	6.75	399.43	7/09/2019
MDPZ7465A	670002.47	7547874.81	418.86	0.52	DR	0-112	241	>20	111.5	CL18 PVC	50	87.5-111.5	Marra Mamba	9/04/2019	15.67	403.19	8/09/2019
MDPZ7466	671335.89	7550527.64	438.95	0.55	DR / DTH	0-4 /4-64.9	241/191	4.8	64.8	CL18 PVC	50	34.8-64.8	Marra Mamba	12/04/2019	34.66	404.29	8/09/2019

Hole ID	Easting MGA_50	Northing MGA_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilled Airlift (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Depth (m)	Unit Monitored	Completed	SWL (mbTOC)	SWL (mRL)	Date of SWL
MDPZ7467	667654.85	7552968.50	449.78	0.46	DR / DTH	0-4 /4-64	241/191	3.5	64	CL18 PVC	50	34-64	Marra Mamba (& Jeerinah?)	14/04/2019	43.45	406.33	8/09/2019
MDPZ7468A	647192.36	7551560.72	403.60	0.51	DR / DTH	0-82 / 82-89	241/191	25	89	CL18 PVC	50	68-89	Marra Mamba	17/04/2019	4.98	398.62	7/09/2019
MDPZ7468B	647195.75	7551569.71	403.68	0.58	DR	0-65	241	15.2	65	CL18 PVC	50	56-62	Basal Calcrete / Silcrete	19/04/2019	5.02	398.66	7/09/2019
MDPZ7468C	647199.39	7551578.68	403.74	0.62	DR	0-52	241	11.2	52	CL18 PVC	50	21.3-51	CID/Pisolite & Undiff Tertiary	20/04/2019	5.11	398.63	7/09/2019
MDPZ7469A	657312.11	7550018.04	404.31	0.50	DR / DTH	0-88/88-101	241/191	>25	101	CL18 PVC	50	93-101	Marra Mamba	25/04/2019	4.01	400.30	8/09/2019
MDPZ7469B	657307.53	7550026.67	404.25	0.37	DR	0-83	241	18	82	CL18 PVC	50	64-82	Marra Mamba (Hydrated Hardcap)	27/04/2019	3.45	400.80	8/09/2019
MDPZ7469C	657303.02	7550034.90	404.24	0.53	DR	0-53	241	4.3	52.5	CL18 PVC	50	10.5-52.5	Undiff Tertiary	29/04/2019	3.49	400.75	8/09/2019
MDPZ7470A	661397.44	7546376.66	405.64	0.89	DR / DTH	0-58 / 58-108	241	>30	104	CL18 PVC	50	74-104	Mt Newman / West Angela?	22/07/2019	4.51	401.13	9/08/2019
MDPZ7470B	661388.05	7546376.16	405.82	0.96	DR / DTH	0-46 / 46-49	241	10	49.1	CL18 PVC	50	29.1-49.1	Undiff Tertiary	24/07/2019	4.62	401.20	9/08/2019
MDPZ7470C	661378.85	7546375.58	405.80	0.95	DR	0-23	241	6	23	CL18 PVC	50	11-23	Upper Calcrete	24/07/2019	4.56	401.24	9/08/2019
MDPZ7471A	646670.59	7549390.44	403.60	0.90	DR / DTH	0-58 / 58-78	241	43	78	CL18 PVC	50	68-78	Mt Newman / West Angela?	28/07/2019	4.51	399.09	7/09/2019
MDPZ7471B	646660.88	7549391.41	403.78	1.10	DR / DTH	0-52 / 52-60	241	16	60	CL18 PVC	50	30-60	Undiff Tertiary / Pisolite / Basal Calcrete	29/07/2019	4.65	399.13	7/09/2019
MDPZ7471C	646680.73	7549389.40	403.57	0.93	DR	0-21	241	4.4	21	CL18 PVC	50	11-21	Upper Calcrete	31/9/2019	4.79	398.78	7/09/2019
MDPZ5355	654392.26	7546201.78	404.77	0.71	RC	0-118	150		28	CL18 PVC	50	4-28*	Whole sequence	16/05/2019	4.66	400.11	8/09/2019
MDPZ5360	648007.66	7546597.47	403.59	0.40	RC	0-100	150		58	CL18 PVC	50	4-58*	Whole sequence	21/05/2019	blocked	-	-
MDPZ5362	646402.111	7548201.139	-	-	RC	0-118	150		114	CL18 PVC	50	0-114*	Whole sequence	23/05/2019	-	-	-

*Alternating blank and slotted casing

Table 5.2 2021 Monitoring Bore Details

Hole ID	Area	Easting MGA94_50	Northing MGA94_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilling Airlift Yield (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Interval (m)	Bentonite seal (m)	Completed	SWL (mbTOC)	SWL (mRL)	Date of SWL	Final Airlift EC (µS/cm)	Final Airlift pH
MDPZ9201	Mulga E	665349	7549601	414.90	0.46	DR	0-84	230	28	82.5	PVC CL12	50	18-82.5	-	9/07/2021	12.85	402.05	10/08/2021	1,840	7.89
MDPZ9202	Mulga E	668073	7549439	421.70	0.24	DR	0-88	230	18	88.0	PVC CL12	50	16-88	-	13/07/2021	19.42	402.28	13/07/2021	1,140	7.44
MDPZ9203	Mulga E	666865	7550118	421.40	0.57	DR	0-76	230	14	76.0	PVC CL12	50	16-76	-	16/07/2021	19.24	402.16	10/08/2021	1,086	8.15
MDPZ9204	Mulga E	666361	7548461	413.77	0.48	DR / DTH	0-94 94-100	230 190	19	100.0	PVC CL12	50	16-100	-	20/07/2021	11.73	402.04	10/08/2021	2,690	7.69
MDPZ9205	Mulga E	672010	7548259	419.03	0.53	DR / DTH	0-34 34-70	230 190	10	70.0	PVC CL18	100	16-70	-	24/07/2021	15.76	403.27	10/08/2021	1,603	7.79
MDPZ9206	Mulga E	669177	7549127	421.66	0.50	DR	0-89	230	16	89.0	PVC CL18	100	65-89	57-59	28/07/2021	18.60	403.06	10/08/2021	1,629	6.68
MDPZ9207(L)	Mulga E	661985	7552122	426.90	0.55	DR	0-46	230	8	-	-	-	-	-	30/07/2021	-	-	-	-	-
MDPZ9207	Mulga E	661988	7552119	423.71	0.55	DR	0-77	230	14	76.5	PVC CL18	100	16.5-76.5	-	3/08/2021	22.57	401.14	7/08/2021	913	7.51
MDPZ9208	Mulga E	661329	7550554	412.60	0.50	DR / DTH	0-64 64/75	230 190	16.3	74.0	PVC CL18	100	45-74	35.7-38	7/08/2021	11.85	400.75	10/08/2021	1,438	7.57
MDPZ9209	Mulga E	664776	7550535	419.51	0.42	DR / DTH	0-47 47-70	230 190	8.3	70.0	PVC CL18	100	28-70	19.7-21.7	11/08/2021	17.63	401.88	12/08/2021	473	7.55
MDPZ9210	Mulga E	660323	7550147	410.73	0.45	DR / DTH	0-64 64-82	230 190	35	80.0	PVC CL18	100	50-80	42-44	14/08/2021	9.46	401.27	16/08/2021	3,710	7.73
MDPZ9211	Malay	656000	7545396	404.28	0.40	DR / DTH	0-82 82-130	230 190	31	130.0	PVC CL18	100	34-130	-	17/09/2021	3.89	400.39	23/09/2021	16,000	7.19
MDPZ9212D	Malay	654400	7546689	405.62	0.45	DR / DTH	0-100 100-120	230 190	60	118.5	PVC CL18	100	100.5-118.5	94-96	24/09/2021	5.64	399.98	10/11/2021	18,600	7.68
MDPZ9212S	Malay	654386	7546688	405.39	0.44	DR	0-59	230	31	59.0	PVCL18	100	5-59	-	1/11/2021	5.24	400.15	10/11/2021	15,000	7.72
MDPZ9213	Malay	649610	7544612	404.98	0.45	DR / DTH	0-58 58-120.5	230 190	38.5	120.5	PVC CL18	100	18.5-120.5	-	1/10/2021	5.03	399.95	10/11/2021	3,730	7.77
MDPZ9214	Malay	647989	7547414	403.47	0.45	DR	0-125.5	230	21.5	123.7	PVC CL18	100	3.7-123.7	-	10/10/2021	4.03	399.44	12/10/2021	6,010	7.82
MDPZ9215D	Malay	643992	7550206	403.59	0.38	DR	0-130	230	47	130.0	PVC CL18	100	70-130	61.5-64	18/10/2021	4.74	398.85	17/10/2021	22,200	7.43
MDPZ9215S	Malay	643992	7550192	403.61	0.47	DR	0-59	230	12	59.0	PVCL18	100	5-59	-	27/10/2021	4.47	399.14	29/10/2021	4,460	7.74

Hole ID	Area	Easting MGA94_50	Northing MGA94_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilling Airlift Yield (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Interval (m)	Bentonite seal (m)	Completed	SWL (mbTOC)	SWL (mRL)	Date of SWL	Final Airlift EC (µS/cm)	Final Airlift pH
MDPZ9216	Malay	643199	7551012	403.66	0.42	DR / DTH	0-118 118-119.5	230 190	34	119.5	PVC CL18	100	83.5-119.5	73-75	24/10/2021	5.24	398.42	12/12/2021	21,200	7.21
MDPZ9217	Mulga W	632854	7556252	402.51	0.42	DR / DTH	0-58 58-88	230 190	21.5	89.0	PVCL18	100	5-89	-	20/22/2021	4.78	397.73	21/11/2021	11,400	7.57
MDPZ9218	Mulga W	622035	7555800	399.25	0.40	DR / DTH	0-82 82-92	230 190	27	92.0	PVCL18	100	8-92	-	26/11/2021	3.43	395.82	12/12/2021	8,460	7.66
MDPZ9219	Mulga W	618440	7555798	397.28	0.46	DR / DTH	0-100 100-112	230 190	27.5	112.0	PVCL18	100	10-112	-	30/11/2021	3.69	393.59	5/12/2021	4,180	7.91
MDPZ9220	Mulga W	610046	7558820	395.35	0.37	DR / DTH	0-64 64-94.5	230 190	21.5	94.5	PVCL18	100	10.5-94.5	-	6/12/2021	6.32	389.03	12/12/2021	3,070	7.61
MDPZ9221	Mulga W	609649	7560972	390.34	0.49	DR / DTH	0-70 70-83	230 190	19	83.0	PVCL18	100	11-83	-	12/12/2021	2.50	387.84	13/12/2021	4,240	7.81

Table 5.3 2023 Monitoring Bore Details

Hole ID	Easting MGA_50	Northing MGA_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilling Airlift Yield (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Depth (m)	Bentonite seal (m)	Completed	SWL (mbrp)	Date of SWL	Completion Airlift Yield (L/s)	Final Airlift EC (uS/cm)	Final Airlift pH
MDPZ9222S	643,187	7,551,797	TBC*	0.60	DR DTH	0-106 106-117	241 191	>40	40	CL18 PVC	100	10-40	75.5-77.5 40-41 0-2	17/08/2023	5.41	28/08/2023	4	18,360	7.93
MDPZ9223D	648,835	7,546,202	TBC*	0.53	DR DTH	0-82 82-94	241 191	42	92	CL18 PVC	100	68-92	61.5-63.5	29/09/2023	5.65	29/09/2023	10 to 20	9,900	-
MDPZ9223S	648,838	7,546,180	TBC*	0.57	DR DTH	0-29 29-30	241 191	7	30	CL18 PVC	100	9-30	0-2	14/10/23	5.65	16/10/2023	6	3,160	7.80
MDPZ9224D	647,965	7,547,379	TBC*	0.37	DR	0-89	241	28	87	CL18 PVC	100	75-87	68-70	31/10/23	4.51	31/10/2023	10	9,040	7.60
MDPZ9224S	647,970	7,547,389	TBC*	0.40	DR DTH	0-52 52-52.5	241 191	14	52	CL18 PVC	100	28-52	20-22	20/10/2023	4.53	31/10/2023	6	4,700	8.05
MDPZ9225	649,571	7,544,628	TBC*	0.56	DR	0-61.3	241	15-20	61.3	CL18 PVC	100	57.3-61.3	52-54	11/05/2023	5.52	13/11/2023	2-3	2,900	8.35

*Not surveyed as yet.

AQ2

Table 5.4 2018 to 2023 Production Bore Details

Hole ID	Area	Easting MGA94_50	Northing MGA94_50	Top of Casing (mRL)	Stick-up (m)	Drilling Method	Drill Depth (mbgl)	Drill Diam (mm)	Max Drilling Airlift Yield (L/s)	Cased Depth (mbgl)	Casing	Casing ND (mm)	Screened Interval (m)	Screened Unit	Started	Completed	SWL (mbTOC)	SWL (mRL)	Date of SWL	Completion Airlift Yield (L/s)	Final Airlift EC (uS/cm)	Final Airlift pH
MDPB0011	Mulga E	652202	7552525	406.24	0.41	DR	0-23.5	406	2.9	23.5	CL12PVC	250	11.5 - 23.5	U Calcrete Undiff Tert	3/05/2019	6/05/2019	6.19	400.05	8/09/2019	3.8	810	8.39
MDPB0012	Mulga E	655667	7551805	405.51	0.35	DR	0-46.5	406	15	46.5	CL12PVC	250	10.5 - 46.5	Pisolite/ Hardcap	6/05/2019	9/05/2019	5.06	400.45	8/09/2019	15.0	1,503	8.12
MDPB0013	Mulga E	656694	7548124	405.07	0.37	DR DTH	0-57 57-112	406 375	20.7	112	CL12PVC	250	66-112	Marra Mamba	12/05/2019	17/05/2019	4.88	400.19	8/09/2019	10.3	4,770	8.01
MDPB0014	Mulga E	651169	7549452	405.18	0.38	DR	0-35	406	12	35	CL12PVC	250	5-35	Upper Calcrete	18/05/2019	20/05/2019	4.58	400.60	8/09/2019	8.0	5,670	8.52
MDPB0015	Malay	651327	7545797	404.08		DR	0-52	406	50	52	CL12PVC	250	34-52	Undiff Tert Pisolite	5/08/2019	9/08/2019	4.61	399.47	3/09/2019	30.0	6,550	-
MDPB0016	Mulga E	657318	7550024	404.32	0.48	DR	0-88	432	27.5	88.0	PVC CL12	250	10-88	Tertiary & , MM	16/08/2021	24/08/2021	3.25	401.07	25/08/2021	40	2,900	8.01
MDPB0017	Mulga E	666388	7548453	413.79	0.46	DR / DTH	0-88 88-100	432 368	60	100.0	PVC CL12	250	16-100	Tertiary & , MM	25/08/2021	29/08/2021	11.75	402.04	2/09/2021	45	2,850	7.79
MDPB0018	Mulga E	669188	7549120	421.50	0.41	DR / DTH	0-88 88-91	432 368	42	91.0	PVC CL12	250	13-91	Tertiary & , MM	30/08/2021	4/09/2021	18.50	403.00	8/09/2021	38	1,230	7.15
MDPB0019	Mulga E	661995	7552117	423.70	0.54	DR / DTH	0-58 58-77	432 368	24.4	77.0	PVC CL12	250	17-77	Tertiary & , MM	6/09/2021	10/09/2021	22.59	401.11	15/09/2021	10	864	7.9
MDPB0020	Malay	654415	7546689	405.73	0.39	DR / DTH	0-106 106-112.5	432 368	~140	112.5	SS Screen / PVC CL18	250	70.5-112.5	Hardcap, West Ang	2/11/2021	13/11/2021	5.66	400.07	18/11/2021	50	17,100	7.74
MDPB0021	Malay	643,992*	7,550,206*	TBC*	0.44	DR DTH	0-100 100-125	479 419	80	124	CL18 PVC & SS	300	47-71 112-124	Tertiary, Hardcap & West Ang	18/08/2023	20/09/2023	5.20	TBC*	23/09/2023	40	16,970	7.35
MDPB0022	Malay	648,819*	7,546,180*	TBC*	0.65	DR DTH	0-76 76-82	479 419	82	81	CL18 PVC & SS	300	49-79	Tertiary, Hardcap & Wittm Fm dolomite	30/09/2023	10/10/2023	5.55	TBC*	16/10/2023	62	8,860	8.00

*Not surveyed as yet.
MM = Marra Mamba Formation
West Ang = West Angelas Member
Wittm Fm = Wittenoom Formation

5.3.5 Hydraulic Testing

Hydraulic testing was undertaken at the majority of the bores installed in 2018/2019 and all bores installed in 2021. Testing comprised pumping tests on the 10 production bores (MDPB0011 to MDPB0020) and falling head tests, mini-pumping tests, micro-pumping tests and/or airlift recovery tests at the monitoring bores. As with the drilling, the discharge water from the hydraulic testing was either contained within sumps or discharged to the environment, dependent on the salinity of the pumped water. Testing of the bores installed in 2023 has not yet been undertaken. Although pumping tests / re-injection trials were proposed, this work was deferred, initially due to wet season access restrictions and subsequently due to the requirement for further approvals for work within Mungurrdu.

At production bores MDPB0011 to MDPB0019, a step rate test (comprising four sixty-minute steps) and a two to five-day constant rate test were conducted, each followed by a monitored recovery period. Water levels at the tested production bore and adjacent monitoring bore(s) were recorded both manually and with pressure transducers, with the salinity of the discharge water also recorded. All discharge water was transferred via lay-flat to approved discharge locations at distances ranging between 200 and 1,750 m from the tested production bores to minimise re-circulation.

The pumping test at MDPB0016 was conducted to assess a potential change in salinity with time (i.e. dependent on the duration of the test pumping); therefore, the constant rate test at this bore had to be repeated due to pump failure during the first attempt. Salinity profiling of MDPB0016 and the adjacent monitoring bores was undertaken before and after the testing.

Due to the salinity of the groundwater at MDPB0020, the discharge water for this bore required containment; however, it was evident during the drilling of this bore that the adjacent sump leaked, and the discharge water was being re-circulated. The discharge water from the pumping test of MDPB0020 was transferred, via lay-flat, to the sump adjacent to MDPZ9211 (~3 km via existing tracks). The increased discharge distance reduced the maximum potential yield from the pump and, due to the minimal drawdown associated with the maximum pumping rate, it was determined that conducting a step rate test was a low priority. Although a short step rate test (using the sump adjacent to MDPB0020) was proposed after the completion of the two-day constant rate test, this did not eventuate due to rain (and associated access issues) causing an early end to the pumping test programme.

Details of the production bore pumping tests are presented in Table 5.5, with the data plots presented in Appendix E.

The mini- and micro-pumping tests involved the installation of a small, low-yielding pump, together with a pressure transducer to monitor the water level response to pumping. The bores were pumped for 30 to 60 minutes, with monitoring of water levels throughout the test and for one hour after the test (or until water levels had recovered to 90% of the initial drawdown; whichever was the shorter duration). Mini testing was conducted in the 100 mm cased monitoring bores by MDP; whilst micro-pumping was conducted by the site hydrogeologist using a 12V pump on the 50 mm cased monitoring bores. Not all monitoring bores were tested by mini-and micro-pumping, as sufficient drawdown could only be achieved on the lower yielding bores. In addition, bores MDPZ7454, 7455, 7466 and 7467 could not be micro-tested due to the depth to water at these bores being beyond the pumping capacity of pumps that can fit inside 50 mm ND monitoring bores. As such, falling head tests were instead conducted at these bores.

Each falling head test comprised measuring the aquifer response to a near instantaneous change of water level, achieved by adding approximately 80 litres of water into the bore. A pressure transducer was used to measure the water level rise and fall, following the introduction of the water into the bore.

Airlift recovery tests were undertaken at nine of the higher yielding 2018/2019 monitoring bores as well as MDPZ9215D and MDPZ9216D to induce a greater drawdown than that achieved from the mini- and micro-testing. The bores were airlifted for one hour using a poly pipe and drill rig compressor, with an installed pressure transducer / logger recording the water level drawdown and subsequent recovery at two second intervals.

The results of all hydraulic testing were analysed using standard curve-fitting analysis methods; analyses plots are presented in Appendix F.

Table 5.5 Pumping Test Details

Bore	SWL (mbRP)	Step Test			Constant Rate Test								
		Test Date	Step Duration (mins)	Step Discharge Rates (L/s)	Test Start Date	Test Finish Date	Duration	Rate (L/s)	Max Drawdown (m)	EC Range (µS/cm)	Monitoring Bore	Distance from PB (m)	Max Drawdown (m)
MDPB0011	6.19	11/9/19	60	2, 4, 6, 8	12/9/19	17/9/19	120 hrs (5 days)	7	7.49	891-940	MDPZ7450A	13	0.06
											MDPZ7450B	12	0.4
											MDPZ7450C	20	1.39
MDPB0012	5.08	18/9/19	60	10, 20, 30, 37	19/9/19	24/9/19	120 hrs (5 days)	30	16.97	1649-1777	MDPZ7449A	23	0.06
											MDPZ7449B	14	1.27
											MDPZ7449C	10	0.34
											MDPZ1091	182	0.26
MDPB0013	4.88	25/9/19	60	10, 15, 20, 25	26/9/19	1/10/19	120 hrs (5 days)	25	56.78	4860-5790	MDPZ7640A	10	10.18
											MDPZ7640B	10	0.09
											MDPZ7640C	10	0.07
MDPB0014	4.62	3/10/19	60	10, 14, 18, 22	4/10/19	9/10/19	120 hrs (5 days)	22	6.22	5760-6190	MDPZ7457A	20	0.05
											MDPZ7457B	12	0.45
											MDPZ7457C	10	1.75
MDPB0015	4.61	3/9/19	60	10, 20, 30, 40	4/9/19	9/9/19	120 hrs (5 days)	40	10.03	7030-7700	MDPZ7452A	5	1.22
											MDPZ7452B	10	1.68
											MDPZ7452C	15	0.8
MDPB0016	4.28	16/10/2021	60	10, 20, 30, 40	27/11/2021	30/11/2021	75 hrs (3.1 days)	40	7.2	3400-3500	MDPZ7469A	8	0.2
											MDPZ7469B	11	3.6
											MDPZ7469C	18	1.2

Bore	SWL (mbRP)	Step Test			Constant Rate Test								
		Test Date	Step Duration (mins)	Step Discharge Rates (L/s)	Test Start Date	Test Finish Date	Duration	Rate (L/s)	Max Drawdown (m)	EC Range (µS/cm)	Monitoring Bore	Distance from PB (m)	Max Drawdown (m)
MDPB0017	12.66	10/10/2021	60	13, 23, 33, 43	11/10/2021	13/10/2021	52 hrs (2.2 days)	40	1.31	3040 - 3240	MDPZ29204	29	0.44
											MBPZ7456A	767	0.10
											MBPZ7456C	749	0.11
											MBPZ7456B	757	0.13
MDPB0018	19.54	24/09/2021	100	10, 20, 30, 40	25/09/2021	30/09/2021	120 hrs (5 days)	38	4.07	700-1060	MDPZ9206	12	1.42
											MDPZ7933	559	1.2
MDPB0019	23.63	1/10/2021	60	10, 20, 30, 40	4/10/2021	8/10/2021	102 hrs (4.25 days)	38	5.66	740 - 800	MDPZ9207	8	2.7
MDPB0020	6.70	N/A			5/12/2021	6/12/2021	48 hrs (2 days)	20	0.28	17600-18800	MDPZ9212D	15	0.18
											MDPZ9212S	29	0.09
											MDPZ5355	488	0.02

5.3.6 Water Quality Measurements

During all drilling, pH and EC readings of the discharge water were taken at the end of each rod. In addition, a water sample was collected from each completed bore either at the end of airlift development or the end of micro-testing. All collected water samples were analysed by a NATA accredited laboratory (ARL Australia in 2018/2019 and SGS Australia Pty Ltd in 2021 and 2023) for major cations, anions and basic water quality parameters (including pH, EC, total dissolved solids, total hardness and total alkalinity). Hydrochemistry data from the laboratory analyses are tabulated in Appendix G.

Water samples were also collected from the production bores during the constant rate tests. In general, samples for analysis were taken just prior to the completion of the constant rate test. However, for bores MDPB0016 and MDPB0020, samples taken at the commencement of the constant rate test were used for analysis as the test at MDPB0016 finished unexpectedly (due to pump failure) and MDPB0020 could not be accessed following a rainfall event.

5.3.7 Salinity Profiles

Salinity profiles were measured at each completed monitoring bore approximately a week after drilling to allow the water column in the bore to recover, and prior to any hydraulic testing. The process comprised slowly running a Solinst LTC logger or AquaTROLL 200 logger down the bore, by hand, with the logger set at the lowest time-increment.

Salinity profiles for each of the bores are presented in Appendix H, together with the salinity measurements taken during drilling and laboratory salinity data.

5.3.8 Survey Data

Bores installed during the 2018/2019 drilling were surveyed using a Leica Viva GS15 RTK GPS with a horizontal accuracy of 0.1 m and vertical accuracy of +/- 0.05 m. Survey work was conducted by McMullen Nolan Group P/L (MNG) under direct contract to HPPL.

Bores installed in 2021 were surveyed using a Trimble R8S Base - R8 Rover GPS with a horizontal accuracy of 0.05 m and vertical accuracy of +/- 0.05 m. This survey work was conducted by Survey Group under direct contract to HPPL.

To date, none of the 2023 Malay Well bores have been surveyed due to Mungurrdu having restricted access.

5.3.9 Down-hole Survey Data

Down-hole gamma logs were run at each of the 2018/2019 monitoring bores to assist with geological (stratigraphic) logging. These surveys were conducted by Wireline Services Group under direct contact to HPPL. Due to the dimensions of the probe and minor bends in the 50 mm ND bore casing, the probe could not reach total depth for many of the bores. Additionally, the diameter of the drilled hole, together with the annulus fill (i.e. gavel pack / bentonite seal / grout) affected the gamma response.

5.4 Baseline Groundwater Monitoring

During the preliminary hydrogeological investigations (in 2009, 2012 and 2014), selected bores had been equipped with In-Situ Troll transducers / loggers. During the 2018/2019 field programme, these loggers were retrieved, and their status assessed. Data was downloaded from those that were still operational and four selected bores (MDPZ0704, MDPZ0818, MDPZ0757 and MDPZ0072) were re-equipped with loggers.

At the completion of the 2018/2019 bore installation programme, each monitoring bore was equipped with:

- A pressure transducer / logger (Solinst LTC Levelogger Edge) to record water level changes in the bore (set at a 12-hourly reading frequency), as well as EC and temperature at the depth of installation.
- A passive sampler (Hydrasleeve) for the collection of a water sample at the depth of installation. Selected single-completion bores were equipped with two Hydrasleeves if salinity profiles indicated distinct changes in salinity with depth.

The depths of these installations were determined from the salinity profiles. Where a change in salinity was evident with depth, the transducer / logger was installed at or near the transition zone and the passive sampler was installed either above or below the transition zone (or in some cases, both).

Since then, bi-annual groundwater monitoring rounds have been undertaken. Each round comprises groundwater level measurements (logger downloads and manual dip), salinity profiling and groundwater sampling/analysis. In addition, periodic manual water level readings were taken during the 2021 field investigations.

Significant manufacturer problems were experienced with the Solinst loggers with the instruments giving erroneous readings (i.e. unexplained drift or jumps in the data) and / or ceasing to record data. As such, the Solinst loggers were replaced with In-Situ data loggers in December 2021. By that time, sufficient data had been collected to allow a reduced requirement for time-series data and therefore a reduced number of loggers were required. For example, where some bores within a "cluster" (i.e. deep, intermediate and shallow monitoring bores at one location) show similar water levels and EC readings, loggers were no longer required at each of the three bores. Similarly, where EC profiles (recorded during monitoring rounds) provided sufficient information on EC changes, LTC loggers were no longer required and only groundwater level measurements were deemed necessary, rather than time-series EC data as well. In general, time-series EC data is only required in the uppermost aquifer unit in the claypan area, with salinity profiles considered to be sufficient in most other areas (with one or two exceptions). AquaTROLL 200 loggers were installed where groundwater level and EC time-series data is required and LevelTROLL 400 loggers were installed where only groundwater level data is required.

Following the 2021 drilling programme, monitoring bores that had been installed in the Malay Well and Mulga West areas, plus the easternmost monitoring bore in the Mulga East area (MDPZ92015), were added to the baseline monitoring network. Similarly, minor modifications were made to the baseline monitoring network in the Malay Well area following the 2023 bore installation programme.

Details of the current logger and passive sampler installations are summarised in Appendix I.

6. GROUNDWATER DATA ASSESSMENT

6.1 Hydrogeological Units

The results of the 2018/2019, 2021 and 2023 field investigations have been combined with those of previous hydrogeological investigations and publicly available hydrogeological data to develop the conceptual understanding of the area. The investigations and data assessment to date have focused on the Mulga East and Malay Well (tenement) areas, with only a preliminary assessment of the Mulga West area.

Five main hydrogeological units have been identified across the Study Area:

- Tertiary / Quaternary Cover (comprising Basal "Crete", CID/Pisolite, Undifferentiated Tertiary and Upper Calcrete).
- Fresh Jeerinah and Marra Mamba Formations.
- Altered Marra Mamba Formation and West Angela Member.
- Fresh West Angela Member (Wittenoom Formation).
- Dolomite of the Wittenoom Formation.

Bedrock Units

Each of these units and respective sub-units are described in more detail below. Hydrogeological cross-sections are presented in Figure 6.1 to Figure 6.4, with the locations of the cross-sections shown in Figure 6.5.

6.1.1 Tertiary / Quaternary Cover

Basal Crete: This unit directly overlies the bedrock and occurs in all bores across the valley floor area. It has been intersected at depths of between 46 and 66 mbgl at bores MDPZ7451A, 7452A, 7453A, 7457A, 7458A, 7462A, 7463A, 7468A, 7469A, 7470A, 7471A, MDPZ9211 to MDPZ9216 and MDPZ9222 to MDPZ9225. It ranges in colour from white / cream to beige / yellow-brown and is variable in both composition and nature. It occurs as calcrete, silcrete, dolomite or calcite, and ranges between hard, crystalline, massive, vuggy, brecciated and weathered; potentially weathering to a waxy clay at MDPZ7468 or puggy clay at MDPZ9216. At MDPZ7461, the unit occurs only as 5 m of calcite veining within the black chert bedrock, between 55 and 60 m depth. Similarly, at MDPZ7452A, beneath ~8 m of calcite / calcrete, calcite veining extends into the grey dolomite bedrock. Drilling yields from this unit ranged from 0 to 2 L/s (at MDPZ7468 and MDPZ7469) where it is clayey or highly siliceous, to between 21 and 31 L/s (at MDPZ9211 to MDPZ9216, MDPZ7453 and MDPZ7463) in the centre of the valley area, where the unit is vuggy or brecciated with goethitic staining. This unit is believed to be comparable with the Pinjan Chert, identified in the Fortescue Marsh area to the east (MWH 2015). It may have formed as an alteration and weathering product on the basement; processes that here are assigned to the early Tertiary.

In the Mulga West area, the Basal Crete was intersected at bores MDPZ9218 and MDPZ9219 at depths ranging between 52 and 76 mbgl, with maximum yields ranging between 6 and 16 L/s.

CID / Pisolite (TD2): This unit occurs along the northern flanks of the valley and extends out across the valley floor area. It occurs below the Undifferentiated Tertiary and directly overlies the Basal Crete unit; however, where the Basal Crete unit laterally pinches (on the flanks of the valley), it directly overlies the bedrock. In such locations (where the Basal Crete is absent), it is difficult to differentiate between CID and a hardcap (bedrock) unit and it is believed there may be inconstancies with the logging of these units, including the HPPL mineral exploration logging.

This unit is variable in nature, comprising both magnetic pisoliths (with varying red-brown silt to clay content) and hard, friable or vuggy grey-black CID. On the valley flanks (i.e. at bores MDPZ9207 and MDPZ9209) the unit occurs at shallow depths above the water table. Across the centre of the valley (at bores MDPZ9211 to MDPZ9216 and MPZ9222 to MDPZ9225) the CID / Pisolite unit occurs at depths ranging between 46 to 56 mbgl, although at MDPZ9215 the unit was not clearly identifiable with pisolites occurring within the Undifferentiated Tertiary and Basal Crete units. Drilling yields from this unit range from <1 L/s (at MDPZ7450, MDPZ7456 and MDPZ7464) up to 16 to 28 L/s (at MDPZ7453, MDPZ9215 and MDPZ9211 to MDPZ9214). Although the unit is mineralised in some areas, drilling yields are also high where no mineralisation has occurred. Bores completed in this unit include MDPZ7449B, 7450B, 7458B, 7460B and MDPB0012.

In the Mulga West area, bores MDPZ9217 to MDPZ9220 intersected the CID / Pisolite unit at depths ranging between 26 and 58 mbgl. Drilling yields ranged between 9 to 22 L/s.

Undifferentiated Tertiary (TD2/TD3): Where present in the valley area, this unit overlays the CID/Pisolite. Further up the flanks of the valley, it may directly overlie bedrock where the CID/Pisolite and Basal Crete "pinches out". The thickness of the unit, where intersected by the hydrogeological drilling, ranges between 12 and 42 m, although it is absent from bores MDPZ9211, MDPZ7457, 7458 and 7461. At these locations the Upper Calcrete directly overlies the CID Pisolite unit. The Undifferentiated Tertiary unit includes both scree/colluvium and detrital material, including alluvial fan material. The unit is predominantly red brown, comprising BIF, chert and quartz gravel with varying silt and clay content / matrix; it may also include magnetic pisoliths (although not as a dominant component). Where intervals of clay occur (i.e. with no or minimal clasts), they tend to be between only 1 to 14 m thick. Drilling yields from this unit are variable, dependent on the clay content and sorting; recorded yields generally ranged between 0 and 12 L/s, although a yield of 16 L/s was recorded at MDPZ9212, and 30 L/s was recorded at MDPZ7452. Production bore MDPB0015 is installed in this unit adjacent to MDPZ7452. The unit represents detritus from the hills to the south interdigitating with the valley fill and is likely to have been deposited over an extended period of time. It has been grouped in this assessment due to the lack of clear hydrogeological divisions within it.

In the Mulga West area, all 2021 bores intersected the Undifferentiated Tertiary unit with drilling yields ranging between 0 and 10 L/s (MDPZ9218).

Upper Calcrete (TD2 Oakover Formation): This unit comprises white to light-brown, unstructured calcrete, often friable and sometimes vuggy; at some locations, such as MDPZ7449, MDPZ7452 and MDPZ7457, it is more siliceous. It occurs across the valley floor area at surface or under a thin cover of alluvium, with a maximum recorded thickness of 46 m at MDPZ9211. Bores completed in this unit (i.e. bores with the slotted interval installed against this unit) include: MDPZ7452C, 7453C, 7457C, 7458C, 7462C, 7470C, 7470C and MDPB0014. Drilling yields from this unit (excluding MDPB0011) ranged from 2 to 20 L/s at MDPZ7471 and MDPZ7458 respectively, with a yield of 0.1 L/s recorded at MDPZ7449 where half of the unit occurs above the water table, resulting in a saturated thickness of only 4 m.

In the Mulga West area, the Upper Calcrete was intersected by the 2021 bores nearest the Fortescue River (MDPZ9218 to MDPZ9221), at depths ranging between 0 and 44 mbgl. Drilling yields ranged between 0 (due to the limited saturated thickness of the aquifer unit) to 12 L/s.

Alluvium: A thin layer of silty alluvium (up to ~4 m thick) covers much of the lower lying ground of Study Area. Near the claypans (i.e. MDPZ7468 and MDPZ7471), it comprises 2 to 3 m of clay. It predominantly occurs above the water level and is therefore not considered as a hydrogeological unit.

Summary: The Tertiary overburden forms a highly transmissive and continuous aquifer within the valley of the Study Area. Maximum thicknesses of up to approximately 60 m occur in the middle of the valley, thinning on the valley slopes.

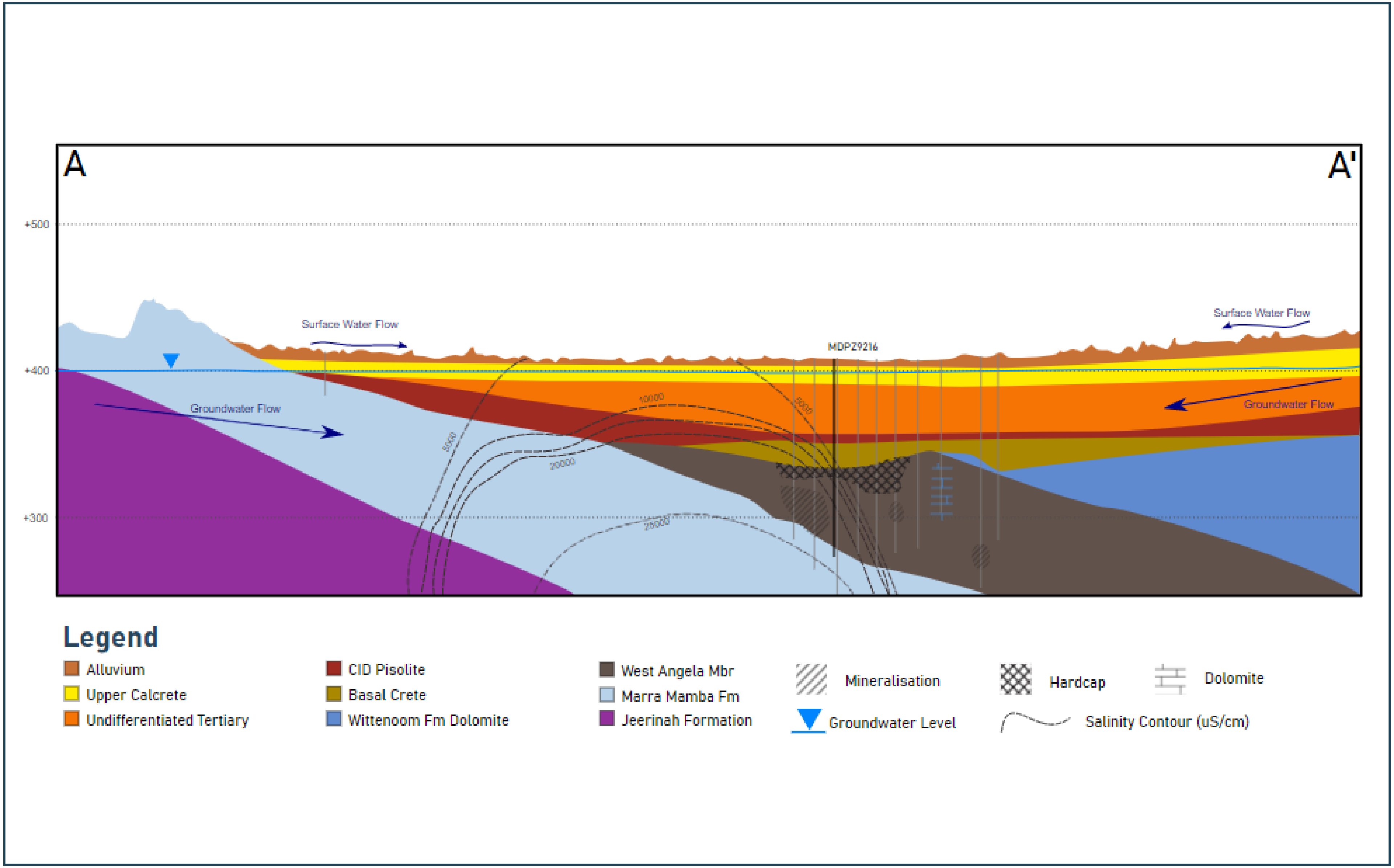


Figure 6.1 Hydrogeological Section A (looking east)

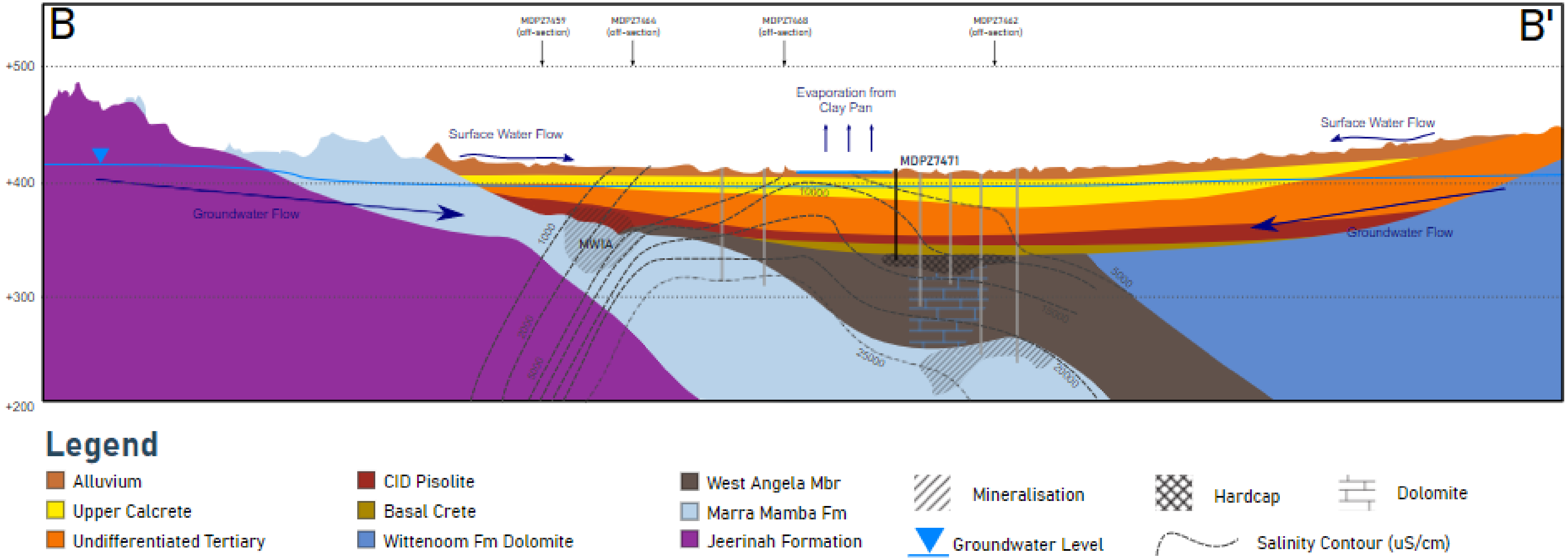


Figure 6.2 Hydrogeological Section B (looking east)

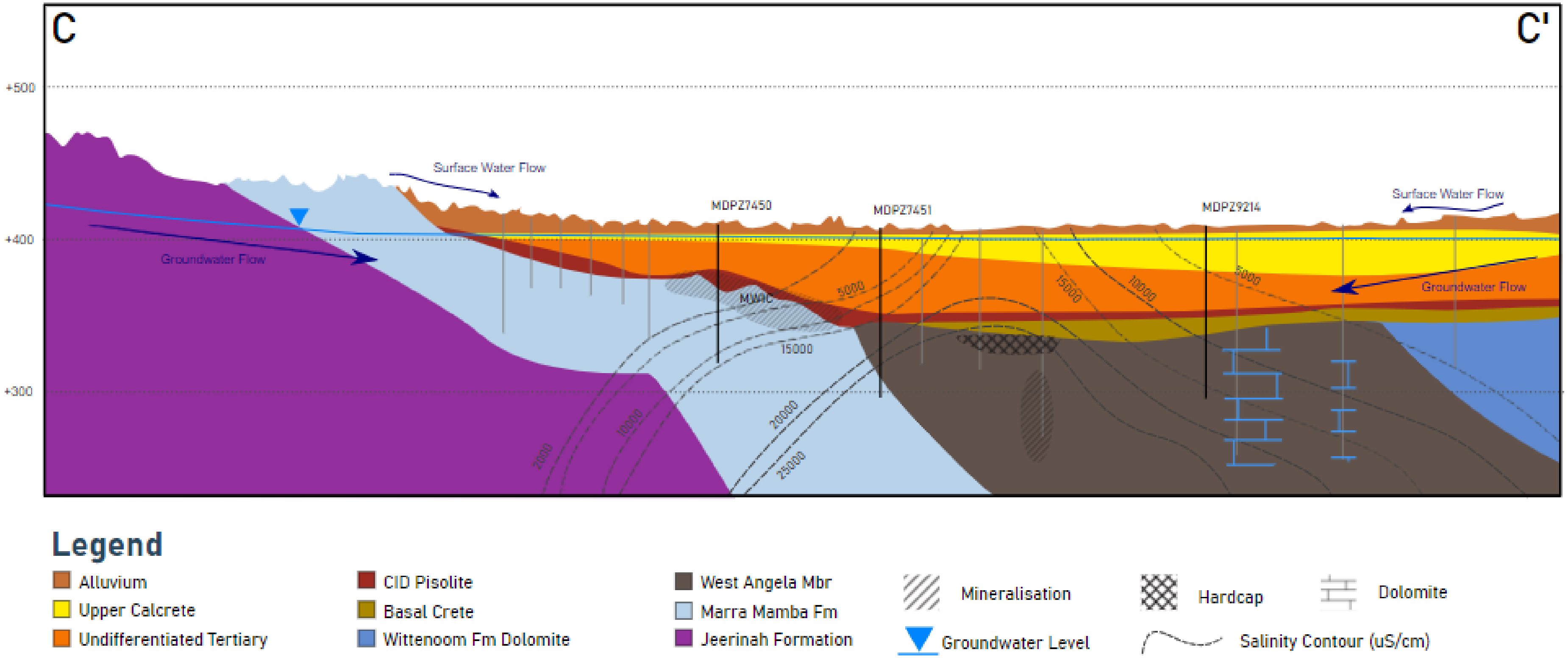


Figure 6.3 Hydrogeological Section C (looking east)

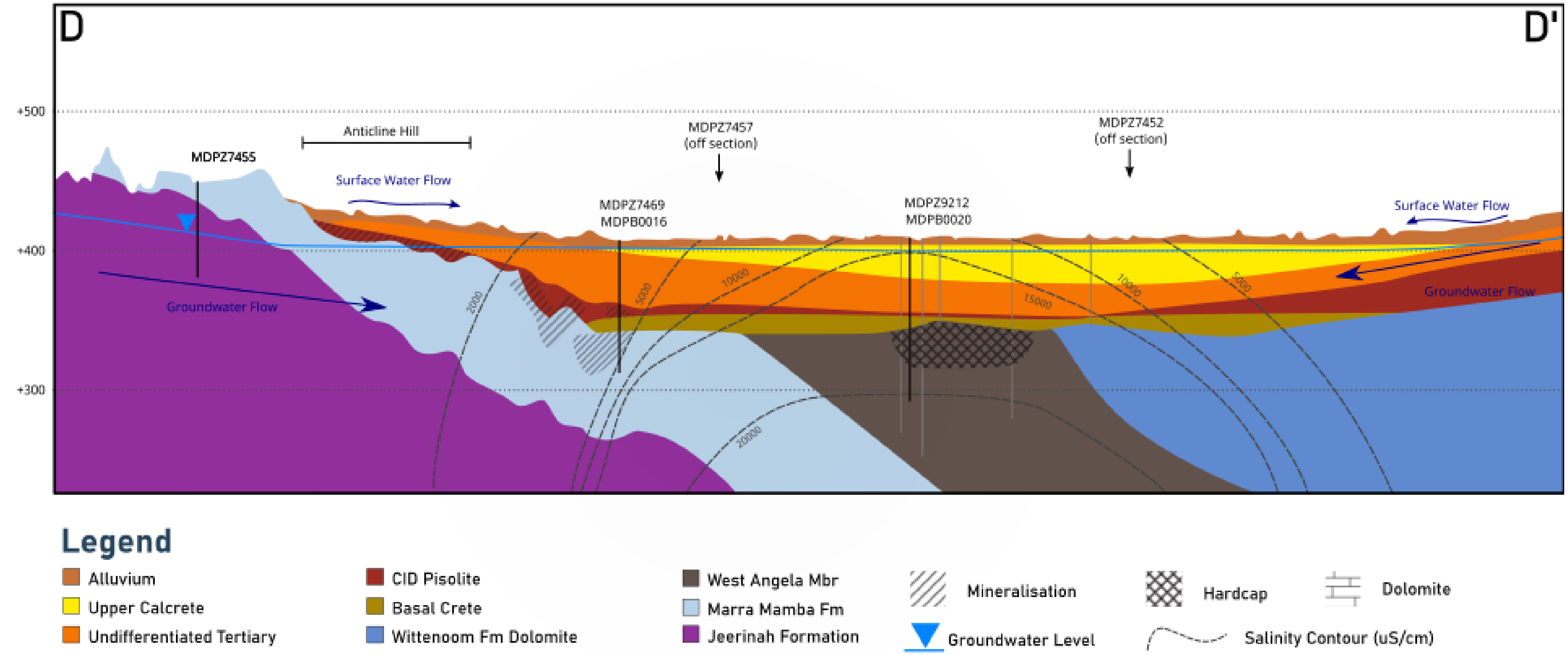


Figure 6.4 Hydrogeological Section D (looking east)

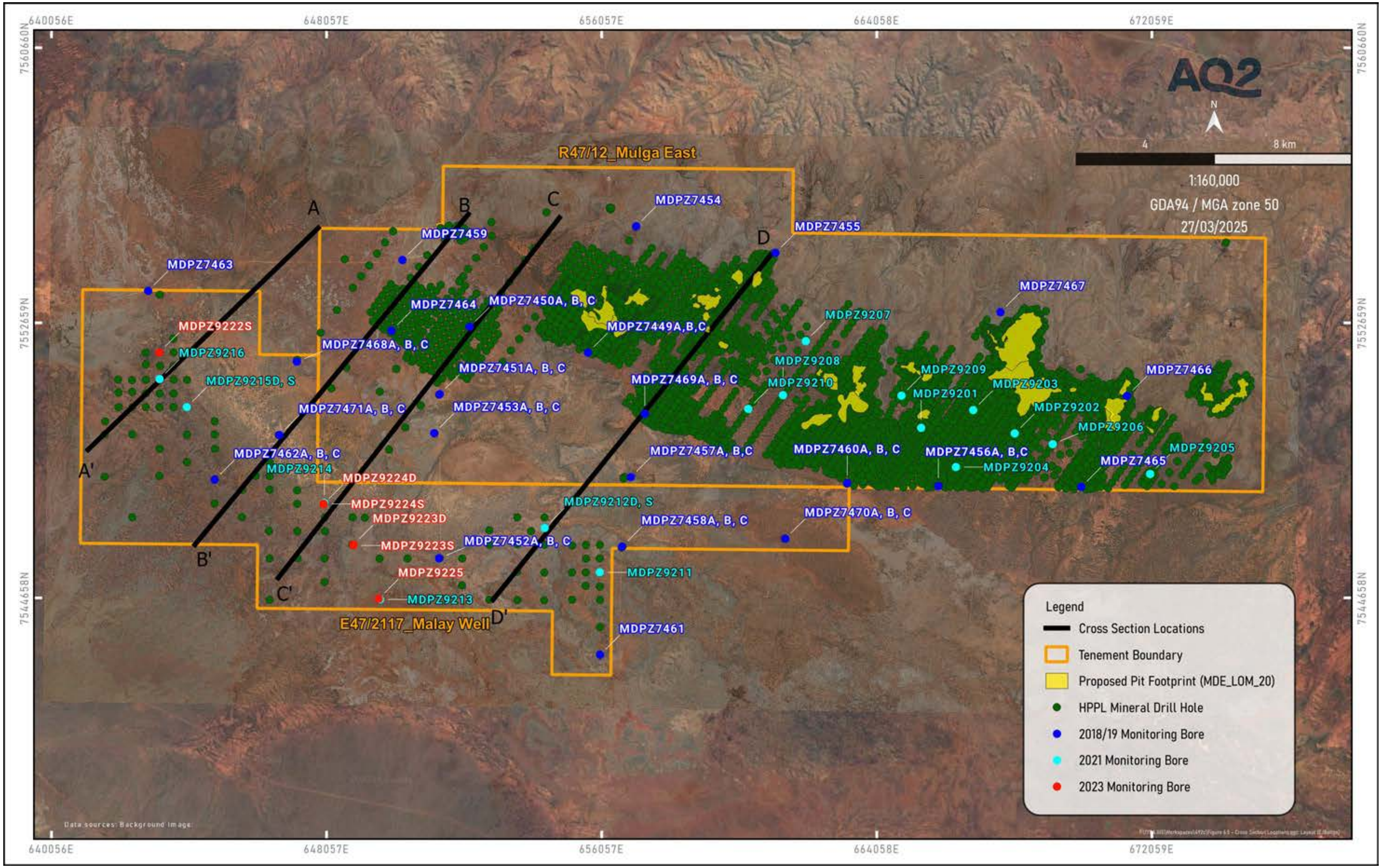


Figure 6.5 Location of Hydrogeological Sections

6.1.2 Bedrock Units

Fresh Jeerinah Formation & Marra Mamba Formation: The Jeerinah Formation is the oldest stratigraphic unit in the Study Area and outcrops along the northern Study Area boundary. Where fresh, this unit comprises black, pyritic and carbonaceous shale with minor chert beds and weathers to pink, brown and/or white puggy clay.

Overlying the Jeerinah Formation is the Nammuldi Member of the Marra Mamba Formation, with similar carbonaceous black shale occurring at its base. In the HPPL geological model, this unit is classified as "dolomitic Nammuldi" (code: DNAM), however, it is often logged on site as Jeerinah Formation given the similarities of the two units. The dolomitic Nammuldi Member and Jeerinah Formation have been grouped as a single hydrostratigraphic unit, referred to as "the Jeerinah".

The northernmost monitoring bores, MDPZ7454 and MDPZ7455, are screened against the Jeerinah, with the overlying chert of the Marra Mamba Formation being above the water table. Airlift yields during the drilling of these bores were generally very low (<0.1 L/s) although yields at total depth (i.e. 60 mbgl) increased to 0.3 and 1.3 L/s respectively, indicative of very minor intervals of increased permeability at MDPZ7455.

Overlying the Jeerinah hydrostratigraphic unit, the Marra Mamba Formation comprises interbedded BIF, shale and chert. The Marra Mamba Formation above the dolomitic Nammuldi Member has been sub-divided into two main hydrostratigraphic units based on its hydrogeological characteristics; low permeability is categorised as "Fresh Marra Mamba" and increased (secondary) permeability is categorised as "Altered Marra Mamba".

Bores MDPZ7466 and MDPZ7467 are screened against lower permeability (Fresh Marra Mamba) and the Jeerinah at depth. Although the airlift yields from these bores were 5 and 3.5 L/s respectively, yields occurred from discrete intervals (i.e. at ~46 m in MDPZ7466 and at the contact of the Jeerinah at ~56 m in MDPZ7467) and are indicative of minor fracture zones with increased permeability.

Altered Marra Mamba: Of the 14 drill locations completed in 2018/19 and the ten 2021 drill locations that intersected the Marra Mamba, all demonstrated secondary permeability to some extent. Drilling yields in most bores ranged between 14 and ~35 L/s, with only MDPZ7466 and MDPZ7467 (to the northeast of the orebodies) having lower yields of 5 and 3.5 L/s respectively (as mentioned above). The increased permeability in the other 22 holes occurs along the northern flanks of the valley (both within and between the identified orebodies), along the southern margin of the orebody area and extends south beneath the valley. Secondary permeability appears to be related to mineralisation, weathering and / or fracturing, hence termed "altered".

The Altered Marra Mamba unit can be further categorised into Marra Mamba Ore and Unmineralised / Fractured Marra Mamba. Monitoring bores MDPZ7465, 7469B, 9201, 9202, 9203 and 9204 were all drilled within the proposed pit areas with maximum yields in the Marra Mamba Ore ranging between 14 and 25 L/s. Production bores MDPB001, MDPB002, MDPB0016 and MDPB0017 all intersect mineralised CID and Marra Mamba Ore. Many of the 2021 drill sites (MDPZ9205 to MDPZ9210) targeted Unmineralised Marra Mamba between the orebodies with maximum drilling yields through the Marra Mamba unit generally ranging between 10 and 16 L/s, although MDPZ9209 had a lower yield of 8 L/s. Increased yields were recorded at the contact between the Marra Mamba Formation and the Jeerinah hydrostratigraphic unit at bores MDPZ9207 (where the yield increased from 10 to 14 L/s) and MDPZ9210 (where the yield increased from 16 to 35 L/s). Production bores MDPB004, 5, 6, 13 and 19 are installed in the Altered Marra Mamba unit, noting that all except MDPB0013 also intersect the Jeerinah at depth, with MDPB005, 6 and 19 also indicating increased yields at the Marra Mamba – Jeerinah contact.

Although weathering of the Marra Mamba generally results in enhanced permeability, at bores MDPZ7464 and MDPZ7451A weathering of a shale unit has resulted in a low permeability saprolitic clay horizon overlying the permeable aquifer unit. At MDPZ7464 the saprolite is 12 m thick (between 52 and 64 m depth), whilst at MDPZ7451A it is 26 m thick (between 66 to 92 m).

There are only limited hydrogeological drilling data for the Mulga West area, however, enhanced permeability in the Marra Mamba Formation appears to generally be limited to weathered / mineralised / hardcap zones immediately below the Tertiary overburden, with drill samples between 86 and 90 m depth at MDPZ9219 also indicative of a permeable fracture zone. Although airlift yields during drilling increased at the base of most holes, this was associated with open-hole drilling (therefore indicative of cumulative yields) and was generally associated with very hard drilling and slow penetration rates, with no evidence in the drill cuttings of enhanced permeability.

West Angela Member: Similar to the Marra Mamba Formation, the West Angela Member comprises interbedded BIF, shale and chert with some beds of dolomite. It directly overlies the Mt Newman Member of the Marra Mamba Formation and sub-crops the Tertiary deposits, beneath the valley floor. The West Angela Member has also been sub-categorised based on its hydrogeological characteristics, with "West Angela Hardcap" and "West Angela Ore" units having increased (secondary) permeability to the "Weathered West Angela Member".

Within the Malay Well area, increased permeability was encountered within a mineralised zone directly underlying the Basal Crete at bores MDPZ9211, 9212D and 9215D, with maximum drilling yields within this unit ranging between 24 and 33 L/s. At depths ranging between 60 and 76 mbgl the unit is dark grey / black with a metallic lustre, moderately vuggy and with goethitic staining. Whilst at MDPZ9212D, the unit extends to 90 mbgl, becomes vuggier and comprises yellow-brown limonitic shale with a honeycomb structure. Production bore MDPB0020 is installed at this location and yields of ~140 L/s were estimated when drilling through this unit.

As outlined above, the differentiation between CID and hardcap is difficult and consideration was given as to whether these mineralised zones are part of a locally incised channel(s), beneath the Basal Crete, infilled with CID (as is known to occur to the west from Weelumurra downstream towards Millstream).

Based on the assays of the Malay Well HPPL drilling, similar zones of mineralisation and composition were mapped and compared to publicly available magnetic data for the area (DMIRS 2016) (Figure 6.6). Attempts were made to map a potential channel thalweg through the Malay Well area. Although a channel-like feature is evident in the Mulga West area near the mapped mineralisation of similar composition, no incised channel could be identified in the Malay Well area. Instead, it is considered that where BIF units of the West Angela Member (and Marra Mamba Formation) have previously been exposed to extensive weathering (i.e. immediately underlying the Tertiary overburden) a permeable hardcap has formed. Where this unit is deeper (i.e. at MDPZ9212D / MDPB0020), it may be due to deeper weathering / alteration along an exposed fault / structure or at the contact between the West Angela and Paraburdoo Members. At this location in particular, weathering has resulted in a highly permeable, honeycomb-like texture. In contrast, where shale of the West Angela Member (and Marra Mamba Formation) has been exposed to weathering, it may occur as pale-coloured, waxy or puggy clay (i.e. at MDPZ9215D underlying the hardcap and at MDPZ9214, 9216 and 9222). Although this puggy clay could be locally confining, current data do not show that it occurs as an extensive and continuous layer.

Based on the HPPL geological model, the recent hydrogeological drilling at Mulga West did not intercept the West Angela Member; however, the HPPL site logging interpreted 6 m of West Angela Member at MDPZ9218 (directly underlying the Tertiary overburden and overlying the Marra Mamba Member).

Airlift yields were recorded by HPPL at the completion of mineral exploration holes drilled by RC methods in the Mulga West area. This data indicates higher yields in the vicinity of shallow mineralisation, possibly associated with hardcap, within the West Angela Member to the west / west-northwest of MDPZ9219; however, these higher yields could also be associated with increased permeability in the Tertiary unit or potentially bedrock fracturing (similar to MDPZ9212).

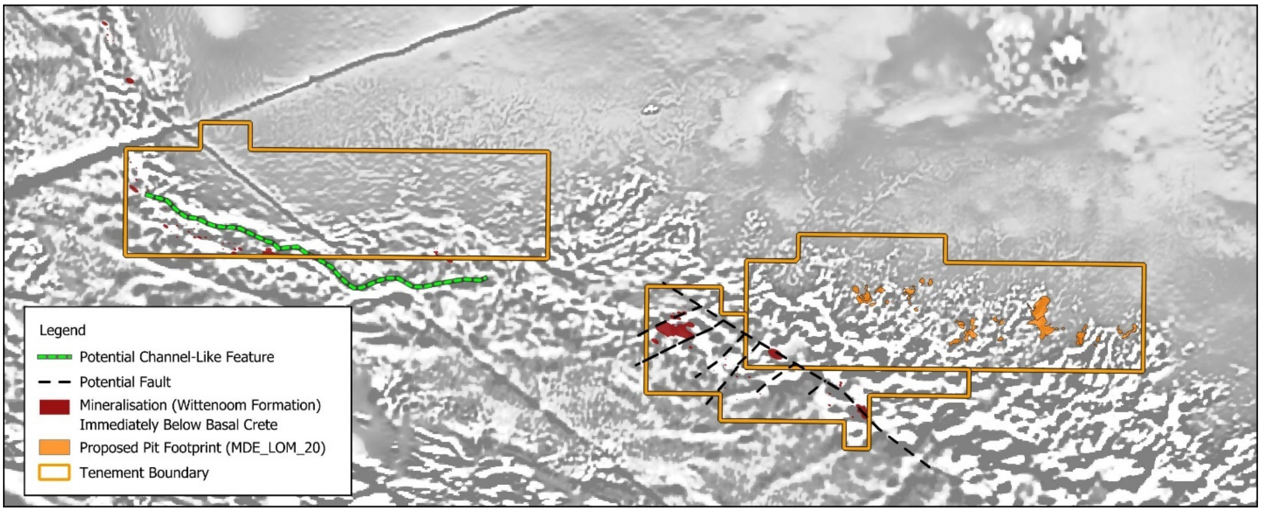


Figure 6.6 Examples of Inferred Geological Features for Mulga West & Malay Well Tenements from Magnetic Data

West Angela Ore is intersected at bores MDPZ9215D, MDPZ9216 and MDPZ9222 in the Malay Well area, below the West Angela Hardcap at depths of up to ~130 mbgl. Drilling yields through this unit ranged between 12 and 35 L/s at MDPZ9215D, between 5.5 and 27 L/s at MDPZ9216 and between 12 and 16 L/s at MDPZ9222, increasing to 43 L/s below the main mineralised interval.

Weathered West Angela is intersected at MDPZ9214. Although calcite veining is present immediately below the Basal Crete, with drilling yields of ~22 L/s, below this is predominantly yellow-brown to grey and beige shale with minor bands of chert and dolomite. Drilling yields through this unit ranges between 3 and 6 L/s and this is anticipated to be representative of the majority of the West Angela Member in the Malay Well area.

Highly weathered bedrock comprising shale, dolomite and BIF was intersected at MDPZ9212D and MDPB0020; however, as indicated above, this is anticipated to be a localised zone potentially associated with a fault / structure or at the contact between the West Angela and Paraburdoo Members, rather than being representative of the Weathered West Angela unit. Drilling yields at MDPZ9212D reached ~60 L/s and high yields prevented further drilling of both this bore and the adjacent production bore (MDPB0020).

Dolomite of the Wittenoom Formation (presumed to be Paraburdoo Member) overlies the West Angela Member and sub-crops the Tertiary deposits beneath the valley floor. It is intersected by bores MDPZ9211, 9213, 7452A, 7458A, 7461 and 7462A. Where intersected, the dolomite is generally light grey, fresh, crystalline and hard, with no recordable increase in airlift yields during drilling. However, at MDPZ9211 (between 76 and 82 mbgl) and MDPZ7458A (between 66 and 68 mbgl), a weathered zone of dolomite (vuggy at MDPZ7258A) yielded 24 and ~30 L/s respectively, indicating significant secondary permeability. A 5 L/s increase in yield at MDPZ7452A may also be associated with increased permeability at the top of the dolomite. Thus, from the drilling to date, the dolomite of the Wittenoom Formation is likely to have discontinuous zones of significant permeability.

Complexities within the Wittenoom Formation: In the Malay Well area, between the sub-cropping West Angela Member and Paraburdoo Member described above, there appears to be a zone of very variable bedrock lithology where neighbouring HPPL drill holes show thick intervals of fresh grey dolomite adjacent to interbedded shale, BIF, chert and dolomite of what appears to be West Angela Member (i.e. BIF, chert, shale) overlying what appears to be Paraburdoo Member (i.e. thick, fresh, crystalline dolomite). It is anticipated that this is due either to:

- Faulting resulting in the juxta-positioning of the Paraburdoo and West Angela Members; or
- The West Angela and Paraburdoo Members (and potentially other members of the Wittenoom Formation) in fact not being present in the area, but instead being represented by the stratigraphically equivalent Carawine Dolomite (Kepert 2018).

Although magnetic data indicates that faulting may be present in this area of Malay Well (refer Figure 6.6), the presence and orientation (as well as the hydraulic characteristics) of any potential faulting is unknown and is recognised as an uncertainty.

Summary: The Study Area is underlain by low permeability Jeerinah Formation and unmineralised Marra Mamba Formation that form a basement aquitard with minor local fractured aquifers. A highly transmissive and continuous aquifer is hosted in the mineralised, fractured and weathered Marra Mamba Formation. The overlying West Angela Member of the Wittenoom Formation forms a moderately permeable aquifer unit with localised (discontinuous) zones of enhanced permeability associated with mineralisation and extreme weathering / alteration. To the south of claypan area, this aquifer is overlain by the Paraburdoo Member of the Wittenoom Formation that forms a discontinuous fractured rock aquifer in generally low-permeability basement. Additional faulting may also result in the juxtaposition of the West Angela Member aquifer and Paraburdoo Member aquitard units, potentially resulting in reduced hydraulic connection along strike.

6.2 Aquifer Parameters

Estimates of aquifer transmissivity have been derived from the hydraulic testing data. AQTESOLV software (by HydroSOLVE Inc.) was used for the analysis of the production bore pumping tests, whilst manual straight-line curve-fitting analyses were applied to the airlift micro- and mini- pumping test and airlift recovery test data. Analyses plots are presented in Appendix F.

For all analyses, the estimated transmissivity (T) has been divided by the assumed aquifer thickness (b) to provide an estimate of permeability (k). The estimated aquifer parameters derived from the pumping tests on the recent and historic production bores are presented in Table 6.1whilst the estimated aquifer permeabilities derived from all the hydraulic testing are presented in Table 6.2.

Table 6.1 Hydraulic Parameters from Production Bore Test Pumping

Pumped Bore (Aquifer Unit)	Test	Monitoring Data	Analytical Method	T (m^2/d)	k (m/d)	S	Summary
MDPB001 (Detritals & Altered Marra Mamba)#	Constant Rate	MD0574	Dual Porosity	729	15	0.02	Summary of Analysis Average T = 1149 m^2/d Average S = 0.138 Average k = 24 m/d b = 48 m
			Logan's Approximation	81	2	0.15	
			Neuman	904	19	-	
			Theis (Cooper-Jacob Correction)	884	18	0.66	
		MD0573	Dual Porosity	2930	61	0.00005	
			Logan's Approximation	84	2	0.0004	
			Neuman	953	20	-	
			Theis (Cooper-Jacob Correction)	2630	55	0.00027	
MDPB002 (Detritals & Altered Marra Mamba)#	Constant Rate	MDPB002	Theis (Cooper-Jacob Correction)	500	31	-	Summary of Analysis Average T = 405 m^2/d Average S = 0.0025 Average k = 25 m/d b = 16 m
		MD0551	Dual Porosity	486	30	0.001	
			Logan's Approximation	347	22	0.004	
			Neuman	488	31	-	
			Theis (Cooper-Jacob Correction)	276	17	0.0026	
	Recovery	MDPB002	Theis (Cooper-Jacob Correction)	337	21	-	
		MD0551	Theis (Cooper-Jacob Correction)	404	25		
MDPB004 (Altered Marra Mamba)#	Constant Rate	MDPB004	Estimation from specific capacity	3430	132	-	Summary of Analysis Average T = 4526 m^2/d Average S = n/a Average k = 174.1 m/d b = 26 m
			Jacob Straight Line (early time)	6081	234	-	
			Jacob Straight Line (late time)	3437	132	-	
	Recovery	MDPB004	Residual Drawdown	5856	225	-	
MDPB005 (Altered Marra Mamba)#	Constant Rate	MDPB005	Estimation from specific capacity	377	15.7	-	Summary of Analysis Average T = 205 m^2/d Average S = 8.3x10-5 Average k = 8.5 m/d b = 24 m
			Jacob Straight Line (early time)	82	3.4	-	
			Jacob Straight Line (late time)	334	13.9	-	
		MD0790	Jacob Straight Line (early time)	4506*	187.7*	8.3x10-5	
			Jacob Straight Line (late time)	4506*	187.7*	8.3x10-5	
	Recovery	MDPB005	Residual Drawdown	111	4.6	-	
		MD0790	Residual Drawdown (late data)	-	-	5.5x10-4	

Pumped Bore (Aquifer Unit)	Test	Monitoring Data	Analytical Method	T (m²/d)	k (m/d)	S	Summary
MDPB006 (Altered Marra Mamba)#	Constant Rate	MDPB006	Estimation from specific capacity	1597	48.4	-	Summary of Analysis Average T = 1817 m²/d Average S = 2.8x10-3 Average k = 55.1 m/d b = 33 m
			Jacob Straight Line (early time)	3117	94.4	-	
			Jacob Straight Line (late time)	836	25.3	-	
		MD1297	Jacob Straight Line (early time)	3117	94.4	3.9x10-3	
			Jacob Straight Line (late time)	945	28.6	1.2x10-3	
	Recovery	MDPB006	Residual Drawdown	1914	58	-	
		MD1297	Residual Drawdown (late data)	2797	84.8	-	
MDPB0011 (Upper Calcrete & Undiff Tert / Alluvial Fan)	Constant Rate	MDPB0011	Cooper-Jacob early time	528	44	-	Summary of Analysis Average T = 399 m²/d Average Sy = 0.2% Average k = 33 m/d b = 12 m
			Cooper-Jacob late time	174	15	-	
			Theis	327	27	-	
		MDPB7450C	Theis	298	25	0.2%	
	Recovery	MDPB0011	Theis	642	54	-	
		MDPB7450C	Theis	701	58	-	
MDPB0012 (Pisolite / Hardcap)	Constant Rate	MDPB0012	Cooper-Jacob	843	22	-	Summary of Analysis Average T = 805 m²/d Average S = n/a Average k = 21 m/d b = 38 m
			Theis	785	21	-	
		MDPZ7449B	Theis	5078*	134*	-	
	Recovery	MDPB0012	Theis	788	21	-	
MDPB0013 (Marra Mamba)	Constant Rate	MDPB0013	Cooper-Jacob	556	12	-	Summary of Analysis Average T = 441 m²/d Average S = n/a Average k = 10 m/d b = 46 m
			Theis	689	15	-	
		MDPZ7460A	Theis	6361*	138*	-	
	Recovery	MDPB0013	Theis	346	8	-	
		MDPZ7460A	Theis	285	6	-	
MDPB0014 (Upper Calcrete)	Constant Rate	MDPB0014	Cooper-Jacob	1881	63	-	Summary of Analysis Average T = 1900 m²/d Average Sy = n/a Average k = 63 m/d b = 30 m
			Theis	1591	53	-	
			Theis	1941	65	-	
		MDPZ7457C	Theis	1950	65	1.20E-07*	
	Recovery	MDPZ7457C	Theis	2185	73	-	

Pumped Bore (Aquifer Unit)	Test	Monitoring Data	Analytical Method	T (m^2/d)	k (m/d)	S	Summary
MDPB0015 (Undiff Tertiary)	Constant Rate	MDPB0015	Theis	12380	688	-	Summary of Analysis Average T = 6573 m^2/d Average S = n/a Average k = 365 m/d b = 18 m
		MDPZ7452B	Theis	15250	847	-	
	Recovery	MDPB0015	Theis	1504	84	-	
MDPB0016 (Undiff Tert / CID / Basal Crete / Mineralised MM)	Constant Rate	MDPB0016	Cooper-Jacob early time	647	8	-	Summary of Analysis Average T = 819 m^2/d Average S = 4x10^{-5} Average k = 10 m/d b = 78 m
			Hantush-Jacob (Leaky)	619	8	-	
		MDPZ7469B (MM only)	Hantush-Jacob (Leaky)	619	8	0.00005	
			Cooper-Jacob early time	731	9	2.37E-05	
			Cooper-Jacob early time (manual)	1265	16	-	
		MDPZ7469C (Undiff Tert / CID)	Cooper-Jacob early time (manual)	1265	16	0.007	
	Recovery	MDPB0016	Theis (recovery)	585	8	-	
MDPB0017 (CID / Mineralised MM)	Constant Rate	MDPB0017	Cooper-Jacob early time	4433	57	-	Summary of Analysis Average T = 4669 m^2/d Average S = 8x10^{-4} Average k = 57 m/d b = 78 m
			Cooper-Jacob early time (manual)	2875	37		
			Theis	3524	45	-	
		MDPZ9204	Cooper-Jacob early	6426	82	5.38E-04	
			Theis	6086	78	0.0011	
		MDPZ7456B	Theis	10150*	145*	0.001533*	
MDPB0018 (CID / Unmin MM)	Constant Rate	MDPB0018	Cooper-Jacob early time	751	10	-	Summary of Analysis Average T = 1065 m^2/d Average S = 4x10^{-3} Average k = 13 m/d b = 78 m
			Theis	996	14		
		MDPZ9733	Cooper-Jacob early time	732	10	0.0004	
			Theis	535	7	0.0006	
		MDPZ9206 (sealed at depth, MM only)	Theis	1741	24	0.0085	
			Cooper-Jacob early time	1785	24	0.006	
	Recovery	MDPB0018	Theis (recovery)	915	13	-	
		MDPZ9206 (sealed at depth, MM only)	Theis (recovery)	2420*	33*	-	

Pumped Bore (Aquifer Unit)	Test	Monitoring Data	Analytical Method	T (m^2/d)	k (m/d)	S	Summary
MDPB0019 (CID / Unmin MM)	Constant Rate	MDPB0019	Cooper-Jacob early time	720	19	-	Summary of Analysis Average T = 722 m^2/d Average S = $1.4x10^{-3}$ Average k = 19 m/d b = 38 m
			Theis	708	19	-	
			Hantush-Jacob (Leaky)	698	18	-	
		MDPZ9207	Cooper-Jacob early time	693	18	0.0013	
			Theis	680	18	0.0013	
			Hantush-Jacob (Leaky)	698	18	0.0015	
	Recovery	MDPB0019	Theis (recovery)	859	23	-	
MDPB0020 (Hardcap / Dolomite)	Constant Rate	MDPB0020 (Sealed below Basal Crete)	Cooper-Jacob early time	5238	125	-	Summary of Analysis Average T = 5516 m^2/d Average S = 0.04 Average k = 131 m/d b = 42 m
			Theis	6388	152	-	
		MDPZ9212D	Cooper-Jacob early time	5455	130	0.1467	
			Hantush-Jacob (Leaky)	5783	138	0.0113	
		MDPZ9212S	Hantush-Jacob (Leaky)	9510*	226*	0.001335*	
		MDPZ5355	Cooper-Jacob early time	5663	135	0.0008	
			Hantush-Jacob (Leaky)	4740	113	0.0003	
	Recovery	MDPB0020 (Sealed below Basal Crete)	Theis (recovery)	5342	127	-	

T = transmissivity, S = Storativity (for confined aquifers), Sy = Specific Yield (for unconfined aquifers), k = permeability, b = saturated aquifer thickness

MM = Marra Mamba Formation

Representative storage values (S and Sy) could not always be derived from the test data.

Average = geometric mean

Analyses results for bores MDPB001 to MDPB006 taken from MWH reports (MWH 2009 & 2014).

* Data considered to be outliers and not included in statistics.

Table 6.2 Hydraulic Parameters from all Hydraulic Testing

Hole ID	Cased Depth (m)	Screened Geology	Max Drilled Airlift Yield (L/s)	Completed Airlift Yield (L/s)	Testing Method	Effective T (m^2/d)		Aquifer Thickness (m)	k (m/d)		Average k (m/d)
						Pumping	Recovery		Pumping	Recovery	
MDPZ7452C	32	Upper Calcrete	7	2	Micro CRT	237		27	8.79		
MDPZ7453C	17	Upper Calcrete	5	0.8	Micro CRT	474	316	11	43.13	28.75	
MDPZ7457C	35	Upper Calcrete	14	2.8	Micro CRT	237	237	25	9.49	9.49	
MDPZ7458C	41	Upper Calcrete	20	0.5	Airlift Recov		26	12		2.20	
MDPZ7462C	35	Upper Calcrete	12.2	1.23	Micro CRT	700	9804**	27	25.94		10
MDPZ7470C	23	Upper Calcrete	6	2.2	Micro CRT	79		16	4.94		
MDPZ7471C	21	Upper Calcrete	4.4	1.2	Micro CRT	107	96	14	7.66	6.89	
MDPB0014	35	Upper Calcrete	12	8	CRT	1900		30	63		
MDPZ7449C	10.65	Upper Silcrete (+ Pisolititic Clay)	0.1	0.01	Micro CRT	22	23	6	4.00	4.21	
MDPZ7459	28	Alluvial Fan Gravel (Undiff Tert)	3.5	0.4	Micro CRT	95	79	17	5.63	4.69	
MDPZ7450C	22	Undiff Tertiary	5	0.7	Micro CRT	119	237	14	8.47	16.94	
MDPZ7451C	44	Undiff Tertiary	5	1.4	Micro CRT	264	158	32	8.24	4.94	
MDPZ7460C	29.3	Undiff Tertiary	3.7	1.4	Micro CRT	316	506	17	18.28	29.25	
MDPZ7469C	52.5	Undiff Tertiary	4.3	2.2	Micro CRT	207	134	46	4.53	2.94	
MDPZ7470B	49.1	Undiff Tertiary	10	1.8	Micro CRT	117	201	25	4.64	8.02	8
MDPZ7462B	58.5	Undiff Tertiary	12	1.8	Micro CRT	41		23	1.82		
MDPZ7468C	52	Undiff Tertiary	11.2	2.1	Micro CRT	101	101	34	2.98	2.98	
MDPB0011	23.5	Undiff Tertiary / Upper Calcrete	2.9	3.8	CRT	399		12	33		
MDPB0015	52	Undiff Tertiary	50	30	CRT	6573		18	365		
MDPZ7470B	49.1	Undiff Tertiary	10	1.8	Airlift Recov		114	25		4.54	

Hole ID	Cased Depth (m)	Screened Geology	Max Drilled Airlift Yield (L/s)	Completed Airlift Yield (L/s)	Testing Method	Effective T (m^2/d)		Aquifer Thickness (m)	k (m/d)		Average k (m/d)
						Pumping	Recovery		Pumping	Recovery	
MDPZ7450B	42	CID/Pisolite	5	1.6	Micro CRT	474.41	237.20	22	21.56	10.78	
MDPZ7453B	48	CID/Pisolite & Undiff Tertiary	22	2.4	Micro CRT	158.14	237.20	23.5	6.73	10.09	
MDPZ7456C	41	CID/Pisolite & Undiff Tertiary	10	1.1	Micro CRT	196.79	553.48	37	5.32	14.96	
MDPZ7458B	52	CID/Pisolite	20	2.75	Airlift Recov		830.22	9		92.25	14
MDPB0012	46.5	Pisolite / CID / Hardcap	15	15	CRT	805		38	21		
MDPZ7457B	59	CID/Pisolite & Basal Calcrete	20	3.5	Micro CRT	237.20	296.51	24	9.88	12.35	
MDPZ7453A	72.5	Basal Calcrete	25	3	Micro CRT	276.74	184.49	23	12.03	8.02	
MDPZ7453A	72.5	Basal Calcrete	25	3	Airlift Recov		94.88	23		4.13	
MDPZ7451B	62	Basal Calcrete	10	1.5	Micro CRT	39.53	47.44	12	3.29	3.95	9
MDPZ7468B	65	Basal Calcrete / Silcrete	15.2	2.8	Micro CRT	126.51	168.68	11	11.50	15.33	
MDPZ7452A	72	Basal Calcite & Dolomite	45	3.5	Airlift Recov		737.97	22.5		32.80	
MDPZ9206	89	Unmin MM / Jeerinah	16	5.5	Mini CRT	822		30	27.40		
MDPZ9208	74	Unmin MM / Jeerinah	16	5.5	Mini CRT	633		36	17.58		
MDPZ9209	70	Unmin MM (no inc yield in Jeerinah)	8	4.5	Mini CRT	216		32	6.76		
MDPZ9210	80	Unmin MM (Jeerinah)	35	10	Mini CRT	513		36	14.25		
MDPZ7450A	102	Unmin MM (below CID)	35	1.95	Micro CRT	95	237	44	2.16	5.39	10
MDPZ7456A	120	Unmin MM (deep)	20	2.75	Micro CRT	44	43	20	2.21	2.13	
MDPB004	54.5	Unmin MM/ Jeerinah	6	unknown	CRT	4526		26	174		
MDPB005	62	Unmin MM (below CID)/Jeerinah	14	unknown	CRT	205		24	8.5		
MDPB0013	112	Unmin MM (down dip of pit)	21	10	CRT	441		52	8.5		
MDPB0019	77	Unmin MM / Jeerinah	24	10	CRT	722		32	23		

<table>
<tr><th rowspan="2">Hole ID</th><th rowspan="2">Cased Depth (m)</th><th rowspan="2">Screened Geology</th><th rowspan="2">Max Drilled Airlift Yield (L/s)</th><th rowspan="2">Completed Airlift Yield (L/s)</th><th rowspan="2">Testing Method</th><th colspan="2">Effective T (m²/d)</th><th rowspan="2">Aquifer Thickness (m)</th><th colspan="2">k (m/d)</th><th rowspan="2">Average k (m/d)</th></tr>
<tr><th>Pumping</th><th>Recovery</th><th>Pumping</th><th>Recovery</th></tr>
<tr><td>MDPB0018</td><td>91</td><td>Undiff Detritals /CID/Unmin Marra Mamba</td><td>42</td><td>38</td><td>CRT</td><td colspan="2">1065</td><td>78</td><td colspan="2">13</td><td rowspan="2">24</td></tr>
<tr><td>MDPB006</td><td>60</td><td>CID (2m) / Unmin MM</td><td>15</td><td>unknown</td><td>CRT</td><td colspan="2">1817</td><td>33</td><td colspan="2">55</td></tr>
<tr><td>MDPZ7469A</td><td>101</td><td>MM (below main ore zone)</td><td>>25</td><td>2.1</td><td>Micro CRT</td><td></td><td>115</td><td>11</td><td></td><td>10.46</td><td rowspan="4">13</td></tr>
<tr><td>MDPZ7469A</td><td>101</td><td>MM (below main ore zone)</td><td>>25</td><td>2.1</td><td>Airlift Recov</td><td></td><td>369</td><td>11</td><td></td><td>33.54</td></tr>
<tr><td>MDPZ7456B</td><td>62</td><td>Mineralised MM (upper)</td><td>20</td><td>3</td><td>Micro CRT</td><td>138</td><td>89</td><td>18</td><td>7.69</td><td>4.92</td></tr>
<tr><td>MDPB002</td><td>32</td><td>Mineralised MM (poss. Detritals)</td><td>unknown</td><td>unknown</td><td>CRT</td><td colspan="2">405</td><td>16</td><td colspan="2">25</td></tr>
<tr><td>MDPB001</td><td>55</td><td>CID / Mineralised MM</td><td></td><td></td><td>CRT</td><td colspan="2">1149</td><td>48</td><td colspan="2">24</td><td rowspan="3">24</td></tr>
<tr><td>MDPB0016</td><td>88</td><td>CID / Mineralised MM / Jeerinah</td><td>27.5</td><td>40</td><td>CRT</td><td colspan="2">819</td><td>78</td><td colspan="2">10</td></tr>
<tr><td>MDPB0017</td><td>100</td><td>Undif Tert/CID/Mineralised MM</td><td>60</td><td>45</td><td>CRT</td><td colspan="2">4669</td><td>78</td><td colspan="2">57</td></tr>
<tr><td>MDPB0020</td><td>112.5</td><td>West Angela / Fault? (Hardcap/Shale/Dolomite/Chert)</td><td>~140</td><td>50</td><td>CRT</td><td colspan="2">5516</td><td>42</td><td colspan="2">131</td><td>131</td></tr>
<tr><td>MDPZ9215D</td><td>130</td><td>Hardcap / West Angela (Min & Unmin)</td><td>47</td><td>12</td><td>Airlift Recov</td><td>1898</td><td>3795</td><td>66</td><td>28.75</td><td>57.50</td><td rowspan="4">20</td></tr>
<tr><td>MDPZ9216</td><td>119.5</td><td>Hardcap / West Angela (Min)</td><td>34</td><td>8</td><td>Airlift Recov</td><td>633</td><td>1265</td><td>45</td><td>14.21</td><td>28.43</td></tr>
<tr><td>MDPZ7470A</td><td>104</td><td>Hardcap / West Angela</td><td>>30</td><td>4</td><td>Airlift Recov</td><td></td><td>553</td><td>40</td><td></td><td>13.94</td></tr>
<tr><td>MDPZ7471A</td><td>78</td><td>Hardcap / West Angela</td><td>43</td><td>3.3</td><td>Micro CRT</td><td>148</td><td></td><td>14</td><td>10.54</td><td></td></tr>
<tr><td>MDPZ7454</td><td>58</td><td>Jeerinah</td><td>0.3</td><td>0.3</td><td>Falling Head</td><td>0.68</td><td></td><td>44</td><td>0.015</td><td></td><td rowspan="2">0.02</td></tr>
<tr><td>MDPZ7455</td><td>60</td><td>Jeerinah</td><td>1.25</td><td>0.25</td><td>Falling Head</td><td>0.83</td><td></td><td>48</td><td>0.017</td><td></td></tr>
<tr><td>MDPZ7466</td><td>64.8</td><td>Fresh Marra Mamba / Jeerinah</td><td>4.8</td><td>0.02</td><td>Falling Head</td><td>0.42</td><td></td><td>27</td><td>0.015</td><td></td><td rowspan="2">0.02</td></tr>
<tr><td>MDPZ7467</td><td>64</td><td>Fresh Marra Mamba / Jeerinah</td><td>3.5</td><td>0</td><td>Falling Head</td><td>0.58</td><td></td><td>27</td><td>0.022</td><td></td></tr>
</table>

* Parameters are only derived from Recovery data for Airlift Recovery and Falling Head Tests. Drawdown data has significant “noise” resulting from the airlifting process, therefore the recovery provides better data for analysis; whilst falling head tests comprise the monitoring of the aquifer recovery to the instantaneous rise in water levels (in this case by introducing water into the bore).
** Considered outliers and not included in statistics.
+ permeable horizon limited to 60 to 70 m.
Average = geometric mean
MM = Marra Mamba Formation

A total of 79 estimates for aquifer permeability (k) relating to the identified hydrostratigraphic units have been derived from all studies to date. Permeability generally follows a log-normal distribution and estimates of mean permeability and the standard deviation have been derived for the log of permeability. Table 6.3 summarises the derived mean, maximum and minimum permeability values for each tested hydrostratigraphic unit, with the maximum and minimum values based on 90% confidence limits (assessed using the two-tailed Student's t-test); these values have been converted from the analysis on the log-normal distribution.

Table 6.3 Summary of Aquifer Permeability Values Derived from Testing

Hydrostratigraphic Unit	No. of Tests	Min k (m/d)	Mean k (m/d)	Max k (m/d)	Adopted k (m/d)
Upper Calcrete	13	6.29	10.34	17.00	10
Undifferentiated Tertiary	18	5.00	8.31	13.84	8
CID / Pisolite	10	8.85	14.04	22.26	14
Basal Crete	8	5.06	8.60	14.62	9
Altered MM: Unmineralised / Fractured MM	12	5.03	9.75	18.89	10
Altered MM: Ore	8	9.22	16.11	28.14	25*
WA Hardcap	6	12.77	21.48	36.12	20
Jeerinah (Fresh Jeerinah / MM)	4	0.014	0.017	0.021	0.01

*Updated based on model calibration to test pumping (Refer AQ2 2024)
Maximum and minimum values based on 90% confidence limits (assessed using the two-tailed Student's t-test)
MM = Marra Mamba Formation

6.3 Hydraulic Response During Pumping Tests

The pumping tests on the 2018/2019 production bores and recorded data at the associated monitoring bores also provided information with respect to the hydraulic connection of the hydrostratigraphic units. The key findings are summarised below:

- MDPB0011 - The drawdown and water quality data indicate hydraulic connection between the Tertiary and bedrock units at this location despite an interval of pisolitic clay underlying the pumped aquifer.
- MDPB0012 - The flattening of the drawdown curve for the pumped unit and increased rate of drawdown at MDPZ7449C after approximately 1000 minutes, indicated leakage from the Upper Calcrete through the underlying pisolitic clay.
- MDPB0013 – Results indicated much of the pumped water, when pumping from the Marra Mamba bedrock, is sourced from the overlying units, where the groundwater is less saline.
- MDPB0014 - Although most of the water abstracted from the pumping bore is sourced laterally from the Upper Calcrete unit, it also appears that the reduction in pressure from pumping allows up-coning of higher salinity groundwater at depth. This up-coning is insufficient to report to the pumping bore, although it is recorded in the deeper monitoring bore.
- MDPB0015 - The hydrostratigraphic units at this location grade into one another and it appears the entire Tertiary sequence, together with the underlying dolomite, are in hydraulic connection. The salinity of the pumped water suggests it is predominantly sourced laterally and from overlying units where the groundwater is less saline.

From the 2021 investigations, the installation and pumping test on MDPB0016 was specifically to assess the potential for the up-coning of saline water when pumping from the mineralised Marra Mamba in a proposed pit area. The salinity of the pumped water did not show an increasing trend during the constant rate test (with salinity readings fluctuating between 3,400 and 3,500 µS/cm). However, as shown in Figure 6.7, salinity profiles for the pumped bore show increasing salinities at depth from before the step rate test (5660 µS/cm), before the constant rate test (7135 µS/cm) and after the constant rate test (8000 µS/cm), potentially indicative of the up-coning of the deeper, more saline groundwater.

Salinity profiles at the adjacent nested monitoring bores are also presented in Figure 6.7. No change in salinity is evident in the shallow monitoring bore (MDPZ7469C), whilst the intermediate monitoring bore (MDPZ7469B) shows a minor increase in salinity from 3,700 to 3,900 µS/cm from before and after the test pumping. The deep monitoring bore (MDPZ7469A) indicates an increase from 18,500 µS/cm before the step rate test to 18,900 µS/cm before the constant rate test and then a decrease in salinity to 17,900 µS/cm following the constant rate test. It is anticipated that the initial increase observed at the MDPZ7469A is probably the result of on-going recovery following the installation of MDPB0016 (rather than due to the short step rate test pumping), whilst the decrease in salinity resulting from the constant rate test may be attributable to the lateral flow of fresher groundwater towards test area.

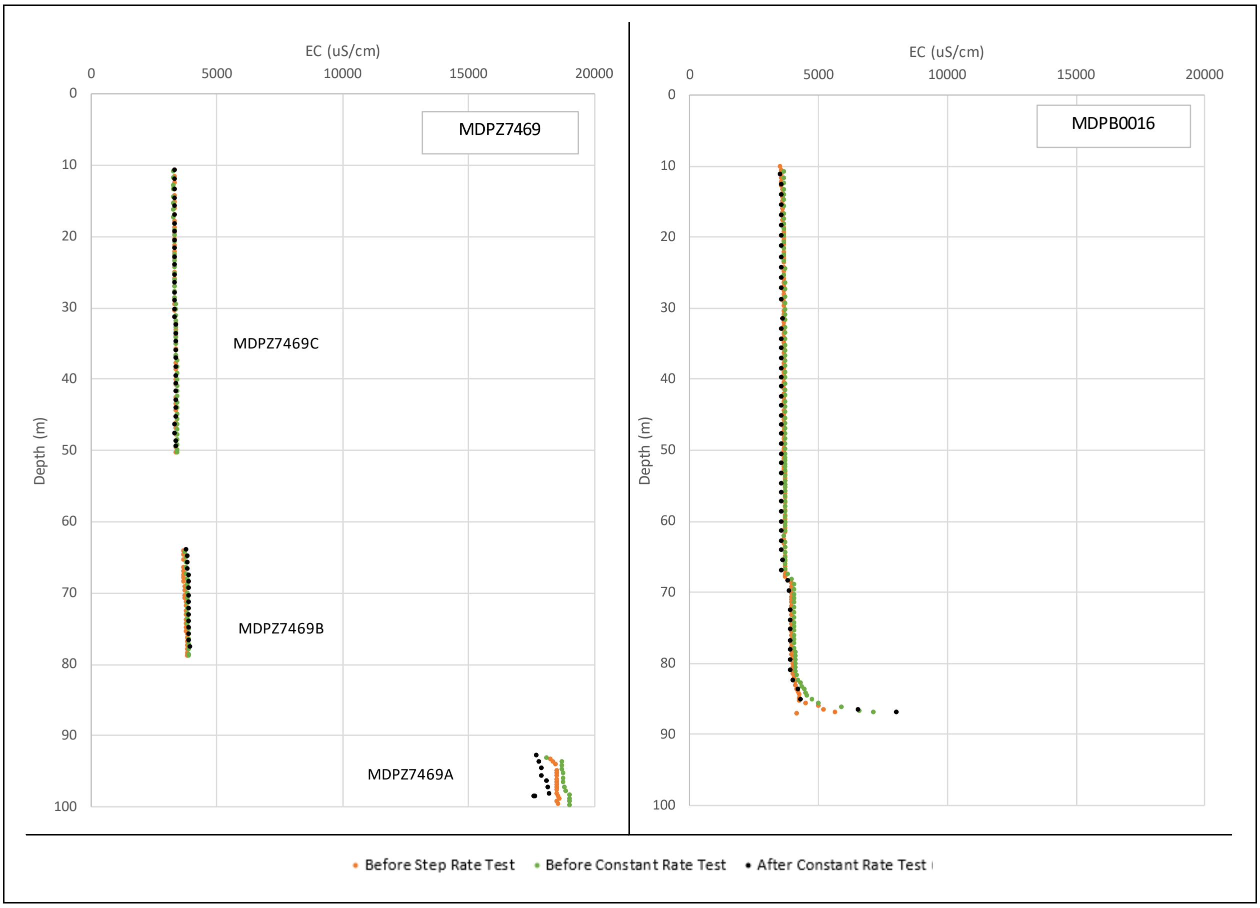


Figure 6.7 Salinity Profiles during the Pumping Test on MDPB0016

6.4 Groundwater Levels and Flow Direction

The surveyed bore collars and measured groundwater levels across the Study Area have been used to plot groundwater level contours (refer Figure 6.8 and Figure 6.9). Additionally, historical site water levels (measured at open mineral exploration holes during previous resource evaluation drilling programmes) and recorded water levels from DWER's database (together with NASA's Shuttle Radar Topography Mission (SRTM) data to set bore elevations) have been used to provide additional guidance to the contouring; noting that the SRTM data has been found to be inaccurate in this area, when compared to the bore survey data.

The water table elevation across the extended Study Area (inclusive of Mulga West) ranges between approximately 385 mRL and 420 mRL, The depth to groundwater In the Mulga East / Malay Well area, the hydraulic gradient is gentle across the lower lying areas, indicative of transmissive aquifers, and steepens along the northern boundary of the Study Area, indicative of lower permeability units (which is consistent with the presence of the Jeerinah Formation and fresh Marra Mamba aquitard). The transition from the Jeerinah aquitard to the Altered Marra Mamba aquifer may also be responsible for the abrupt bends observed in the groundwater contours in the northern Mulga East area (refer Figure 6.9). Hydraulic gradients also steepen down gradient of the Study Area, at the western end of Mulga West, indicative of a less transmissive setting, the narrowing of the valley and / or additional groundwater throughflow (from the Hamersley Ranges / Hamersley Gorge). Localised areas of minor groundwater mounding or potential preferential flow along more permeable structures may be present across the Mulga East orebody area, however, there is insufficient geological and hydrogeological data to validate this concept.

The depth to groundwater is presented in Figure 6.10. This has been derived from available LiDAR data and the contoured groundwater level surface for December 2021 (Figure 6.8). In the Mulga East / Malay Well area the depth to groundwater is shallow in the lower lying, valley areas at approximately 3 and 5 mbgl and increases with elevation, to depths of up to 45 mbgl (at MDPZ7467) in the more elevated areas (i.e. to the north of the inferred resource area). Although no drilling has taken place on the claypans and at the channel pools due to the environmental and cultural heritage significance of these areas, the derived depth to water (i.e. Figure 6.10) indicate these features are not groundwater-related. Further discussion regarding the conceptualisation of the claypans is presented in Sections 4 and 10.

In assessing the vertical gradients between adjacent bores installed at different depths (i.e. the clustered and paired bores), only the manual piezometric measurements (taken after bore installation and during each monitoring round) have been considered due to the potential variations in accuracy with the different depth ratings of pressure transducers. The majority of bores show minimal differences in piezometric head indicating hydraulic connection between the measured overlying / underlying units.

Vertical gradients are only evident at seven cluster bore locations from the 2018/2019 field programme (MDPZ7449, 7451, 7457, 7460, 7462, 7469 and 7471) where the screened units of the bores are separated by an intervening low permeability material, with thicknesses ranging between 2 and 30 m. The distribution of vertical hydraulic gradients within the sequence varies spatially although without any specific trend or distribution. This is believed to be a result of the variable distribution of permeability within the Tertiary deposits.

Only two paired monitoring bore completions were installed during the 2021 drilling programme (MDPZ9212D & S and MDPZ9215D & S) and both locations show downward hydraulic gradients. The collars of the 2023 bores have yet to be surveyed to accurately assess vertical gradients.

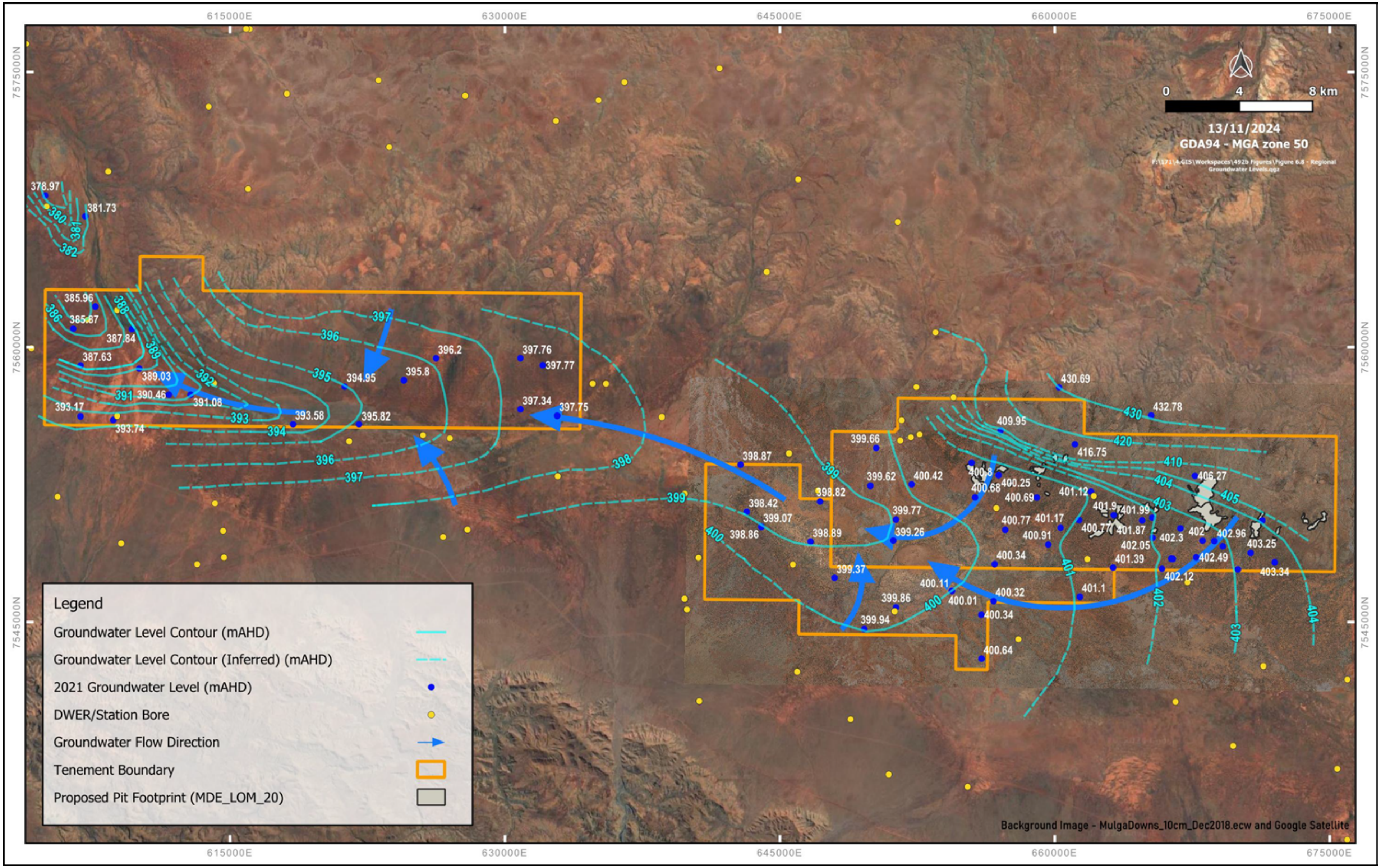


Figure 6.8 Regional Groundwater Level Contours (December 2021)

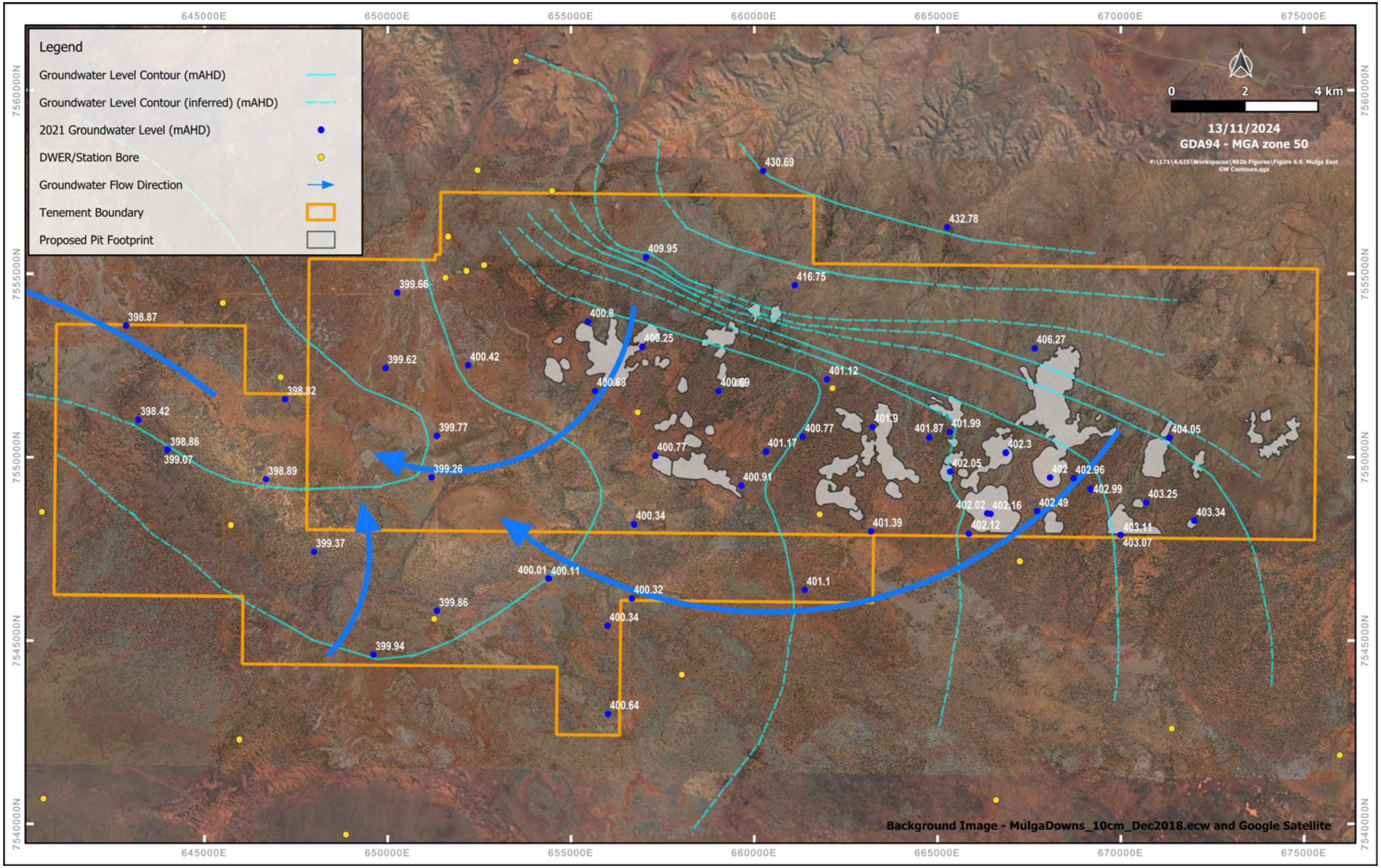


Figure 6.9 Groundwater Level Contours across Mulga East & Malay Well (December 2021)

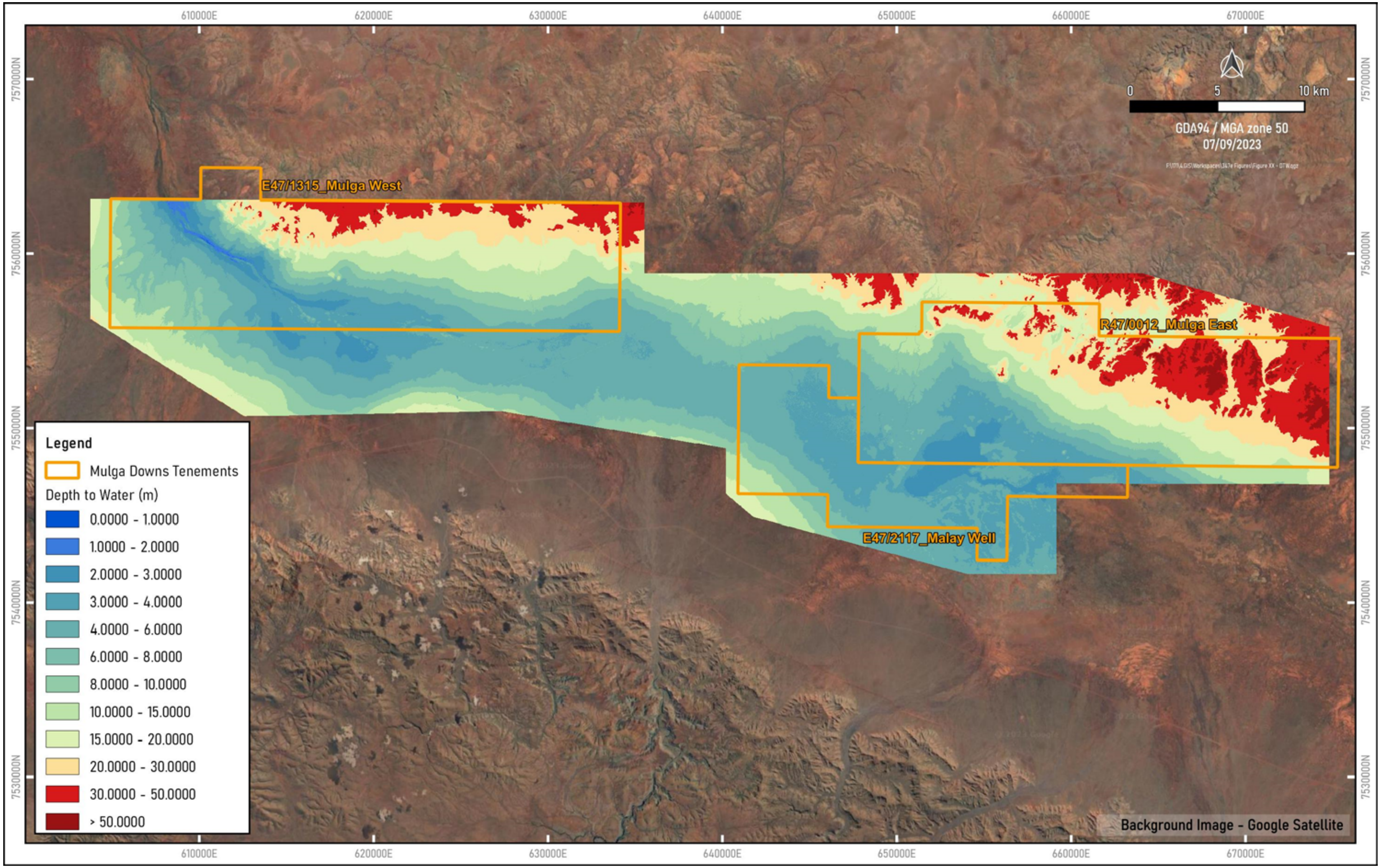


Figure 6.10 Regional Depth to Groundwater (December 2021)

6.5 Groundwater Level Changes

The time-series water level data for bores near to cross-sections B, C and D (refer Figure 6.5 for locations) are presented in hydrographs in Figure 6.11 to Figure 6.13, with hydrographs for the Fridge Hill and Horseshoe Hill areas presented in Figure 6.14 and Figure 6.15 respectively. In addition, Figure 6.16, Figure 6.17 and Figure 6.18 present hydrographs for the Koodjeepindarranna Claypan, Gnalka Gnoona Claypan and Mulga West areas respectively. The following salient observations can be made:

- All bores show varying responses to the rainfall events that have occurred over the monitoring period from January 2019 to November 2023. However, there has not been a significant cyclonic rainfall event during the monitoring period to observe the associated groundwater responses.
- Despite the seasonal fluctuations, all bores show an overall declining trend in water levels over the monitoring period.
- Bores MDPZ7454, 7455, 7466 and 7467, installed in low permeability Marra Mamba and / or Jeerinah Formations on the upper slopes, show a subdued and delayed response to the rainfall events, with only minimal seasonal fluctuation at MDPZ7466 and 7467, in the Fridge Hill / Horseshoe areas.
- Bore MDPZ7459, a shallow bore (20 m deep) in the northern alluvial fan between the two claypans, shows a significant but delayed response to the rainfall events.
- A declining trend in water levels is generally evident at all bores following the 2020/21 wet season, however, many bores show a rapid response to the small November / December 2021 rainfall event. Bores presenting this response are screened against either bedrock or the deeper Tertiary units (i.e. Basal Crete or CID), whilst adjacent bores installed in Upper Calcrete and / or the Undifferentiated Tertiary units, continue to show a declining trend. This suggests recharge to the deeper units.
- In the Gnalka Gnoona Claypan area (Figure 6.18), the bores show a prolonged period of elevated water levels following the rainfall events during the first half of 2022. This is anticipated to be due to on-going seepage from the ponded water in the claypan.
- At bore MDPZ7471, near the Koodjeepindarranna Claypan, an upward flow gradient is evident through the dry season, whilst manual water level readings in May 2020 indicate a downward flow gradient following the 2019/20 wet season. Although the deeper bores at this location show a rapid response to the December 2021 rainfall event, the 2019/20 data indicates the shallow bore (in the Upper Calcrete) has a greater overall response to the wet season recharge, resulting in the change to a downward gradient. This is consistent with a loss of water from the claypans as seepage to groundwater, however, a similar response is not evident in the 2022-2023 dataset. The same change in hydraulic gradient appears to be evident at MDPZ7462, however, data at this location are limited due to the restricted access to this site.

Longer-term water level data (between December 2008 and December 2021) are available for several monitoring bores across the orebody area and are presented in Figure 6.19, with bore locations shown in Figure 6.20. Although bore completion logs are not available, these mineral exploration holes are cased with 25 mm PVC, with slotted casing assumed to be installed from the water table to total depth.

The long-term hydrographs for these bores show groundwater recession with very limited seasonal response during the period late 2008 to late 2010 when annual rainfall totals were lower (i.e. 316 mm, 325 mm and 231 mm in 2008, 2009 and 2010 respectively, compared to 395 mm in 2018). Thereafter (2011 to 2021), seasonal responses have ranged between ~0.2 and 1.5 m with the latter in response to a cyclonic event in January 2012. The data sets provide valuable baseline data, however, each of these sites will be affected by the proposed mine dewatering operations due to their proximity to the proposed pit locations therefore there are no longer-term data sets (i.e. commencing earlier than 2019) outside of the impact zone.

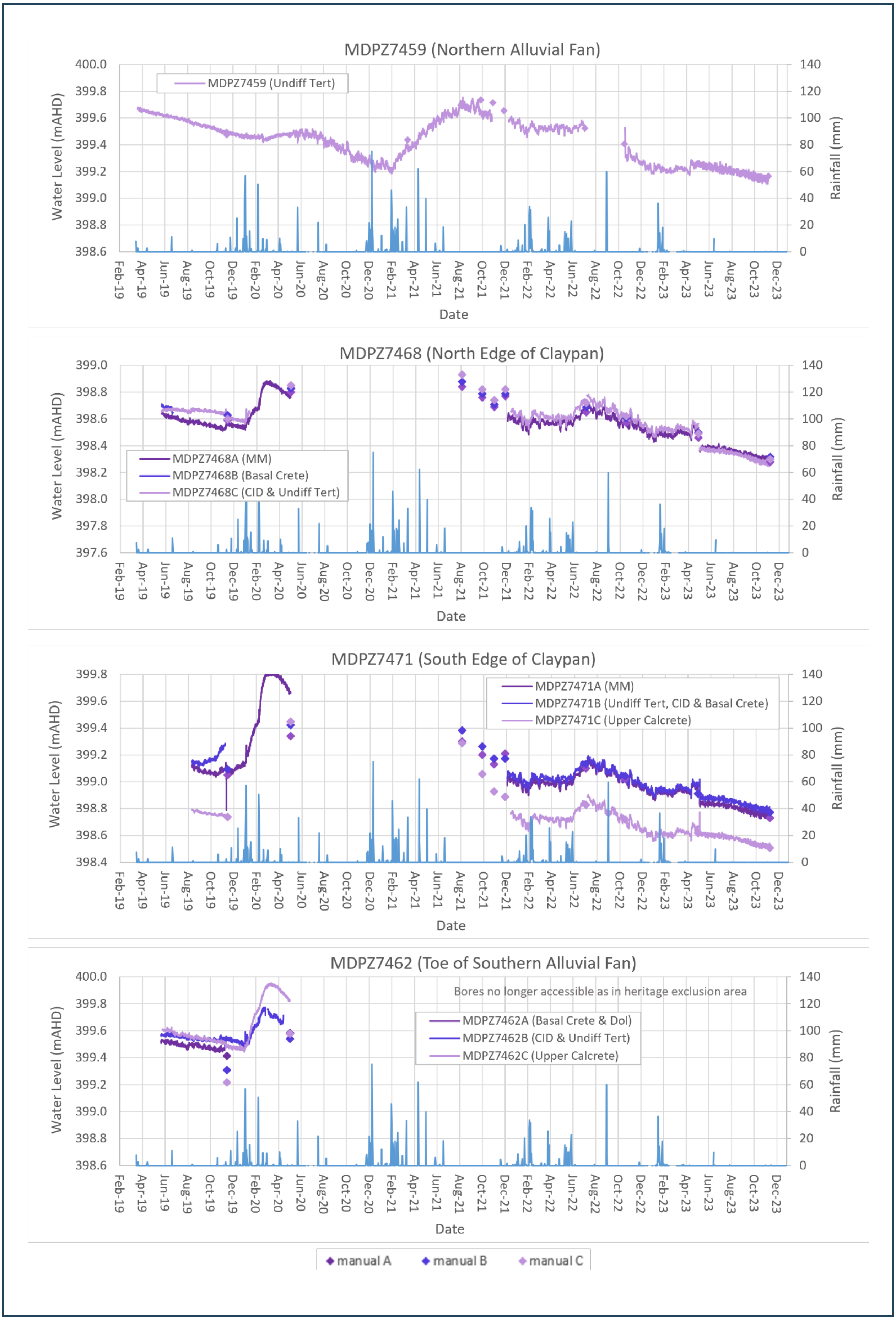


Figure 6.11 Section B Groundwater Level Hydrographs

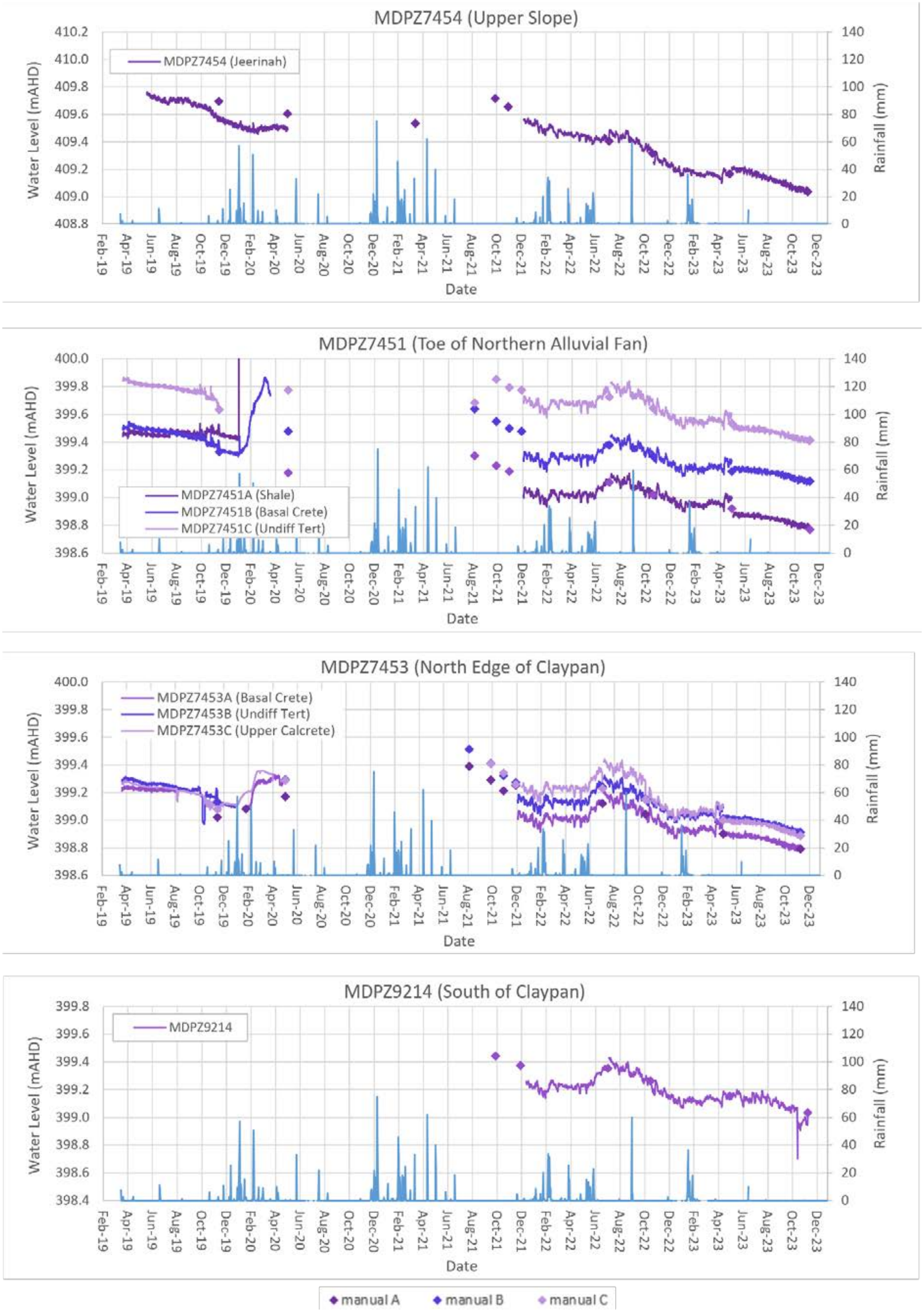


Figure 6.12 Section C Groundwater Level Hydrographs

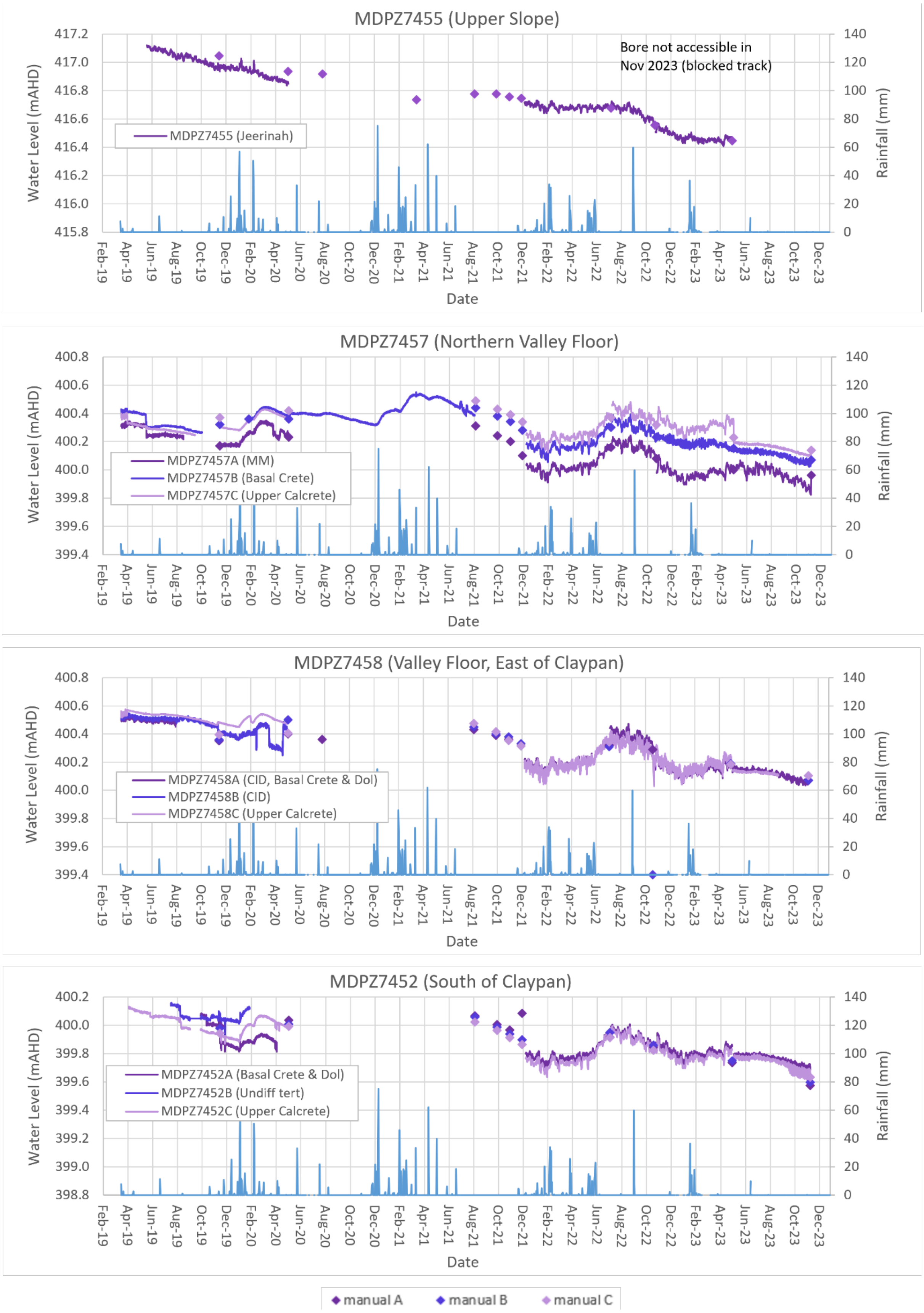


Figure 6.13 Section D Groundwater Level Hydrographs

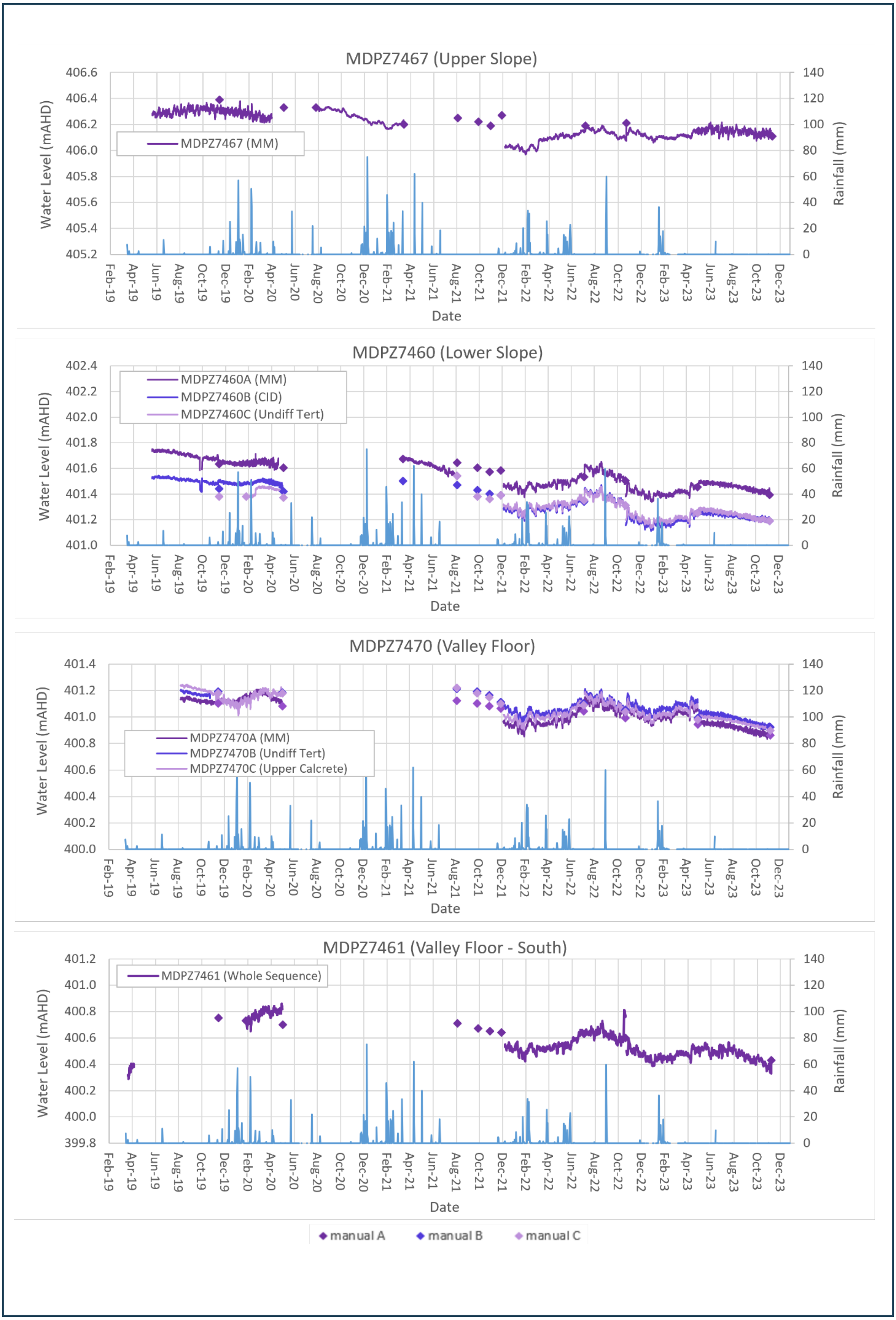


Figure 6.14 Groundwater Level Hydrographs for Extended Fridge Hill Area

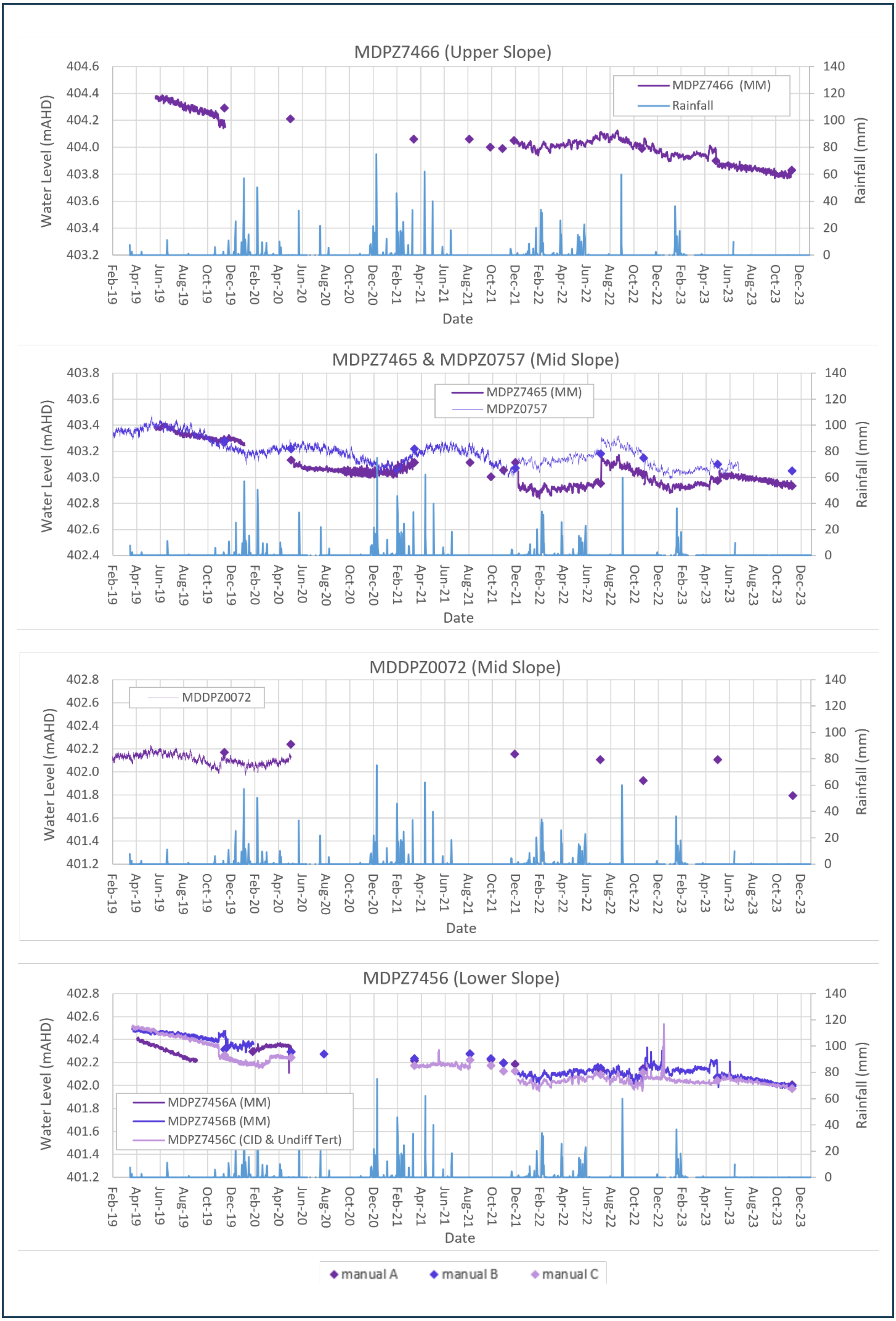


Figure 6.15 Groundwater Level Hydrographs for the Horseshoe Hill Area

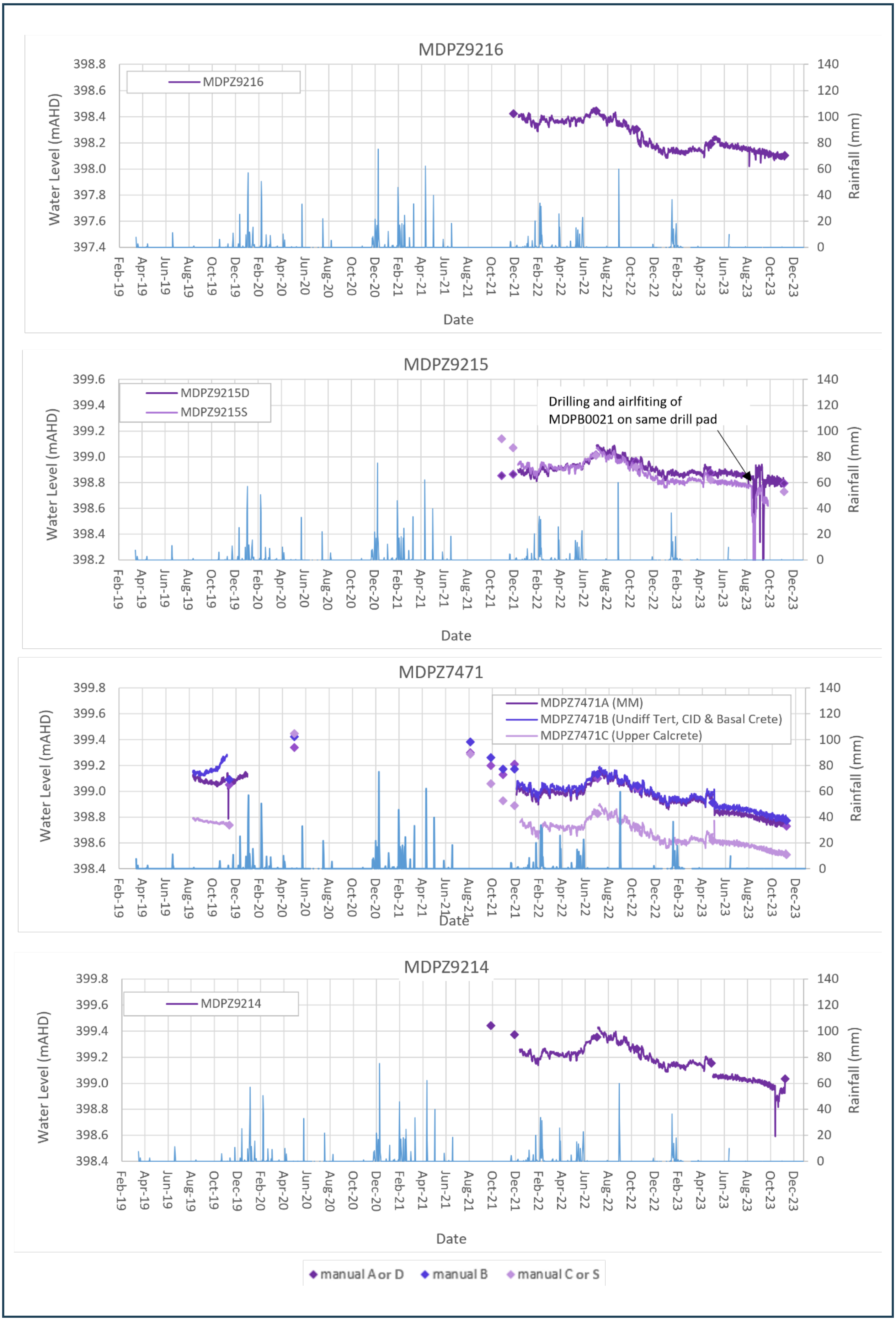


Figure 6.16 Groundwater Level Hydrographs for the Koodjeepindarranna Claypan Area

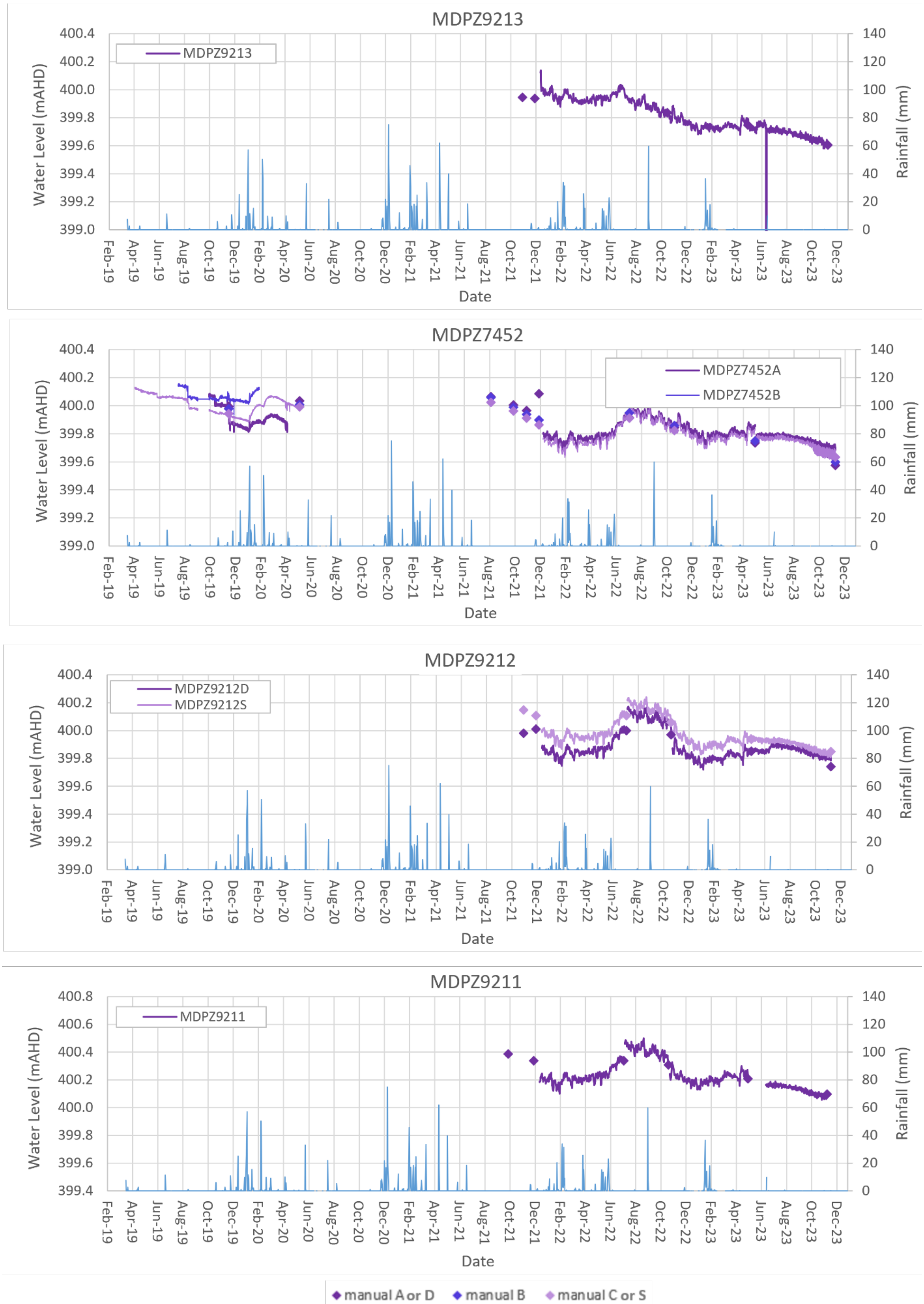


Figure 6.17 Groundwater Level Hydrographs for the Gnalka Gnoona Claypan Area

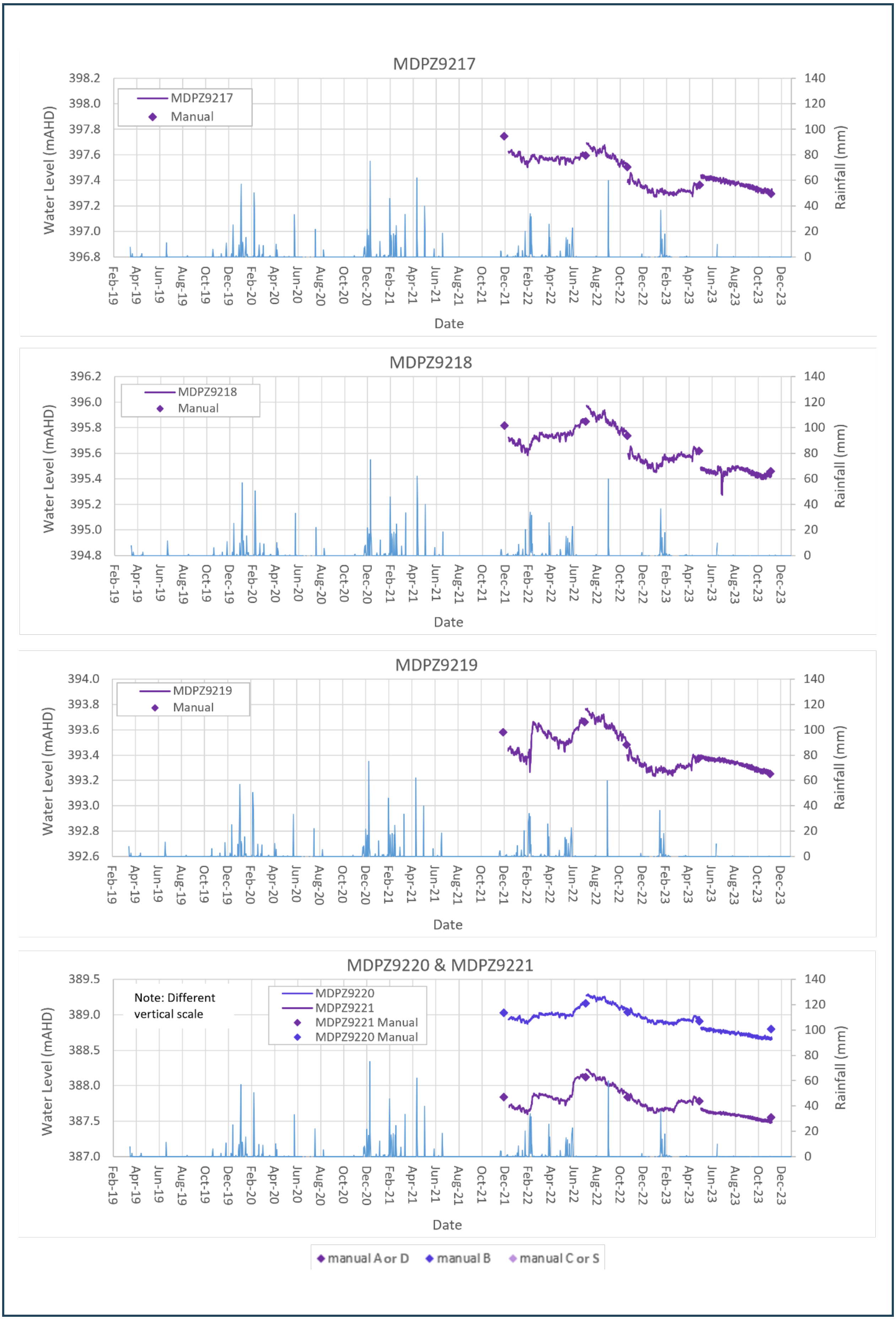


Figure 6.18 Groundwater Level Hydrographs for Mulga West

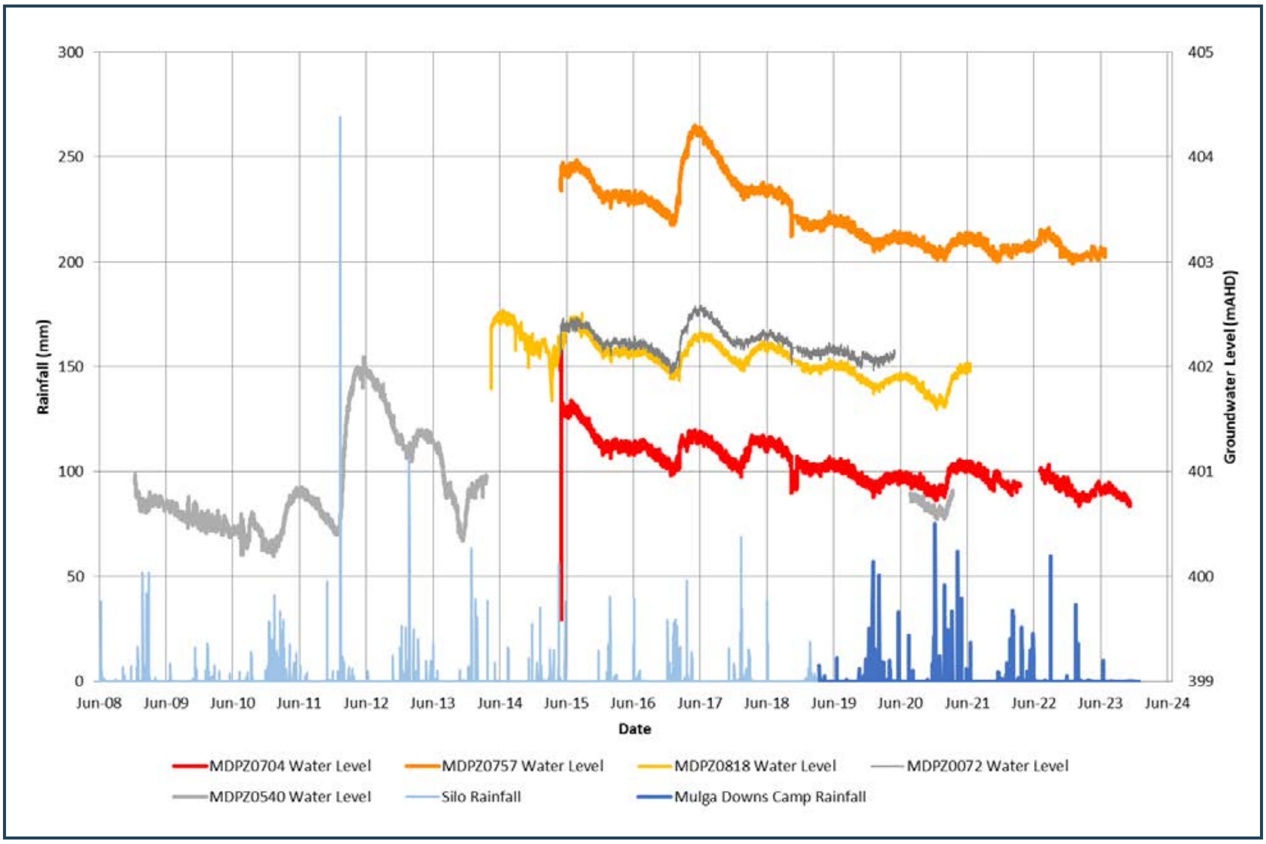


Figure 6.19 Long-term Groundwater Level Hydrographs

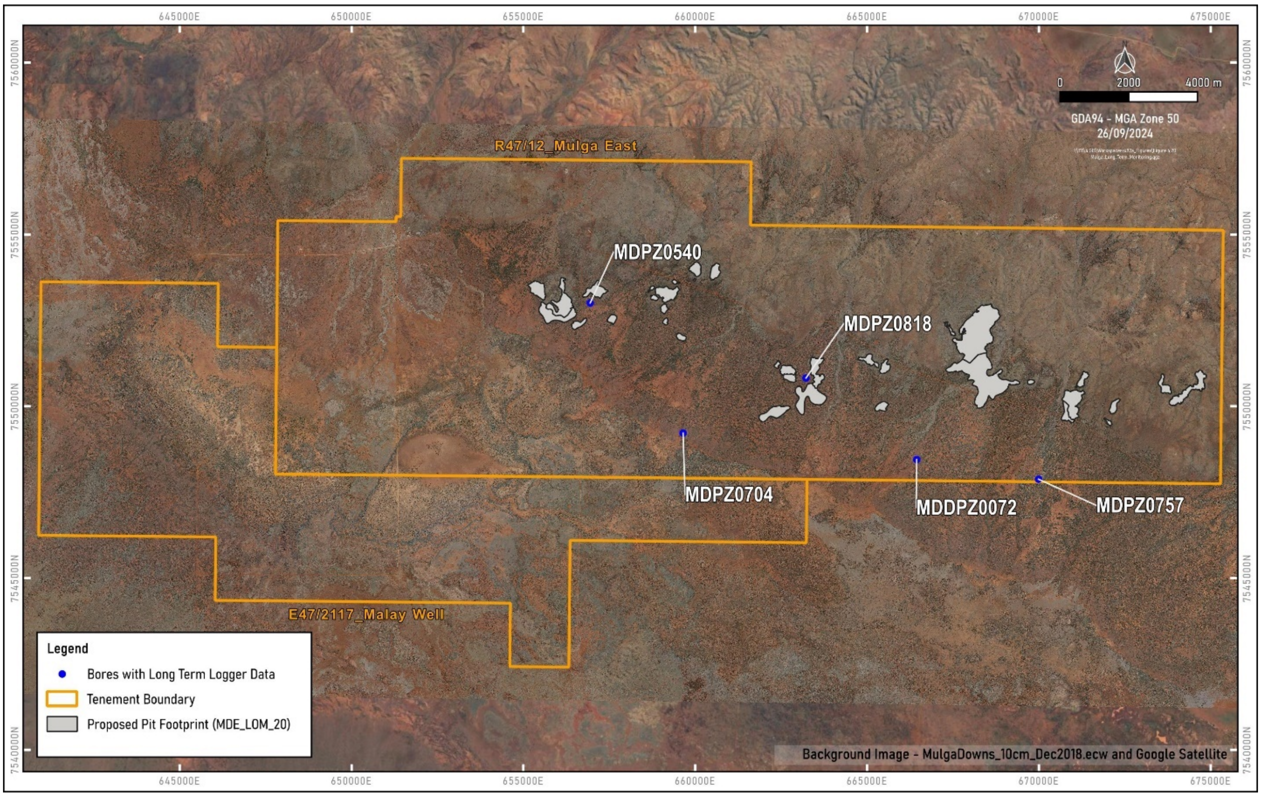


Figure 6.20 Bore Locations for Long-term Groundwater Level Hydrographs

6.6 Groundwater Quality

Groundwater quality data for the Study Area are available from the analysis of water samples, from field readings of salinity during drilling, salinity profiling and some time series data from the installed LTC loggers.

All hydrochemical data from the 2018 to 2023 bore installation programmes and baseline monitoring to November 2023 is presented in Appendix G.

As the shallow groundwater within the Study Area is used for station bores, the hydrochemical data recorded to date have been compared against livestock drinking water guidelines (ANZECC & ARMCANZ 2000), with a summary provided in Table 6.4. Exceedances of aluminium, fluoride and mercury have been recorded at bores where the groundwater salinity is within the preferable drinking water limits for beef cattle (i.e. <5,000 mg/l).

The groundwater across the Study Area ranges from fresh to saline and is generally slightly acidic to slightly alkaline. Concentrations of total dissolved solids (TDS) range from 180 mg/L (EC 300 µS/cm) in the upper reaches of the groundwater system to 17,000 mg/L (EC 23,000 µS/cm) in the valley area. The pH of the groundwater generally ranges between 5.9 and 8.2, however, in the northeastern most bores, the groundwater seems to be more acidic with values of pH 4.0 and 4.4 recorded at depth at bores MDPZ7466 and MDPZ7467 and pH 3.6 recorded at MDPZ7455. These low pH values are anticipated to be a result of the oxidation of sulphides in the Jeerinah Formation, with oxygenated groundwater flowing through minor local fractures. This is consistent with observations elsewhere in the Pilbara, for example on the Wonmunna Plateau adjacent to the West Angelas mine.

All hydrochemical data from bore installation programmes and baseline monitoring rounds are tabulated in Appendix G and plotted on Expanded Durov Diagrams in Appendix J. The Mulga East / Malay Well hydrochemical data from the most recent monitoring round (November 2023) have been plotted on an Expanded Durov Diagram in Figure 6.21 with all (2019 to 2023) Mulga West hydrochemical data plotted in Figure 6.22. Plotted data show that the groundwater in the Study Area can be categorised into several different water types, with generally little change in the water types between the collected water samples over the baseline monitoring period (refer water types versus time summary in Appendix J). Figure 6.23 shows where these various water types occur spatially; salient points are as follows:

- Bicarbonate dominant groundwater (Water Types 1 and 2) occur at shallow depths at MDPZ7459 and at times at MDPZ7450C, indicative of recharge waters in the vicinity of an alluvial fan in the northeast of the Study Area. The most recent shallow sample from nearby bore MDPZ7464 plots as a Type 3, again indicative of the influence of recharge waters.
- Groundwater across the majority of the Mulga East orebody area, and to the north, predominantly has no dominant cations or anions, indicative of potential mixing of several groundwater types and / or some dissolution / ion exchange (on the clay fraction) during recharge or aquifer residency (Water Types 5 and 6). This groundwater type is also present to the south of the claypan / valley area (at MDPZ9213 and MDPZ9225) and on the northern side of the valley in Mulga West (at MD5461, MD5455, MD6605 and MD5382).
- Groundwater down gradient of the Mulga East orebodies, in the valley area, is generally chloride and sodium dominant (Water Type 9) indicative of an end point ("older") water, suggesting the groundwater has been subjected to evapotranspiration and / or mineral dissolution since it was recharged, or it has been affected by the leaching of salts through the unsaturated zones underlying the claypan areas. This groundwater type extends down-gradient from the claypans and is evident along the Fortescue Valley in Mulga West (at bores MDPZ9217 to MDPZ9221); in this area, the groundwater may also be affected by the leaching of salts evident on the riverbanks.

- Groundwater at MDPZ7466 (shallow) and, at times, at MDPZ7465, on the eastern edge of the Study Area, and at MDPZ7499C (November 2019) and MDPB0012 (at installation), in the Malay Well orebody area, are chloride dominant with no dominant cation (Water Type 8), indicative of the reverse ion exchange of a sodium chloride dominant water. This is likely to have occurred on clay-rich facies in the Tertiary Detritals (as were encountered in bores MDPZ7499C and MDPB0012 fin TD2 / TD3) or weathered shale (as was encountered in bores MDPZ7465 and MDPZ7466).
- The water type at MDPZ7450C has been variable over the monitoring period. The initial sample (in May 2019) was Type 2, thereafter Type 6 (November 2019 and March 2021) and Type 3 (May 2020 and December 2021); the latter indicative of the influence of recharge. More recently (May and November 2023) sampled water is Type 8, indicative of the reverse ion exchange within the Tertiary Detritals.

Table 6.4 Summary of Baseline Groundwater Quality Results Compared to Livestock Drinking Water Guidelines (ANZECC & ARMCANZ 2000)

	Preferable Range / Limit (mg/L)	Trigger Range / Value (mg/L)	Maximum in Study Area (mg/L)	Valley Area (mg/L)	Valley Flanks (mg/L)	Upper Slopes (mg/L)	Comment
TDS#	0 to 5,000*	5,000 to 10,000**	18,000	1,200 to 18,000	300 to 16,000	180 to 1,400	Exceedances at many bores in vicinity of the claypans and at depth on the valley flanks
Calcium		1,000	700	42 to 530	22 to 700	7.1 to 170	
Nitrate	400	1,500	51	<0.01 to 33	0.01 to 51	<0.01 to 23	
Nitrite		30	5.3	0.012 to 5.3	<0.005 to 0.16	<0.05	
Sulfate	1,000	2,000	4,200	230 to 4,200	3 to 3,400	13 to 720	Exceedances in many deep and intermediate bores in the valley and flank areas. < 1,000 mg/L at all shallow bores except the following valley area bores: >1,000 mg/L at MDPZ7449C, MDPZ7458C, MDPZ7468C & MDPZ9212S; >2,000 mg/L at MDPZ7452C & MDPZ7453C (max: 2,700 mg/L)
Aluminium		5	9.6	<0.005 to 0.15	<0.005 to 0.31	<0.005 to 9.6	Exceedances at MDPZ7455 & MDPZ7466 (Upper Slopes) Several bores with Total Aluminium exceeding the trigger value, but only in May 2020.
Arsenic	0.5	5	0.033	<0.001 to 0.025	<0.001 to 0.021	0.015 to 0.033	
Boron		5	5	0.26 to 5	0.19 to 4.4	0.15 to 0.75	Exceedances at MDPZ7451A (valley area)
Cadmium		0.01	0.0021	<0.0001 to 0.0011	<0.001 to 0.0020	0.0001 to 0.0021	
Chromium		1	0.025	<0.001 to 0.025	<0.001 to 0.016	<0.001	
Cobolt		1	0.098	<0.001 to 0.098	<0.001 to 0.014	<0.001 to 0.059	
Copper		1	0.016	<0.001 to 0.002	<0.001 to 0.016	<0.001 to 0.013	
Fluoride		2	11	0.6 to 11	0.2 to 2.8	0.2 to 1.3	Exceedances (2 to 3.5 mg/L) at many bores (predominantly in the valley); those with TDS <5,000 mg/L include: MDPZ7470B, MDPZ7470C, MDPZ9217 11 mg/L at MDPZ7458C (one sample)
Lead		0.1	0.005	<0.001 to < 0.005	<0.001 to 0.005	<0.001 to 0.003	
Mercury		0.002	0.0043	<0.0002 to 0.012	<0.0002 to 0.0043	<0.0001 to <0.002	Exceedances at MDPZ7451C, MDPZ7453A (valley area) & MD6605 Lower (Mulga West valley flank). 0.002 mg/L at MDPZ7452A & MDPZ7452B (valley area)
Molybdenum		0.15	0.025	<0.001 to 0.025	<0.001 to 0.009	<0.0001 to <0.005	
Nickel		1	0.22	<0.001 to 0.22	<0.001 to 0.04	<0.002 to 0.12	
Zinc		20	0.51	0.006 to 0.24	<0.005 to 0.51	0.034 to 0.51	

Valley Area = area of Type 9 groundwater (refer Figure 6.23); Valley Flanks = area generally covered by Types 5 & 6 groundwater (refer Figure 6.23); Upper Slopes = Bores in fresh Jeerinah Fm (MDPZ7454, MDPZ7455, MDPZ7466 & MDPZ7467)
Bold indicates bores with groundwater salinity <5,000 mg/L TDS
Recommended TDS Concentrations for Beef Cattle
*TDS of 4,000 to 5,000 mg/L: Animals may have an initial reluctance to drink or there may be some scouring, but stock should adapt without loss of production.
** Loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually.

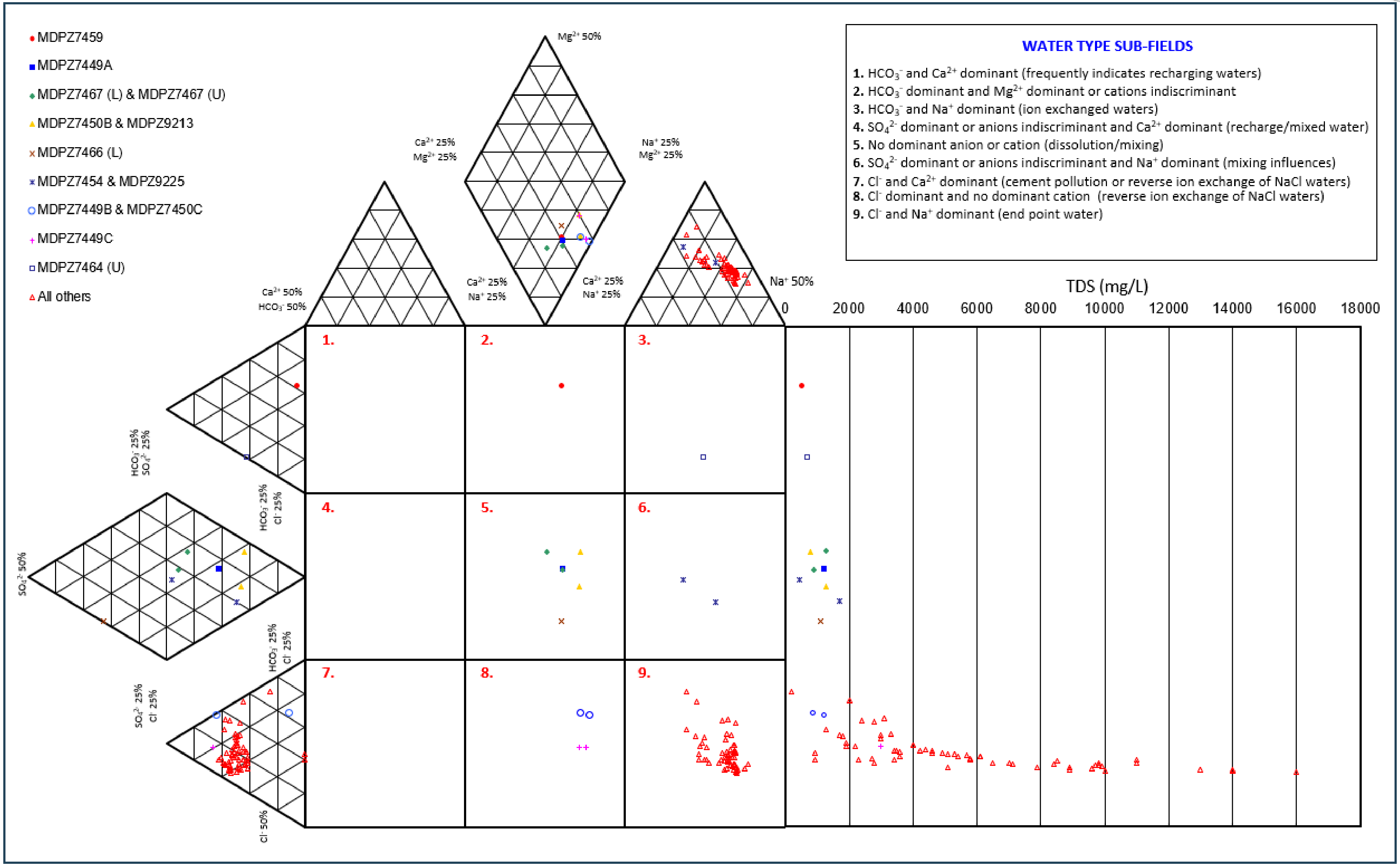


Figure 6.21 Mulga East / Malay Well Expanded Durov Diagram (Baseline Data Nov 2023)

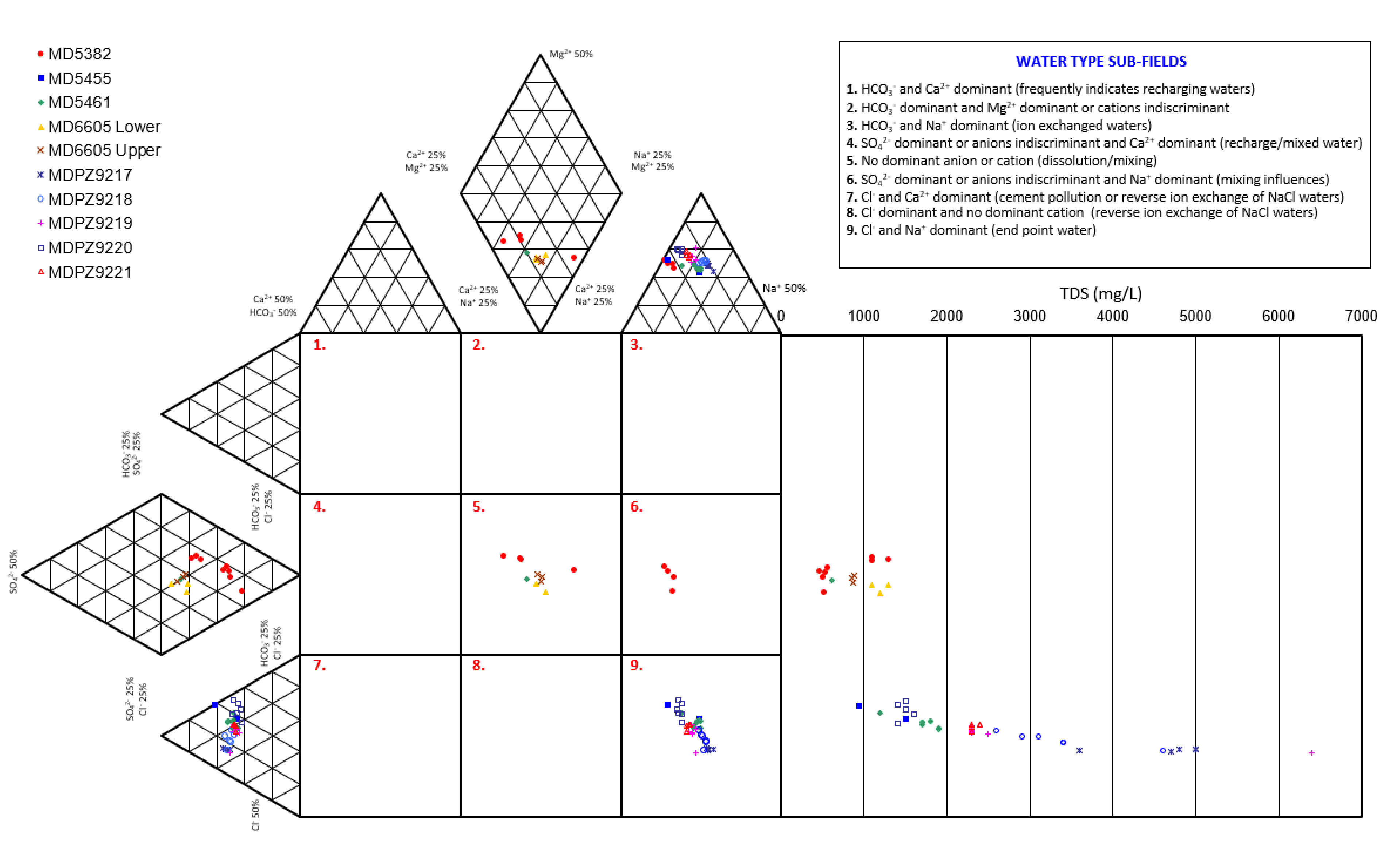


Figure 6.22 Mulga West Expanded Durov Diagram (Baseline Data Aug 2019 to Nov 2023)

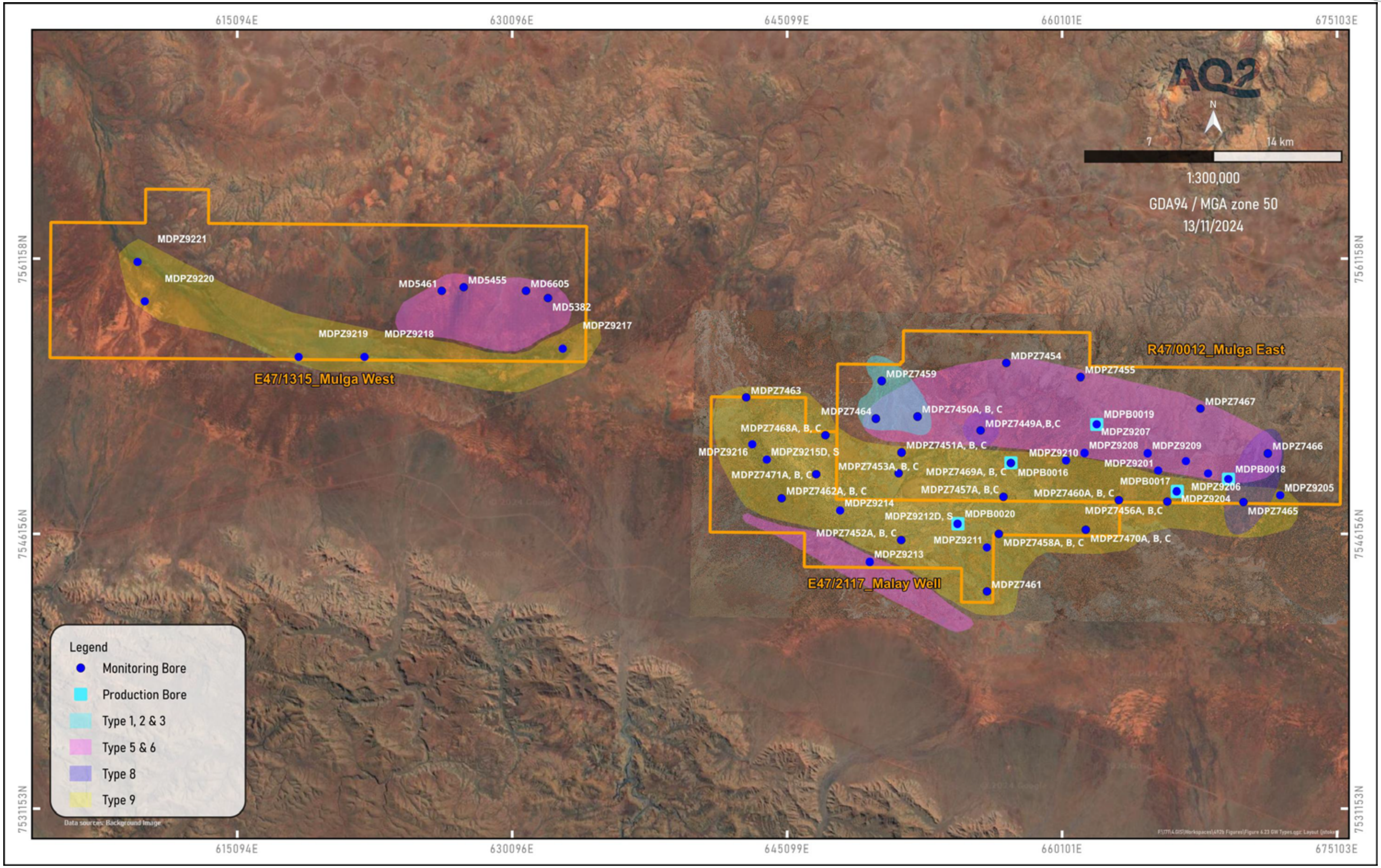


Figure 6.23 Groundwater Types

All static salinity data for each bore at installation and from each monitoring round have been compiled and are presented in Appendix H. It should be noted that salinity profiles have only been plotted for the intervals that are representative of the in-situ mobile groundwater within the screened interval of the bore. Additionally, for paired (deep and shallow) and cluster (deep, intermediate and shallow) monitoring bores, the salinity profiles for each bore have been combined into one profile. Key observations from these salinity plots and those compiled for the baseline monitoring as are as follows:

- The salinity profiles for the shallower and / or higher elevation bores along the northern boundary of the Study Area (i.e. single monitoring bores MDPZ7459 (5 to 28 mbgl), MDPZ7454 (27 to 58 mbgl) and MDPZ7455 (32 to 60 mbgl)) show no change in salinity with depth and are fresh throughout the profiles.
- Where changes in salinity with depth are evident, the salinity generally increases with depth, however, exceptions are as follows:
    - MDPZ7449 (cluster bores) where both salinity profile and laboratory data indicate the groundwater between 5 and 11 mbgl has a salinity of between ~6,000 and 11,000 µS/cm, whilst below this the salinity is ~2,000 µS/cm. However, an EC reading of 1,480 µS/cm was recorded for the drilling discharge water at 8 mbgl. The reason for this localised occurrence of shallow, saline groundwater is uncertain.
    - MDPZ7456 (cluster bores) where a very minor decrease in salinity is evident from the salinity profiles between ~60 and 100 mbgl.
    - MDPZ9204 and adjacent production bore MDPB0017 where a very minor decrease in salinity is evident from the salinity profiles between ~70 and 94 mbgl. The changes in salinity in MDPZ9204 between 19 and 44 mbgl is not evident in MDPB0017 and is thought to be remanent of changes resulting from the drilling and bore airlift development.
    - MDPZ7458 (cluster bores) where the salinity profiles indicate the groundwater salinity increases from ~15,000 to ~18,000 µS/cm at ~35 mbgl for a depth of between 5 and 18 m. This is coincident with a zone of vuggy, high permeability calcrete (at the base of the Upper Calcrete) and underlying pisolite.
    - MDPZ7462 (cluster bores) where the salinity profiles indicate a zone of reduced salinity between ~63 and 70 mbgl, possibly associated with silcrete or top of the dolomite bedrock at this depth.
    - MDPZ7471 (cluster bores) where very minor decreases in salinity are evident from the salinity profiles at ~ 48 and ~55 mbgl, increasing again at 74 mbgl. These reduced salinities are coincident with permeable intervals of pisolite (46 to 55 mbgl) and calcrete (55 to 60 mbgl), with the increased salinity at the base of the bore corresponding with low permeability weathered shale below permeable BIF. It is inferred that the higher permeability units provide preferential pathways for the flow of fresher groundwater from the valley slope areas.
- Field readings taken from the discharge water during drilling generally correlates well with the salinity profile data although in many bores the discharge readings at depth are influenced by the inflow of groundwater from shallower depths (i.e. higher in the hole), this is particularly evident in the following cases:
    - At MDPZ7449 (cluster bores) the drilling discharge shows an increase in salinity from ~50 mbgl indicating down-hole leakage from the shallow high salinity zone when open-hole drilling (below the dual-rotary conductor casing) commenced.
    - The inflow of the fresher water at ~60 to 70 mbgl, at MDPZ7462 (cluster bores), influenced the drilling discharge from this depth to the end of the hole (drilled open-hole), resulting in a recorded salinity of 3,400 µS/cm rather than the ~13,000 to 14,000 µS/cm recorded in the salinity profile.
- The laboratory EC measurements for the initial water samples correlate fairly well with the initial salinity profile readings, particularly considering the collected sample is representative of the entire screened section (as it was collected either from the airlift of the completed bore or using a 12V pump during micro-testing).

The salinity profile data have also been imported into Leapfrog Geo to create a 3D model of the groundwater salinity across the Study Area. Figure 6.24 presents the model and associated cross-sections, whilst Figure 6.25 shows contoured groundwater salinity (EC) at the water table elevation. However, it should be noted that there are no bores and salinity profile data in the immediate claypan areas as access to and working in these conservation areas are restricted. Figure 6.24 and Figure 6.25 show a mound of saline water beneath the claypans, with fresher water to the north and south, particularly over the northern and southern alluvial fan areas. This suggests the saline water is originating from the claypans with increased salinities resulting from evaporation; this is explained further in subsequent sections of the report (Sections 6.7 and 10).

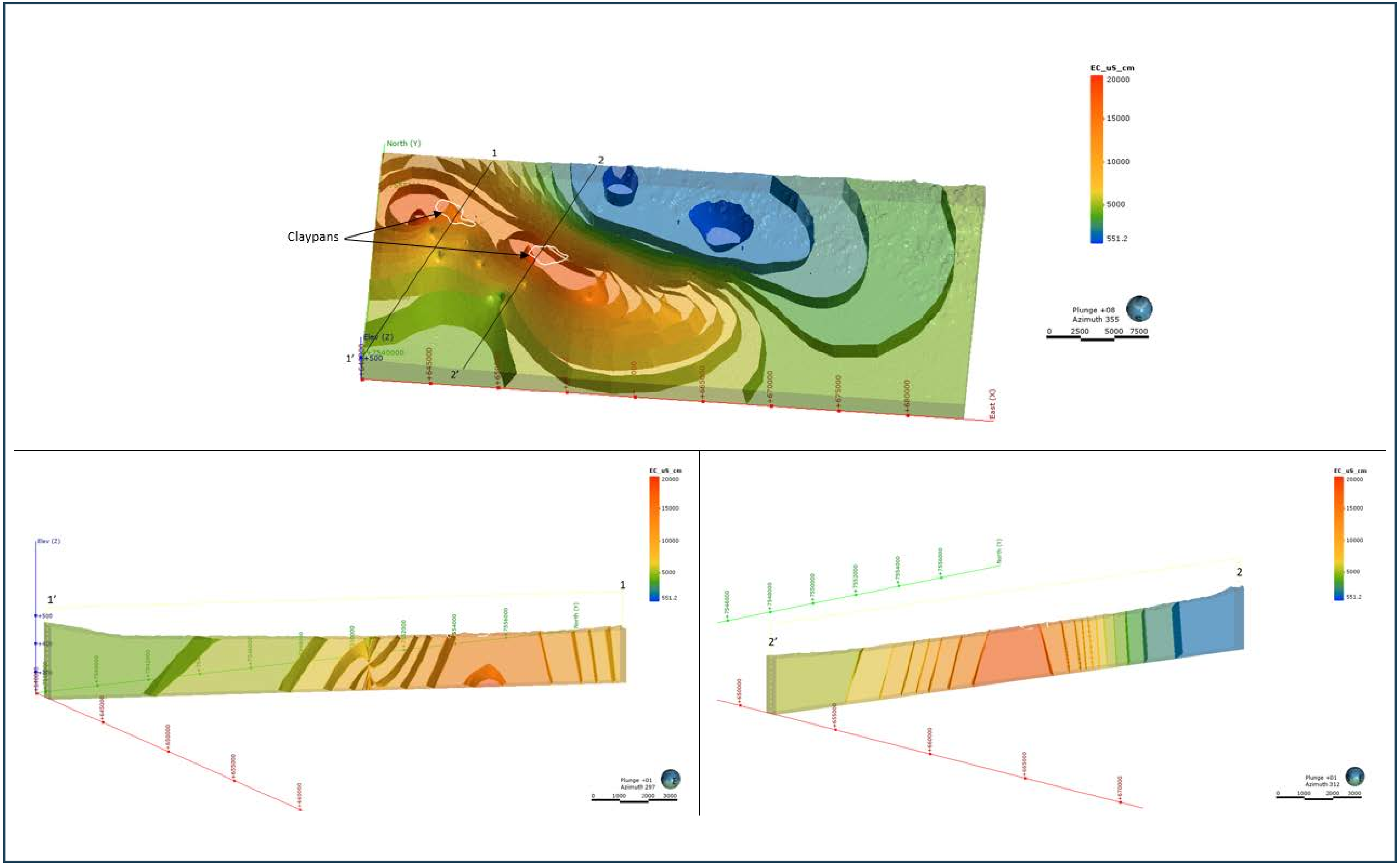


Figure 6.24 Groundwater Salinity Block Model

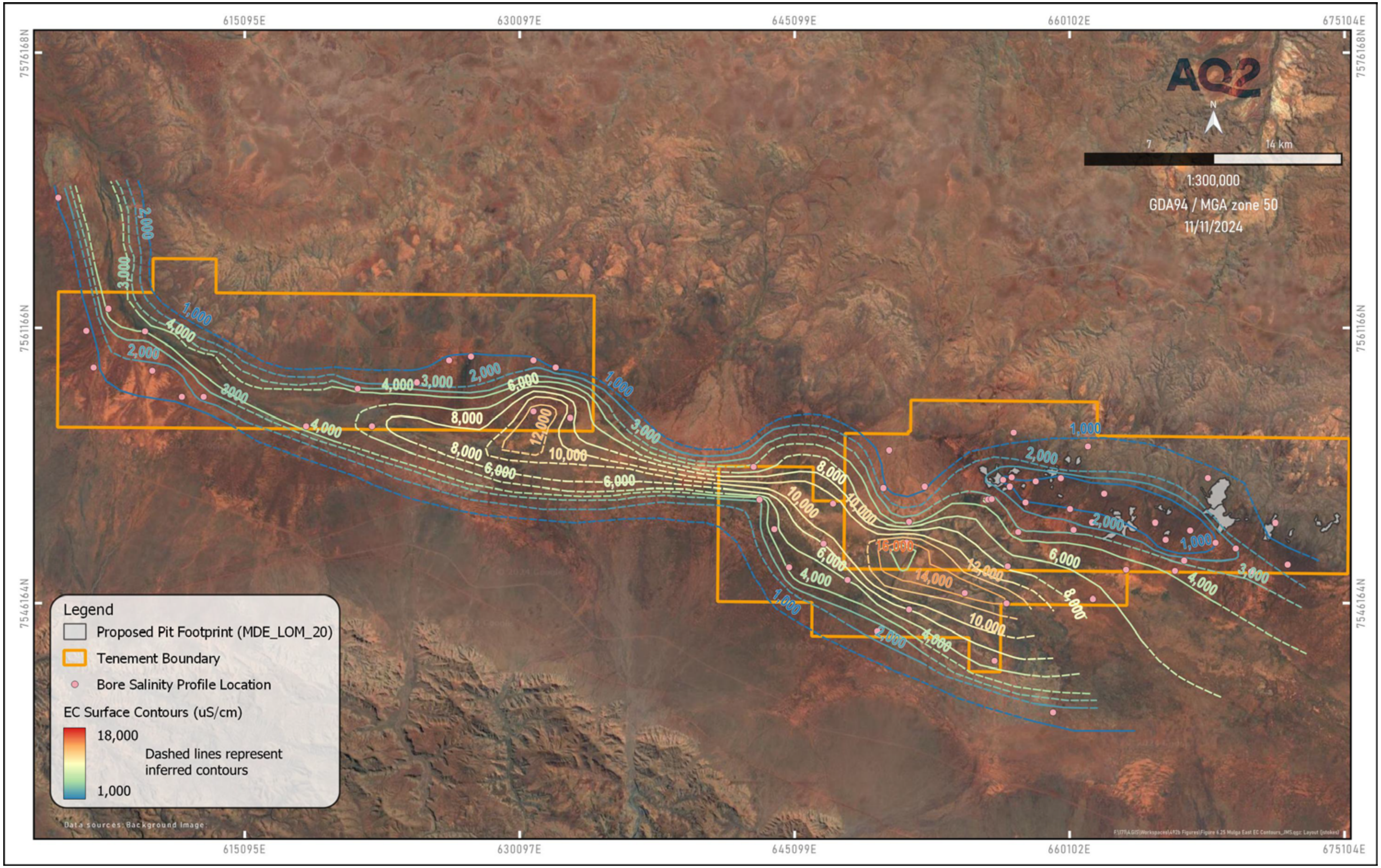


Figure 6.25 EC Contours at Water Table

6.7 Groundwater Salinity Changes

Due to the malfunctioning of the Solinst loggers, there are limited time series EC data between 2018/19 and December 2021 when new AquaTROLL loggers were installed in shallow monitoring bores near the claypans. Hydrographs of groundwater salinity (EC) are presented in Appendix K. The following salient points can be interpreted from the available EC data:

- Short-term spikes (i.e. increases) in groundwater EC at shallow monitoring bores, predominantly located on the valley floor, were evident in the early (Solinst logger) data. These are interpreted to show that salts are leached from the unsaturated zone into the groundwater system during the "first flush" (i.e. the initial surface water seepage leaches accumulated salts). This is most evident at MDPZ7457C (to the east of the Gnalka Gnoona Claypan) during the 2019/20 wet season (refer Figure 6.26). However, a similar response has not been observed in the 2021/22 and 2022/23 wet season; this is anticipated to be due to the smaller rainfall events, though may be related to the change in logger type / sensitivity.
- The reduced EC shown in some shallow salinity profiles, after the wet season (i.e. in May 2020), show that after the first flush of salts, fresher surface water recharges the groundwater system (i.e. on-going seepage of surface water does not continue to leach high volumes of salt as this was flushed during the early stages).
- The delayed increase in EC in deeper monitoring bores (equipped with LTC loggers in 2019/20), in response to the rainfall events, shows the diffusion and density-driven movement of salts from the surface to greater depths within the groundwater zone.

The reason for the increasing EC in response to the 2019/20 wet season at MDPZ456C, located away from the valley floor, is uncertain.

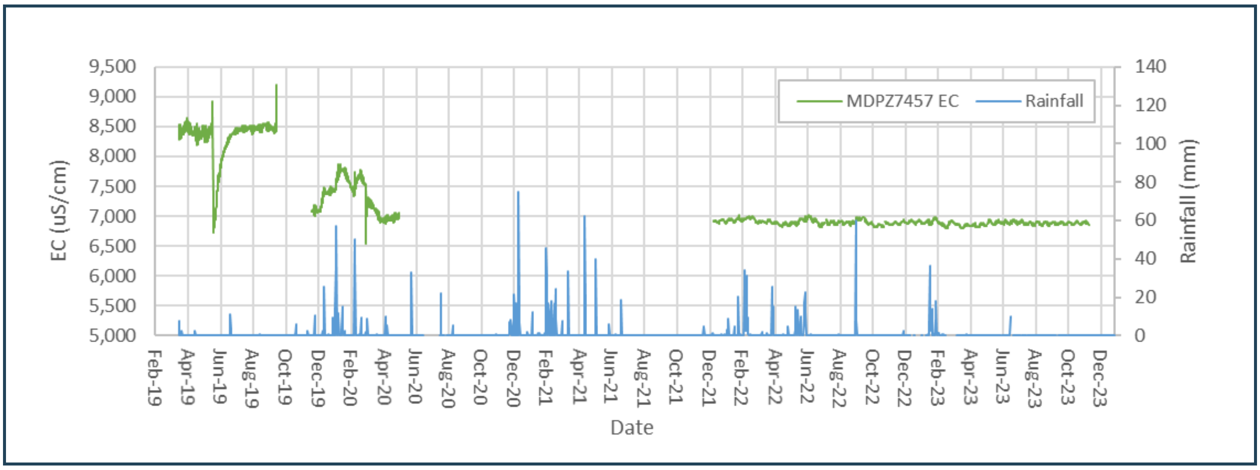


Figure 6.26 Groundwater Salinity Hydrograph for MDPZ7457C

7. ECOHYDROLOGICAL DATA SOURCES

7.1 Overview

AQ2 has undertaken the following four phases of ecohydrological assessment to date:

- Preliminary work in 2019 was focussed on the occurrence of potential groundwater dependent vegetation in the claypan areas.
- In 2021 the assessment of potential groundwater dependent vegetation was extended regionally with Mulga West becoming an additional focus area.
- In 2023 a more wholistic ecohydrological assessment was undertaken over the Mulga East and Malay Well tenement areas to assess the potential impact of a modified surface water regime (resulting from the proposed Project) on vegetation. The area of interest for this study was approximated by the flood modelling domain used for the associated surface water impact assessment.
- In 2024 the mapping of ecohydrological units (as defined in 2023) was extended to cover a wider area to support the recent flood modelling outlined in Section 4. Ground-truthing of the extended ecohydrological mapping area has not been undertaken.

The focus areas / areas of interest for the various ecohydrological assessments are presented in Figure 7.1.

7.2 Knowledge Review

In addition to the AQ2 groundwater and surface water assessments undertaken to date, a large body of environmental information relevant to the Study Area and adjacent areas has been documented in multiple studies. Key reports and data that were reviewed for the purposes of the ecohydrological assessment included the following:

- *Ecologia* 2021, Mulga East Baseline Terrestrial Vertebrate Fauna Assessment, Report prepared for Strategen-JBS&G (February 2021), *Ecologia* Environment, Perth
- Maia 2021a, *Mulga East Iron Ore Project, Mine Study Area Detailed Flora and Vegetation Assessment 2019-2020*, Report prepared for Strategen-JBS&G (March 2021), Maia Environmental Consultancy Pty Ltd, Perth
- Maia 2021b, *Mulga Downs West Flora and Vegetation Desktop Study*, Report prepared for Strategen-JBS&G (October 2021), Maia Environmental Consultancy Pty Ltd, Perth
- Maia 2022, *Mulga Downs Iron Ore Project, Mine and Borefield Study Area Detailed Flora and Vegetation Assessment 2019-2022*, Report prepared for Strategen-JBS&G (July 2022), Maia Environmental Consultancy Pty Ltd, Perth
- Mine Earth 2021, *Mulga East Iron Ore Project Baseline Soil and Landform Assessment*, Report prepared for Hancock Prospecting Pty Ltd (April 2021), Mine Earth Pty Ltd, Perth
- MWH 2015, *Ecohydrological Conceptualisation of the Fortescue Marsh Region*, Report Prepared for BHP Billiton Iron Ore (September 2015), MWH Australia, Perth
- Pinder A, Lyons M, Collins M, Lewis L, Quinlan K, Shiel R, Coppen R & Thompson F 2017, *Wetland diversity patterning along the middle to upper Fortescue valley (Pilbara: Western Australia) to inform conservation planning*, Department of Biodiversity, Conservation and Attractions, Perth.
- Woodgis 2021, *Mulga Downs Groundwater Dependent Vegetation Remote Sensing Assessment*, unpublished report prepared for AQ2 Pty Ltd, by Woodgis Environmental Assessment and Management, Perth.

- Environmental data sets:
    - Interpolated rainfall data are available from the Scientific Information for Land Owners project (SILO; Jeffrey et al. 2001). Available at:
    - Department of Primary Industry and Rural Development (DPIRD) (2019a). Soil Landscape Mapping - Rangelands (DPIRD-063) [shapefile]. Available at: https://catalogue.data.wa.gov.au/dataset/soil-landscape-mapping-rangelands.
    - DWER (2021). Clearing Regulations - Environmentally Sensitive Areas (DWER-046) [shapefile]. Available at: https://catalogue.data.wa.gov.au/dataset/clearing-regulations-environmentally-sensitive-areas-dwer-046.

For reference, background concepts relating to groundwater dependent vegetation are presented in Appendix L.

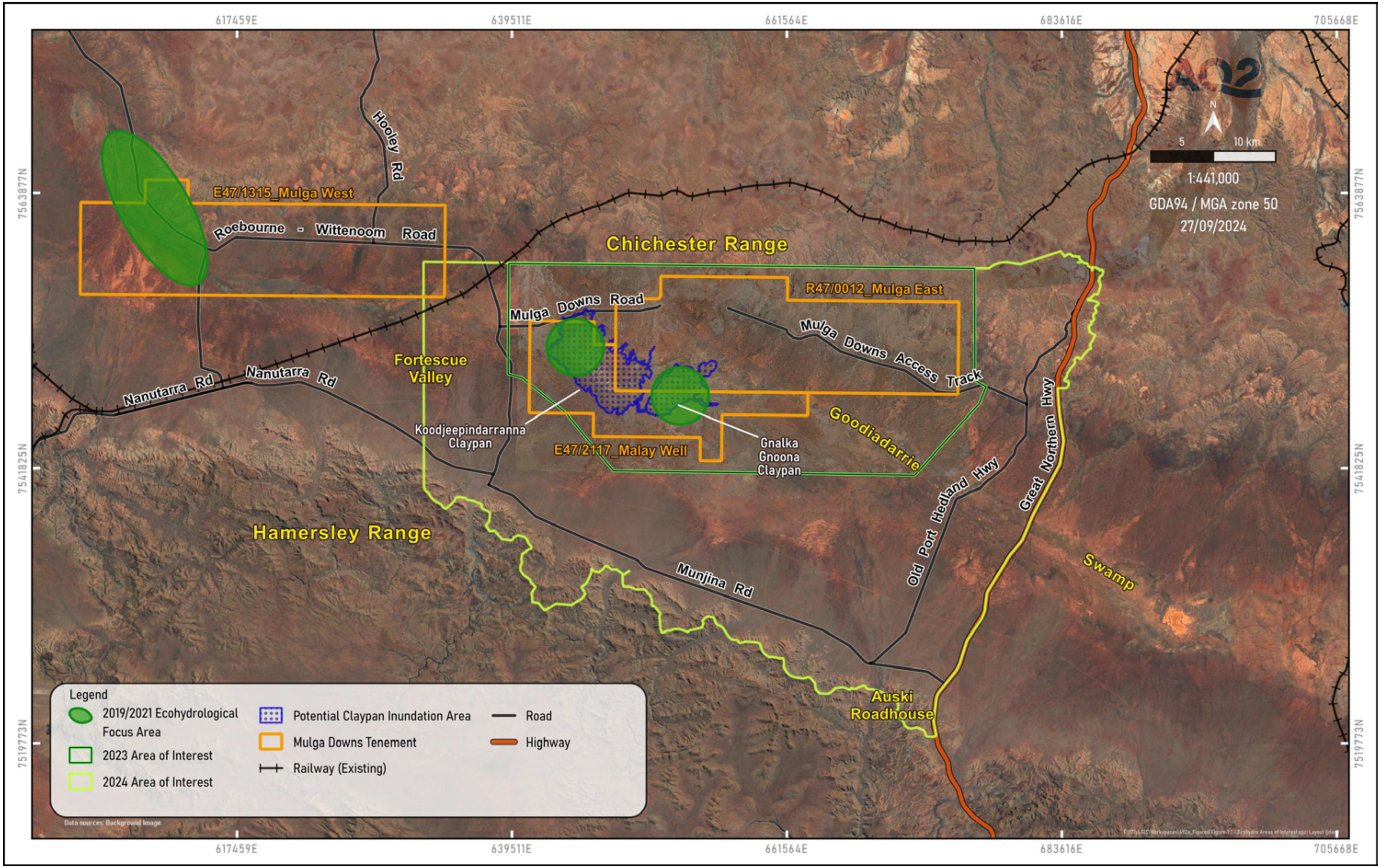


Figure 7.1 Ecohydrological Areas of Interest

7.3 Site Visits

Two site reconnaissance visits were completed by AQ2 personnel targeting the Mulga East / Malay Well tenements and Mulga West areas respectively:

- Mulga East/Malay Well: 11 -13 March 2019, and
- Mulga West: 19-22 October 2021.

During these reconnaissance visits, observations of the local area geomorphology and vegetation structure and composition were made and potential locations for ecophysiological measurements of vegetation were assessed.

Between 16 and 19 May 2023, AQ2 team members Mark Nicholls (Hydrologist) and Dan Huxtable (Ecologist) completed a site inspection of the 2023 area of interest (AOI). This involved an appraisal of the landscape from station tracks (by vehicle) and foot traverses of various landscape elements. Observations were made of the local area hydrological features, geomorphology as well as vegetation composition and structure. These are presented in Section 7.8.

The findings of the site inspection contributed to a landscape ecohydrological conceptualisation of the AOI, which is further described in Section 8.

7.4 2019/2021 Fieldwork Campaign – Ecophysiological Measurements

The overarching objective of the 2019/2021 fieldwork campaign was to determine the ecological water requirements of vegetation types in the Fortescue Valley with the potential to utilise groundwater. This involved consideration of multiple lines of evidence, including the collection of information for vegetation water balance model parameterisation as part of the sampling design.

AQ2 completed four field work campaigns involving the collection of ecophysiological data on the following dates:

- Wet season field program: 6-10 May 2019 (Mulga East and Malay Well tenements).
- Dry season field program: 22-27 October 2019 (Mulga East and Malay Well tenements).
- Dry season field program: 22 – 26 October 2021 (Mulga East, Malay Well and Mulga West tenements).
- Dry season field program: 20 – 25 October 2022 (Mulga East, Malay Well and Mulga West tenements).

Structural characteristics of overstorey tree species and plant water status (predawn and midday Ψ_{leaf}) were measured. Focus areas included *Eucalyptus victrix* woodlands at the Gnalka Gnoona claypan environs (Site A), the Koodjeepindarranna claypan environs (Site B) and the lower Fortescue River area in the western portion of the Mulga West tenement.

Details of the field work rationale and methodology, and subsequent data analysis methodologies, are described in the following sections.

7.4.1 Vegetation Structure Measurements

In 2019, vegetation structure was assessed in 21 randomly located quadrats sized 40 m by 60 m (2,400 m^2) in *E. victrix* dominated woodlands at each of the Gnalka Gnoona (Site A) and Koodjeepindarranna (Site B) claypans respectively. The locations of these quadrats are shown in Figure 7.2.

Within each quadrat:

- The total number of *E. victrix* trees was counted (by species).
- Diameter at breast height (DBH) was measured for all *E. victrix* trees > 10 cm.
- Understorey ground cover (percentage of land area) was visually estimated.
- Quadrat photographs were taken.

The DBH was used to calculate stand basal area (SBA; units m^2/ha) within the quadrat, being the sum of the cross sectional the area of all measured stems.

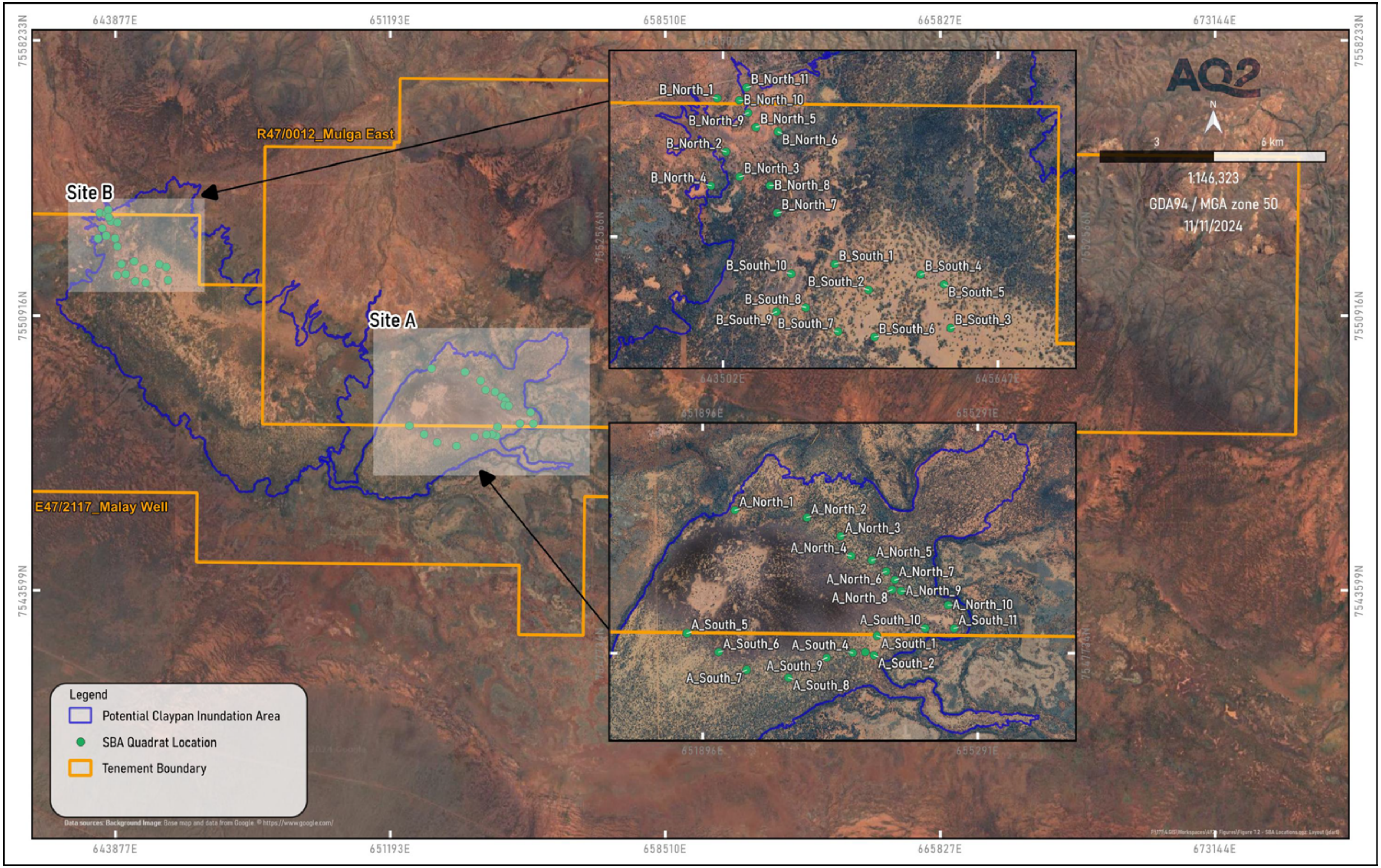


Figure 7.2 Sampling locations for *Eucalyptus victrix* woodland structure

For tree level comparison of stem growth, in the case of multi-stemmed trees the equivalent stem diameter was calculated as follows:

$$Dequiv. = 2 \times \sqrt{\sum_{k=1}^{n} \left(\frac{\mathrm{D}k}{2}\right)^2}$$

where:

D*equiv.* (cm) = equivalent stem diameter at 130 cm above ground level; and

D*k* (cm) = diameter of the *k*th stem at 130 cm above ground level.

7.4.2 Transpiration Flux Estimation

By application of the relationships presented in Figure 2, Appendix L (Basic Concepts), the following procedure was used to estimate the plausible range of annual water use by floodplain trees at each of the Fortescue Valley quadrat locations.

- Using tree stem measurement data from the quadrat, estimate plausible 'book ends' of daily transpiration rates (L/tree/year) using the 'upper bound' and 'lower bound' regression relationships between mean daily tree water use and DBH.
- Up-scale tree-level water use estimates to the stand level using the following procedure:
    - Annual water use per tree (L/year) calculated as tree daily water use (L/day) × 365.
    - Summation of annual water use per tree for all trees in the plot (m^3/year).
    - Conversion to unit area transpiration flux based on the measured plot areas (mm/year).

7.4.3 Leaf Water Potential Measurements

Multiple campaigns of predawn Ψ_{leaf} and midday Ψ_{leaf} measurements were completed in the Fortescue Valley *E. victrix* woodlands, summarised as follows:

Sampling location (refer to Figure 7.3)	6-10 May 2019	22-27 October 2019	22 – 26 October 2021	20 – 25 October 2022
Mulga East and Malay Well tenements Two locations referenced as north (N) and south (S) at the Gnalka Gnoona (Site A) and Koodjeepindarranna (Site B) claypans respectively	✓	✓	✓	✓
Two locations referenced as east (E) and west (W) at the Gnalka Gnoona (Site A) and Koodjeepindarranna (Site B) claypans respectively			✓	✓
Mulga West tenement Two locations referenced as north (N) and south (S) in and downstream of the Mulga West tenement (Site C).			✓	✓

At each of the locations in the Mulga East and Malay Well tenements, ten *E. victrix* trees were selected to cover the range in DBH that were present at each site (i.e. LWP was measured in trees that covered the range in tree sizes at each location).

At the Mulga West locations, Site CS included ten *E. victrix* trees spanning the range in DBH at the site; whilst Site CN included five trees each of the following overstorey species that were sampled given their prominence at this site: *E. victrix*, *Atalaya hemiglauca*, *Acacia ampliceps* and *Melaleuca glomerata*. The locations of all sampling sites are shown in Figure 7.3.

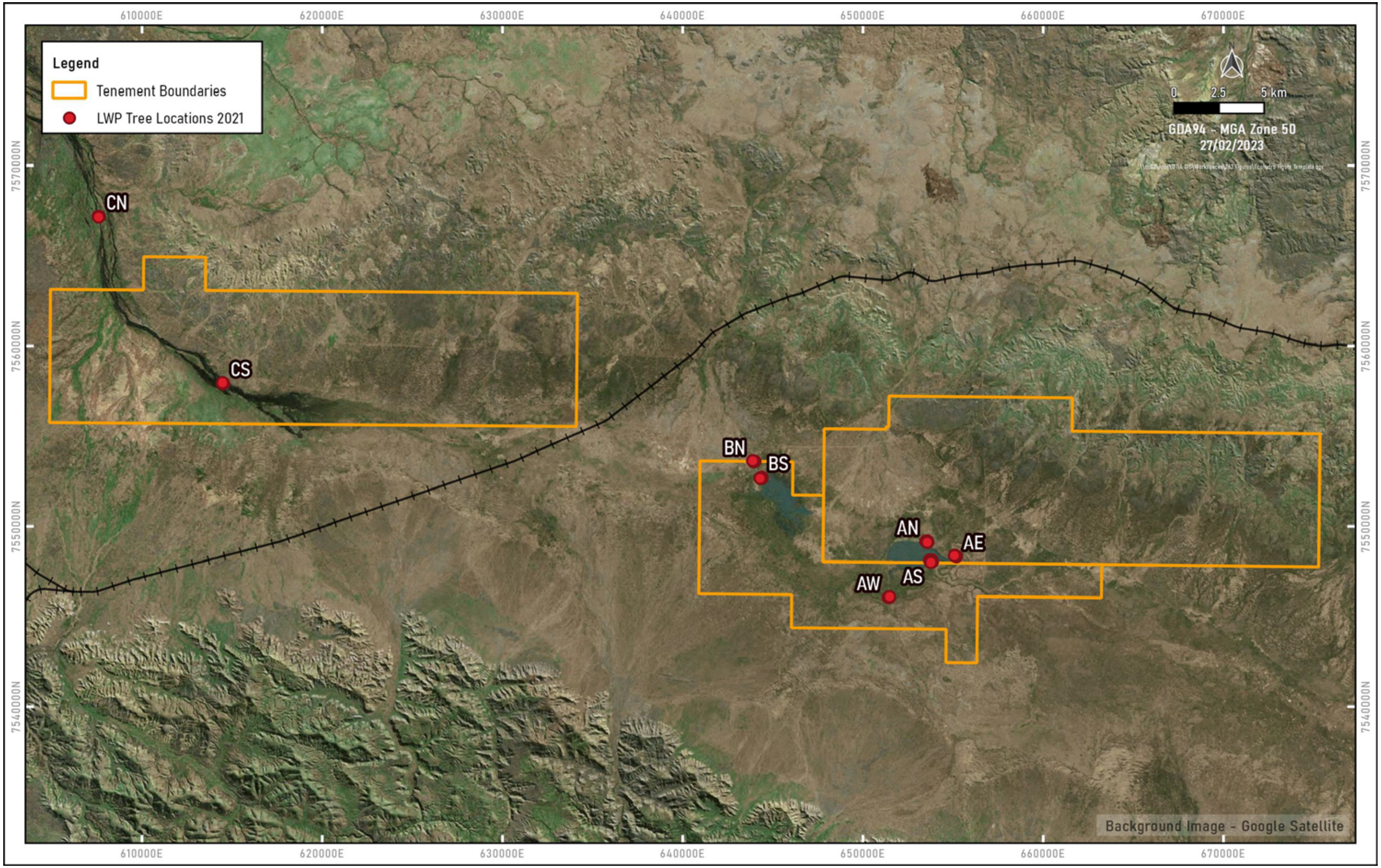


Figure 7.3 Sampling Locations for Leaf Water Potential Measurement

7.5 Land Systems

Land system mapping units developed by the Department of Agriculture and classified on the basis of landform, geology, geomorphology, soils and vegetation provide useful functional information about landscape elements (Van Vreeswyk et al. 2004). Land systems intersecting the 2024 AOI are shown in Figure 7.4. Key ecohydrological attributes of the major land systems are further described in Table 7.1.

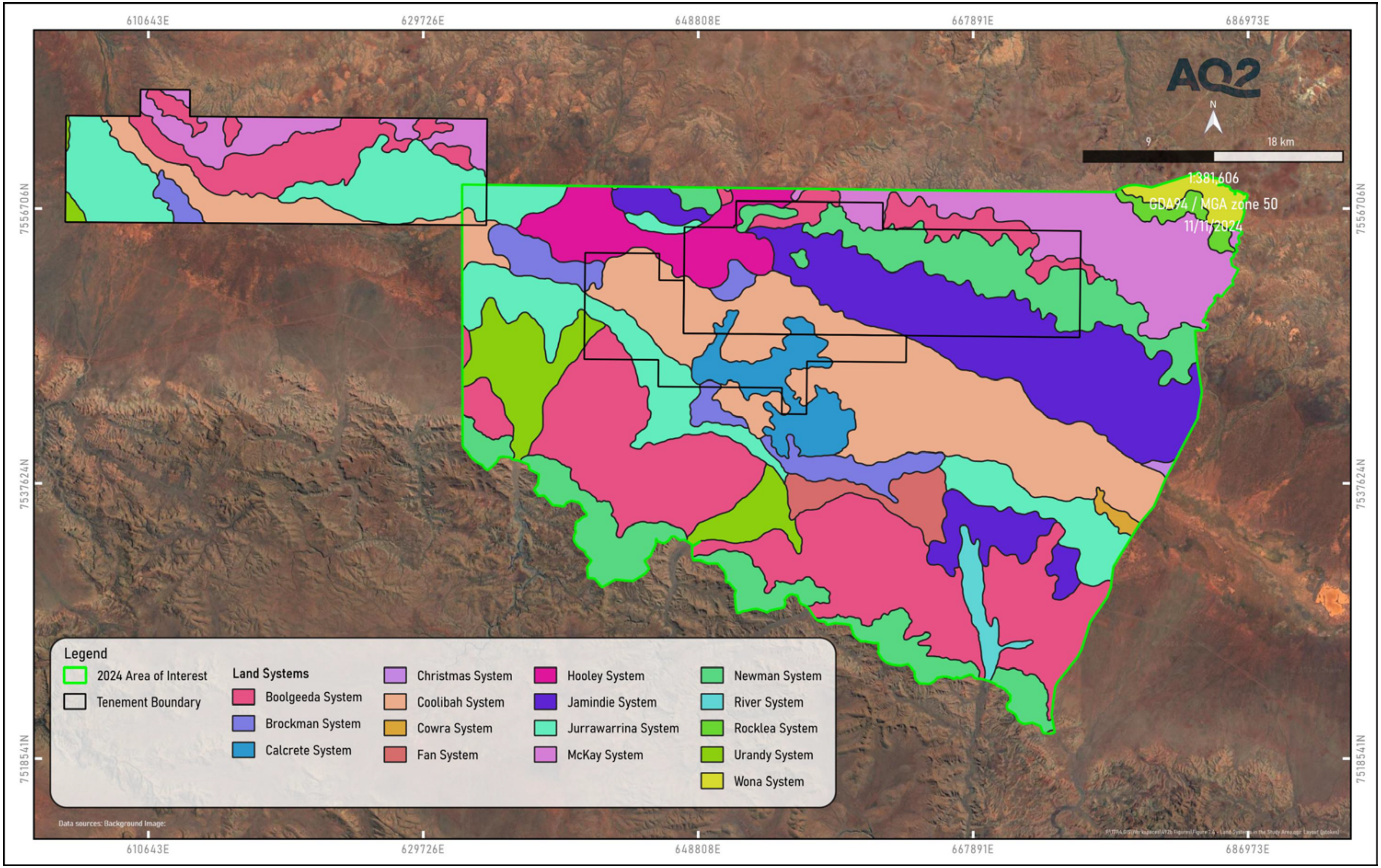


Figure 7.4 Land Systems in the Study Area and Surrounds

Table 7.1 Major Land Systems in the Study Area and Surrounds and their Ecohydrological Characteristics[2]

Land system and extent in Project area	Description	Geomorphology and soils	Key ecohydrology characteristics
Uplands of the Chichester Range			
Newman – comprises most of the Chichester Range uplands in the Mulga East area	Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands. Widespread across the Pilbara region.	Erosional surfaces, characterised by skeletal soils (with abundant pebbles, cobbles and stones) and frequent rock outcropping. Soils are shallow and stony.	Provides catchment water supply to the Fortescue Valley wetlands. Dendritic drainage pattern (numerus small catchments). Xerophytic (drought tolerant) grass dominated vegetation predominantly rain fed.
McKay - comprises the Chichester Range uplands in the Mulga West area.	Hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands.	Erosional surfaces; hill tracts, ridges, plateaux remnants and breakaways with steep upper slopes and more gently inclined lower footslopes, restricted stony plains and interfluves. Soils are shallow and stony.	Provides catchment water supply to the Fortescue Valley wetlands. Moderately spaced tributary drainage patterns incised in narrow valleys in upper parts becoming broader and more widely spaced downstream. Xerophytic (drought tolerant) grass dominated vegetation predominantly rain fed.
Boolgeeda – flanking areas of the Newman uplands	Stony lower slopes and plains below hill systems, supporting hard and soft Spinifex grasslands and less frequently Mulga shrublands. Widespread across the Pilbara region	Quaternary colluvium parent materials. Closely spaced dendritic and sub-parallel drainage lines. Predominantly depositional surfaces characterised by red loamy soils of shallow to moderate depth.	Minimal contribution to the catchments of the Fortescue Valley wetlands. Xerophytic (drought tolerant) vegetation. Living plant cover typically less than 60%; with denser bands associated with drainage lines. Typically <50 mature trees and tall shrubs per hectare.
Wona – comprises a small area in the Chichester Range uplands in the northeast of the 2024 AOI	Extends to the northeast within the Chichester Range.	Level to very gently inclined basaltic plains. Soils mostly comprise self-mulching cracking clays and some deep red-brown non-cracking clay with stony mantles.	Minimal contribution to the catchments of the Fortescue Valley wetlands, mainly local infiltration. Tussock grassland communities predominantly rain fed.

[2] Adapted from Van Vreeswyk et al. (2004).

Land system and extent in Project area	Description	Geomorphology and soils	Key ecohydrology characteristics
Alluvial plains			
Jamindie - comprises the majority of the alluvial plain at the base of the Chichester Range in the Mulga East tenement	Stony hardpan plains and rises supporting groved Mulga shrublands, occasionally with spinifex understorey.	Depositional surfaces including non-saline plains with hardpan at shallow depth, stony upper plains and low rises on hardpan or rock. Minor stony gilgai plains, sandy banks and low rises and hills. Shallow loamy soils (often stony/gravelly) are predominant.	Widely spaced tributary drainage tracts and channels, dissecting and separated by relictual alluvial fans. These support extensive banded vegetation formations sustained by localised surface water distribution (sheet flow). This catchment format controls the delivery of flows to the Fortescue Valley, contributing to heterogeneity in the wetland complex.
Hooley – comprises the alluvial plain in the far west of the Mulga east tenement.	Alluvial clay plains supporting a mosaic of snakewood shrublands and tussock grasslands.	Depositional surfaces including level plains of clayey and stony alluvium as a mosaic of surfaces with gilgai microrelief. Soils are mainly deep red/brown non-cracking clays and self-mulching cracking clays.	Mostly sluggish internal drainage, however several drainage tracts with well-defined channels convey flows into Brockman Land system and Fortescue Valley wetlands downstream. Vegetation is sustained by deep soils with relatively large vadose storage.
Brockman – occurs in a zone between the Hooley and Coolibah land systems in the Mulga East tenement; and between the Jurrawarrina and Coolibah land systems in the Mulga West tenement.	Alluvial plains with cracking clay soils supporting tussock grasslands. Note: In the Hamersley Range, this land system may support a rare tussock grassland dominated by *Astrebla lappacea* constituting a Priority Ecological Community (P1) (DBCA 2022).	Depositional surfaces derived from Quaternary alluvium. Non-saline alluvial plains with clay soils and gilgai micro-relief, flanked by slightly more elevated hardpan washplains. Soils are mainly self-mulching cracking clays and red/brown non-cracking clays, with some red loamy earths on elevated washplains.	Appears to occur at the break of slope in an area of fine textured, outwashed sediment accumulation. Sluggish internal drainage with occasional channel; however in the Mulga East tenement this unit is also crossed by a major channel feeding into the Fortescue Valley wetlands. Vegetation is sustained by deep soils with relatively large vadose storage.
Jurrawarrina - comprises the southern alluvial plain bordering the Fortescue Valley wetlands in Malay Well tenement. The major unit bordering the Fortescue Valley wetlands in the Mulga West tenement.	Hardpan plains and alluvial tracts supporting Mulga shrublands and tussock and spinifex grasslands.	Depositional surfaces derived from Quaternary alluvium and colluvium. Plains receiving overland sheetflow characterised by banded Mulga vegetation; and broad drainage tracts with or without defined channels. Soils are a mixture of red/brown clays, loams, earths and duplex types.	Functionally similar to the Jamindie land system, but with less well-defined drainages and more patchy banded vegetation formations.

Land system and extent in Project area	Description	Geomorphology and soils	Key ecohydrology characteristics
Fortescue River valley/drainage tract			
Calcrete – prominent in the Malay Well tenement and contributes to the Fortescue Valley wetlands area.	Low calcrete platforms and plains supporting shrubby hard spinifex grasslands.	Tertiary calcrete formed in valley fill deposits, with minor Quaternary alluvium. Drainage is generally indistinct. Soils are mainly shallow calcareous loams (<50 cm overlying calcrete), with minor calcareous loamy earths and red shallow loams.	The vegetation mosaic is inter-dispersed by calcrete outcrops and small depressions. Includes some incised channel zones connecting claypans. Vegetation water requirements include localised surface water distribution (e.g. shedding from outcrops). Major floods are likely to replenish deep soil water stores infrequently. Periods of prolonged waterlogging may occur. Subsoil calcrete sheeting is likely to constitute a barrier to tree root penetration.
Coolibah – encompasses the majority of the Fortescue Valley wetlands area in the Mulga East, Malay Well and Mulga West tenements.	Coolibah – Flood plains with weakly gilgaied clay soils supporting Coolibah woodlands with tussock grass understorey.	Depositional surfaces including active flood plains with shallow, meandering and anastomosing drainages and extensive, largely bare claypans. The soil is typified by deep red/brown cracking and non-cracking clays.	Encompasses the Gnalka Gnoona and Koodjeepindarranna Claypans. Fringing woodlands include *Eucalyptus victrix* and *Acacia distans;* also *Acacia stenophylla* is a notable species in eastern areas. Soil water replenishment by surface water inflows is important for sustaining the woodland trees and grasses. Major floods are likely to replenish deep soil water stores infrequently. Includes areas subject to periods of prolonged waterlogging. Contains Environmentally Sensitive Area (ESAs), including the Freshwater Claypans of the Fortescue Valley PEC (DBCA 2022).

7.6 Soil and Landform Assessment

A soil and landform assessment of the AOI and surrounds was completed by Mine Earth (2021). This work involved sampling and observations at 24 locations (refer Figure 7.5); including backhoe pits in areas where deep soil profiles were present (13 sites) or hand digging in areas where only shallow / skeletal soils were present and/or where access was restricted (11 sites).

Observations made at each soil sampling location during the Mine Earth (2021) fieldwork campaign included a description of soil surface characteristics, soil profile morphology, vegetation assemblages and surface drainage characteristics. Samples for physicochemical analysis were taken from two to four depth intervals at each soil sampling location, depending on the near-surface soil profile morphology and depth of excavation possible. The following parameters were measured:

- Physical characteristics:
  - Soil texture and particle size distribution;
  - Soil structural stability (Emerson Dispersion Test);
  - Saturated hydraulic conductivity (Ksat); and
  - Water retention characteristics (field capacity).
- Chemical characteristics:
  - Soil pH;
  - Electrical conductivity;
  - Organic carbon;
  - Exchangeable cations;
  - Plant available nutrients (N, P, K and S); and
  - Total metal concentrations.

Complementing the Mine Earth (2021) data set:

- Soil surface characteristics were appraised at multiple points by AQ2 during the May 2023 site inspection and topsoil (0-10 cm) was opportunistically sampled at eight locations. These samples were submitted to the CSBP Soil and Plant laboratory for selected physicochemical testing to complement the Mine Earth (2021) results (refer to Appendix M). Sampling locations are shown in Figure 7.5 and results are discussed in Section 7.8.2.
- Five alluvium 'grab' samples were collected by AQ2 in 2019 from locations proximal to the Gnalka Gnoona and Koodjeepindarranna claypans (Figure 7.5). These samples were obtained from drilling sump pits at approximate depths of 0.5 mbgl. The samples were submitted to geotechnical laboratory for determination of particle size distribution (PSD) (refer to Appendix M). Results are presented in Section 9.3.

Note that to date no soil sampling has been conducted in the Mulga West area.

From the results of their investigation, Mine Earth (2021) identified five soil-landform associations described as follows:

- Low hills and rises (of the Chichester Range):
  - Low undulating hills, minor outcropping rock in some areas.
  - Shallow / skeletal soils over fractured / weathered and competent rock.
  - High percentage of competent rock fragments through the surface soil profile.
  - Hills dissected by narrow, shallow drainage channels.
  - Soil pH moderately acidic-neutral.

- Alluvial plains (associated with alluvial fans):
  - Relatively flat, with gentle relief towards valley floor. Dissected by multiple minor drainage channels.
  - Relatively deep, earthy soil profiles with well-structured soils close to surface and massive soil horizons below.
  - Moderate percentage of competent rock fragments through the surface soil profile.
  - Soil pH neutral.
- Calcareous flats (of the Fortescue Valley):
  - Relatively flat and slightly elevated above surrounding landscape. Some outcropping calcrete present.
  - High percentage of competent rock fragments through the surface soil profile, typically increasing with depth.
  - Where the calcrete does not outcrop, weathered calcrete is commonly encountered at depths of 50 to 100 cm.
  - Soil pH moderately alkaline near the surface, becoming strongly alkaline at depth.
- Floodplains (of the Fortescue Valley):
  - Valley floor with depositional areas and evidence of surface sheet-flow.
  - Moderate, poorly defined drainage channels.
  - Relatively deep, earthy soil profiles with well-structured soils close to surface and massive soil horizons below.
  - Relatively low coarse fraction through soil profiles.
  - Soil pH neutral near the surface, becoming strongly alkaline at depth.
- 'Claypans':
  - Flat depositional areas associated with break of slope areas in the northern Fortescue Valley, near the base of alluvial fans.
  - Generally homogenous, weakly structured to massive soil profiles with high clay content.
  - Low percentage of competent rock material.
  - Soil pH neutral near the surface, becoming strongly alkaline at depth.

Note that Mine Earth (2021) did not complete any soil sampling in the Gnalka Gnoona and Koodjeepindarranna Claypans.

Soil electrical conductivity (EC), nitrate-N and plant available sulfur-S levels reported by Mine Earth (2021) are shown in Figure 7.6. The soils of the uplands and alluvial plains were non-saline. In the case of soil types in the Fortescue Valley, soil salinity was variable with respect to soil-landform associations and depth within the soil profile. The most saline soils documented by Mine Earth (2021) occurred in a non-vegetated stony plain depression (ME16 and ME18; saturated paste EC 4.5 to 9.1 dS/m); located north of the Gnalka Gnoona Claypan near the base of an alluvial fan originating from the Chichester Range. These results are indicative of:

- A break of slope landscape position, where channelised drainage dissipates and run-off accumulates.
- Low permeability clay at relatively shallow depth, contributing to water ponding and evaporative concentration of salts.

In other parts of the Fortescue Valley floodplains, where the surface soil layers were better structured and more permeable, salts were observed to accumulate in deeper subsoil layers (circa 50 cm depth; Figure 7.6.). This is inferred to be a consequence of:

- Higher infiltration rates and percolation through near surface layers.
- Lower permeability subsoils, which constrain deeper flushing of salts.
- Vegetation root system morphology, with root water uptake concentrated near the lower permeability subsoil interface.

The decrease in EC and nitrate at 100 cm depth at all sampling locations indicates a lack of flushing of salts below the root zone at the time of measurement. These data suggest that the vast majority of surface water inputs are captured in the upper soil profile and used by vegetation (i.e. a store and release dynamic). Percolation and salt flushing into the deeper profile probably only occurs in association with very large and infrequent rainfall events.

From the surficial sampling sites (0-10 cm layer) undertaken by Pinder et al. (2017) at the Gnalka Gnoona and Koodjeepindarranna Claypans, they reported higher clay contents (refer below) compared to the Mine Earth (2021) samples outside of the claypan areas.

- Gnalka Gnoona:
    - Site FV14A: Clay = 34.5%; Silt = 15.5%; Sand = 50.0%
    - Site FV19A: Clay = 40.5%; Silt = 13.5%; Sand = 46.0%
- Koodjeepindarranna:
    - Site FV17A: Clay = 34.4%; Silt = 18.8%; Sand = 46.8%
    - Site FV18A: Clay = 39.0%; Silt = 22.5%; Sand = 38.5%

The high clay content near the surface of the claypans contributes to restricted infiltration and protracted ponding following large rainfall events (i.e. analogous to the aforementioned stony plain depressions at break of slope locations along the northern margin of the Fortescue Valley).

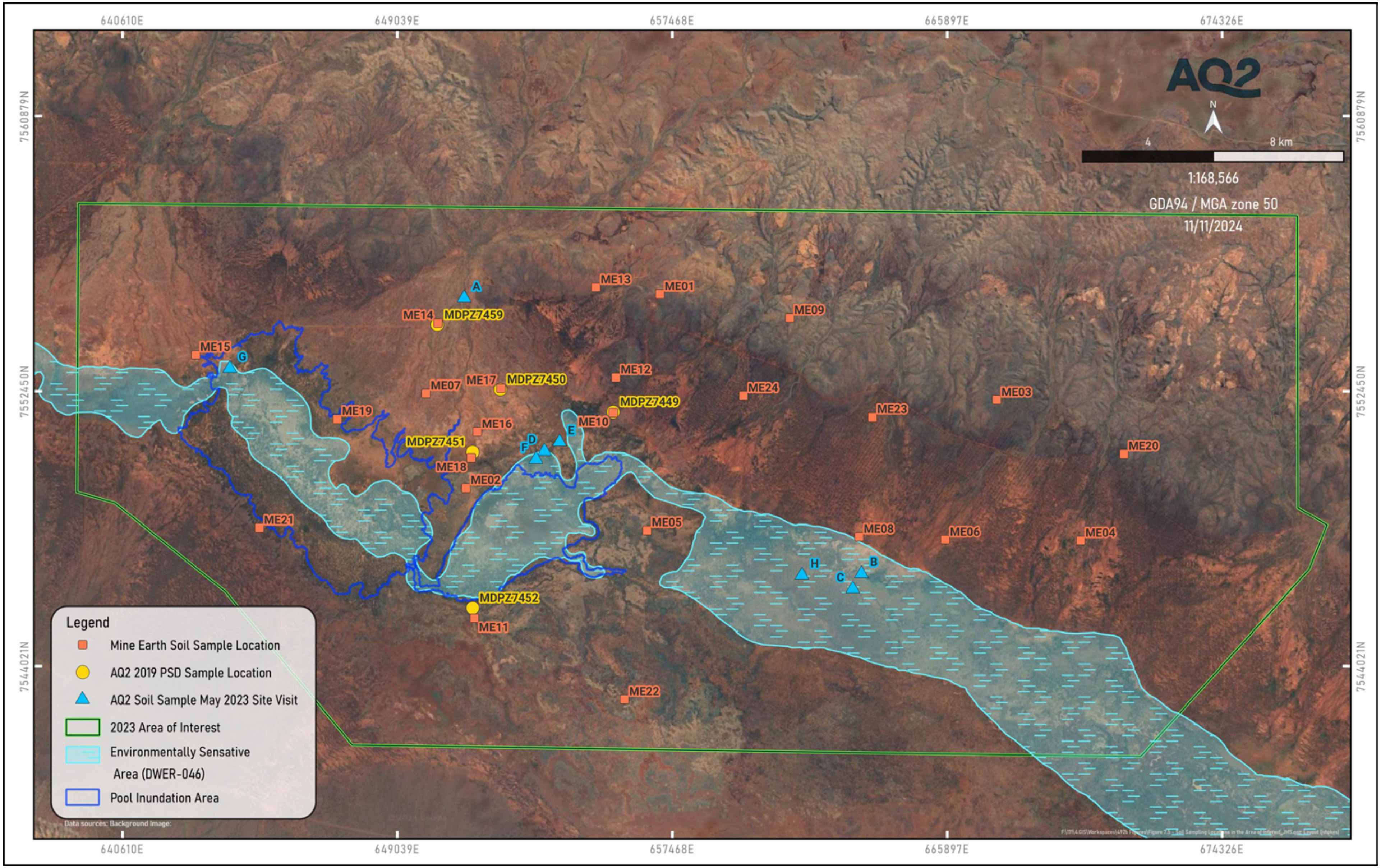


Figure 7.5 Soil Sampling Locations in the Area of Interest

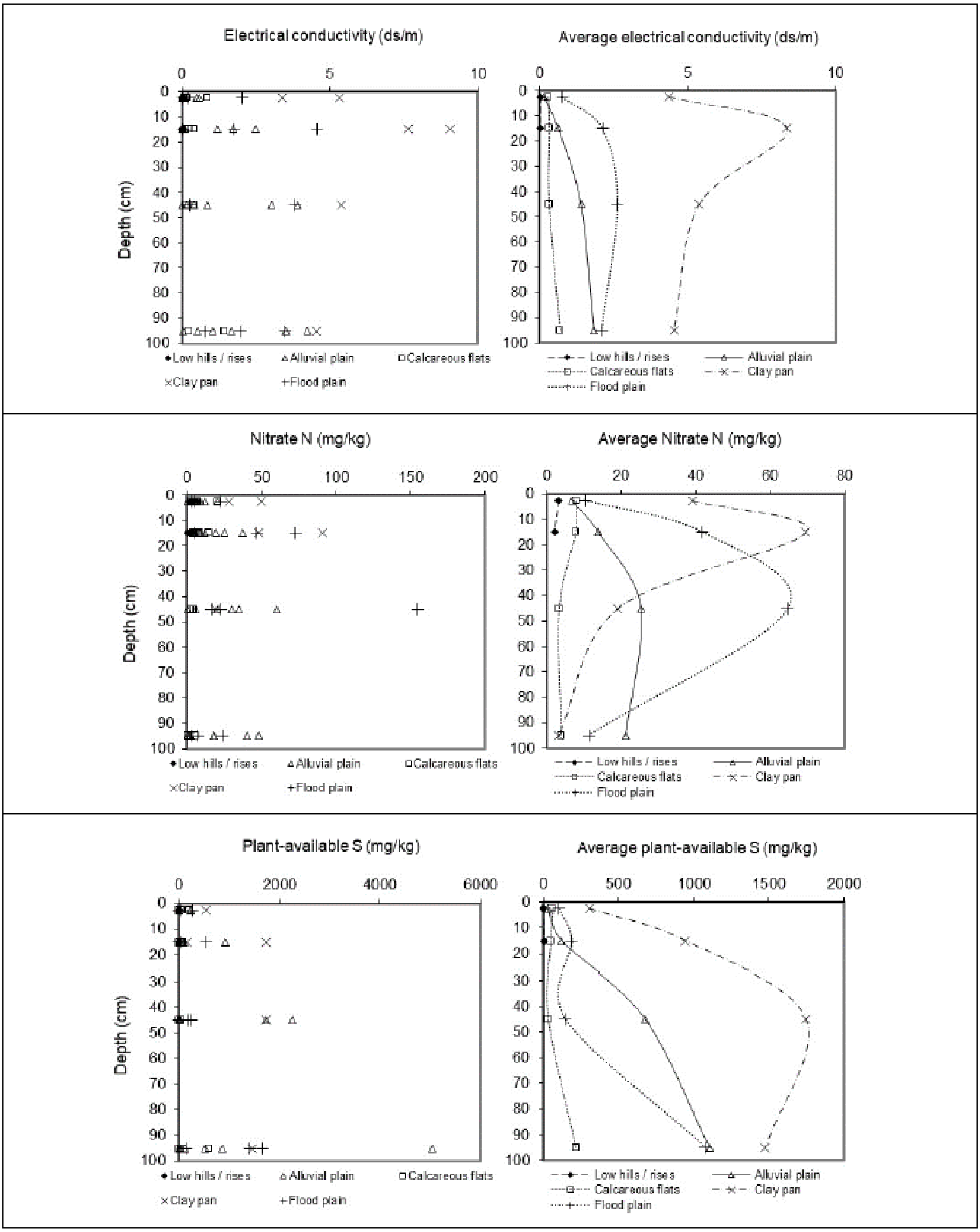


Figure 7.6 Soil Salinity and Nitrate Observations in the Area of Interest - reproduced from Mine Earth (2021)

Top: Individual and average electrical conductivity (saturated paste EC; dS/m) of soils with depth for each soil-landform association.

Centre: Individual and average Nitrate-N concentration (mg/kg) of soils with depth for each soil-landform association.

Bottom: Individual and average plant available Sulfur-S concentration (mg/kg) of soils with depth for each soil-landform association.

7.7 Vegetation Mapping

A comprehensive assessment of vegetation in the Study Area and surrounds, including desktop reviews and multiple on-ground surveys in the period 2012 to 2022, has been completed by Maia Environmental Consultancy Pty Ltd (Maia, 2022). The following sections summarise salient findings from this work.

7.7.1 Vegetation Types

As shown in Figure 7.7, 23 vegetation types, including one mosaic vegetation type, have been mapped over the Study Area and surrounds (Maia, 2022); including the Mulga West area. Those within the Study Area are summarised in Table 7.2 and their key ecohydrological characteristics are described in Table 7.3.

Maia (2022) considered twelve of these vegetation types (including the mosaic) to be locally significant for a number of reasons as described in Table 7.3; these types included ASL (2), AWL (1), AWL (2), AWL (3), AdEvWL, MSL (1), MSL (2), EfEbTG, BpoFL, MTG (2) and TvHG plus the mosaic of AdEvWL and BpoFL.

The keystone species *Eucalyptus victrix* occurs in 10 vegetation types: AdEvWL, ASL (2), AWL (2), BpoFl, EfEbTG, EvWL, MSL (1), MSL (2), MTG (1) and MTG (2). Salient aspects are as follows:

- *E. victrix* occurs in low, open woodland to woodland formations in vegetation types AdEvWL and EvWL on the Fortescue Valley flats. In all other vegetation types, in upgradient locations, *E. victrix* occurs as scattered or isolated trees. These trees constitute outliers from the core valley woodlands, with recruitment presumably facilitated by a combination of specific hydrological regimes (e.g. major floods providing seed dispersal) and micro niche habitat characteristics (e.g. pockets of deeper soil with soil moisture retention).
- The *Acacia* woodland/shrubland vegetation types (i.e. ASL (2) and AWL (2)), sparse to open shrubland types (i.e. MSL (1), and MSL (2)) and tussock grass dominated types (i.e. MTG (1) and MTG (2)) are all upgradient of the *E. victrix* woodland units, on the alluvial fans or calcrete rises in the Fortescue Valley.
- Vegetation type BpoFl is downgradient of the *E. victrix* woodland units, with the subtlety of the topography giving rise to mosaic patterning. It is associated with largely bare claypans/depressions. The dominant species *Bergia perennis* subsp. *obtusifolia* (herb), *Duma florulenta* (shrub), *Eriachne benthamii* (grass) and *Sporobolus mitchellii* (grass) all have a high tolerance of flooding/waterlogging, drought and salinity; reflecting the adverse growing conditions in these areas. Where present, *E. victrix* trees occur on slightly raised areas within these claypans. A notable subordinate species is the samphire *Tecticornia verrucosa*, which is an indicator of fresh water or slightly saline claypans and lakes (Wilson 1972), Unlike many other samphire species, it is a short-lived perennial that typically persists for 2-3 years (Pinder et al. 2017).
- Vegetation type EfEbTG is associated with local depressions in slightly elevated parts of the Fortescue Valley, flanking the valley thalweg that support relatively dense tussock grass communities *of Eriachne flaccida* and *E. benthamii*. Both of these grass species are adapted to periodic phases of flooding/waterlogging.

Two claypan areas in the AOI are listed as the P1 PEC 'Freshwater claypans of the Fortescue Valley'. Vegetation types EfEbTG, AdEvWL, BpoFl, the mosaic of AdEvWL / BpoFL, MSL(1), MSL(2) and MTG (3) are mapped within the buffered extent of these PEC units (Maia, 2022).

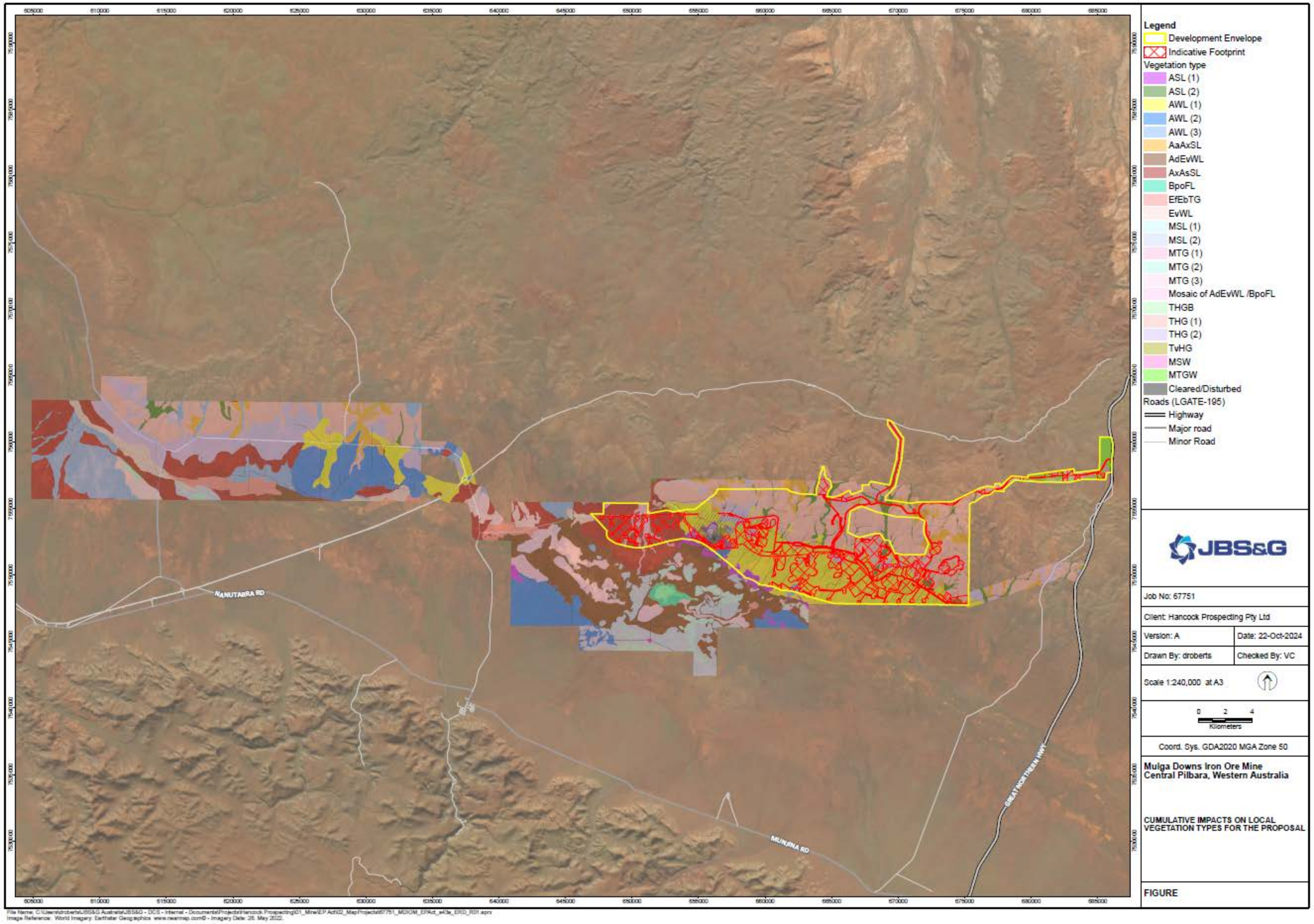


Figure 7.7 Vegetation Mapping Units in the Area of Interest and Surrounds (from JBS&G 2024b)

Table 7.2 Mapped Vegetation Types in the Area of Interest

Vegetation Type	Description
***AaAx*SL**: Acacia Tall Sparse Shrubland	Tall Sparse Shrubland of *Acacia aneura* (alliance) and *A. xiphophylla* with a Low Sparse Shrubland of *Eremophila cuneifolia* and a Sparse Hummock Grassland of *Triodia epactia* and/or *T.basedowii*.
***AdEv*WL**: Acacia and Eucalyptus Low Open Woodland	Low Open Woodland to Low Woodland of *Acacia distans* and *Eucalyptus victrix* sometimes with a Tall Sparse Shrubland of *Acacia stenophylla* or *A. tetragonophylla* and a Shrubland to a Sparse Shrubland of *Duma florulenta*.
***A*SL (1)**: Acacia Tall Sparse to Open Shrubland	Tall Sparse to Open mixed Shrubland mainly of *Acacia synchronicia*, *A. tetragonophylla*, *A.xiphophylla* with a mixed Sparse Chenopod Shrubland mainly of *Sclerolaena densiflora*, *S. cuneata* and *S. costata* and Isolated mixed Tussock Grasses mainly of *Sporobolus australasicus*, *Enneapogon polyphyllus* and *Dactyloctenium radulans*.
***A*SL (2)**: Acacia Tall Shrubland	Mixed Tall Acacia Shrubland mainly of *Acacia tumida* var. *pilbarensis*, *A. pyrifolia* and *A. maitlandii* with a Sparse Tussock Grassland of *Themeda triandra* and Low Isolated Trees of *Corymbia hamersleyana* and / or *Eucalyptus victrix*.
***A*WL (1)**: Acacia Low Woodland or Tall Shrubland	Low Woodland / Tall Shrubland to Low Isolated Trees / Shrubs of *Acacia aneura* (complex) with a mixed Low Sparse Shrubland mainly of *Dodonaea petiolaris*, *Eremophila forrestii* and *Abutilon otocarpum* and Isolated Low Trees of *A. pruinocarpa*.
***A*WL (2)**: Acacia Low Woodland or Tall Shrubland	Low Woodland / Tall Shrubland to Low Isolated Trees / Tall Shrubs of *Acacia aneura* (complex,) *A. synchronicia* and *A. tetragonophylla* with a mixed Low Sparse Shrubland mainly of *Solanum lasiophyllum*, *Abutilon otocarpum* and *Sida platycalyx* and a Sparse Tussock Grassland to Isolated Tussock Grasses mainly of *Sporobolus australasicus*, *Enneapogon cylindricus* and *Aristida contorta*.
***A*WL (3)**: Acacia Low Woodland	Low Woodland of *Acacia aneura* (complex) mainly *Acacia aptaneura*, *A. aneura* and *A. incurvaneura* with a mixed Tall Shrubland mainly of *A. synchronicia*, *A. tetragonophylla* and *Hakea lorea* subsp. *lorea* with a Sparse Tussock Grassland to Isolated Tussock Grasses mainly of *Sporobolus australasicus*, *Enneapogon cylindricus* and *Aristida contorta*.
***AxAs*SL**: Acacia Tall Shrubland	Tall Sparse Shrubland of *Acacia xiphophylla* and / or *A. synchronicia* with a mixed Sparse Chenopod Shrubland mainly of *Sclerolaena cuneata*, *S. bicornis*, *S. cornishiana* and a Sparse Tussock Grassland of *Eragrostis xerophila*.
***Bpo*FL**: Bergia Forbland	Claypans mostly bare of vegetation but with scattered *Bergia perennis* subsp. *obtusifolia* and mixed tussock grasses mainly of *Eriachne benthamii* and *Sporobolus mitchellii*.
***EfEb*TG**: Eriachne Tussock Grassland	Tussock Grassland of *Eriachne flaccida* and *E. benthamii* with Isolated Trees of *Eucalyptus victrix*.
***Ev*WL**: Eucalyptus Low Open Woodland	Low Open Woodland of *Eucalyptus victrix* and +/- *Acacia distans* with a Tussock Grassland of *Eulalia aurea*, *Eriachne benthamii* and *E. flaccida* and an Open Shrubland of *Melaleuca glomerata*.
Mosaic of ***AdEv*WL** / ***Bpo*FL**.	Refer to *AdEvWL* and *BpoFL* descriptions.

Vegetation Type	Description
MSL (1): Mixed Mid Shrubland	Sparse to Open mixed Shrubland mainly of *Melaleuca glomerata*, *Acacia synchronicia* and *A. tetragonophylla* and with a mixed Tussock grassland mainly of *Eragrostis pergracilis*, *Eriachne benthamii* and **Cenchrus setiger* or occasionally with a Hummock Grassland of *Triodia epactia* and Low Isolated Trees of *Eucalyptus victrix*.
MSL (2): Mixed Tall Shrubland	Sparse to Open mixed Tall Shrubland mainly of *Acacia synchronicia*, *A. tetragonophylla*, and *Melaleuca glomerata* over a mixed Low Shrubland mainly of *Indigofera monophylla*, *Solanum lasiophyllum* and *Stemodia grossa* and either a Sparse Tussock grassland of *Eragrostis desertorum* or a Hummock Grassland of *Triodia epactia*.
MTG (1): Mixed Tussock Grassland	Mixed Tussock Grassland mainly of *Eragrostis xerophila*, *Eulalia aurea* and **Cenchrus setiger* with a mixed Tall Sparse Shrubland mainly of *Acacia coriacea* subsp. *pendens*, *A. tetragonophylla* and *A. synchronicia* with a Low mixed Sparse Shrubland mainly of *Pluchea rubelliflora*, *Pterocaulon sphacelatum* and *Salsola australis*.
MTG (2): Mixed Tussock Grassland	Sparse to Open mixed Tussock Grassland mainly of *Eriachne benthamii*, *Aristida latifolia* and **Cenchrus setiger* with a Sparse mixed Shrubland mainly of *Acacia synchronicia*, *A. tetragonophylla*, *A. distans* with Low Isolated Trees of *Eucalyptus victrix*.
MTG (3): Mixed Tussock Grassland	Sparse to Open mixed Tussock Grassland mainly of *Eragrostis xerophylla*, *Eriachne benthamii*, and *Astrebla lappacea* with a mixed Forbland, mainly of *Stemodia kingii*, *Operculina aequisepala* and *Cullen cinereum* with Isolated shrubs of *Acacia synchronicia* or *Vachellia farnesiana*.
THGB: Triodia Hummock Grassland on Basaltic Terrain	Includes Triodia *epactia* and *T. brizoides* hummock grassland with sparse *Acacia inaequilatera* and *Grevillea pyramidalis subsp. leucadendron*
*T*HG (1): Triodia Hummock Grassland	Mixed Hummock Grassland mainly of *Triodia basedowii*, *Triodia brizoides* and *T. vanleeuwenii* with a Tall Sparse Shrubland of mixed Acacia species mainly *Acacia atkinsiana*, *A. maitlandii*, *A. ancistrocarpa* with Low Isolated Trees of *Eucalyptus leucophloia* subsp. *leucophloia* +/- *Corymbia hamersleyana*.
*T*HG (2): Triodia Hummock Grassland	Mixed Hummock Grassland mainly of *Triodia basedowii*, *T. epactia* and *T. vanleeuwenii* with a Sparse mixed Shrubland mainly of *Acacia aneura*, *A. aptaneura* and *A. atkinsiana* and Isolated Low Trees of *A. pruinocarpa* and / or *Eucalyptus leucophloia* subsp. *leucophloia*.
*Tv*HG: Triodia Hummock Grassland	Hummock Grassland of *Triodia veniciae* with Isolated Shrubs of *Acacia marramamba* and *A. atkinsiana*.
Cleared	

Table 7.3 Ecohydrological Characteristics of Vegetation Types in the Area of Interest

Vegetation Type	Key Ecohydrological Characteristics
***AaAx*SL**: Acacia Tall Sparse Shrubland	Occurs in upland areas of the Chichester Range. Vegetation water sources comprise direct rainfall. Dominant species include members of the *Acacia aneura* (complex) and *A. xiphophylla,* with Low Sparse Shrubland of *Eremophila cuneifolia* and a Sparse Hummock Grassland of *Triodia epactia* and/or *T. basedowii*. These are generally regarded as shallow rooted, drought tolerant species.
*AdEv*WL: Acacia and Eucalyptus Low Open Woodland	Widespread in valley areas adjacent to claypans where surface water inflows accumulate. *Eucalyptus victrix* open woodland to woodland formations, with little to no understorey to a dense overstorey of *Acacia distans*. Other notable shrub species can include *A. stenophylla, A. tetragonophylla* and *Duma florulenta*. Maia (2022) noted that in some areas the understorey is impacted by current and historical grazing. Vegetation water sources comprise direct rainfall augmented by surface water inflows. Vegetation density is likely to positively correlate with soil depth and a larger relative contribution of surface inflows to soil water replenishment (topographically controlled).
ASL(1): Acacia Tall Sparse to Open Shrubland	Associated with the Jamindie Land System, at the base of alluvial fans on hardpan plains dissected by throughflow drainages. Water sources include direct rainfall and redistributed runoff. Tall Sparse to Open mixed Shrubland mainly of *Acacia synchronicia*, *A. tetragonophylla*, *A. xiphophylla* with a mixed Sparse Chenopod Shrubland and occasional patches of mixed Tussock Grasses. These are generally regarded as shallow rooted, drought tolerant species.
ASL(2): Acacia Tall Shrubland	Associated with creek banks, minor drainage channels and floodplains. *E. victrix* is present as scattered trees (low density). Other notable species include *Corymbia hamersleyana, A. tumida* var. *pilbarensis*, *A. pyrifolia* and *A. maitlandii* and the understorey tussock grass *Themeda triandra.* Vegetation water sources comprise direct rainfall augmented by drainage inflows, with soil water storage controlled by alluvium depth. Vegetation density is likely to positively correlate with soil depth.
*A*WL(1): Acacia Low Woodland or Tall Shrubland	A spatially extensive vegetation types that occurs on stony, washout flats with indistinct drainage on the northern side of the Fortescue Valley. Distinct banded vegetation formations supported by localised surface water redistribution processes. Dominated by *Acacia aneura* (complex) - shallow rooted, drought tolerant species.
*A*WL(2): Acacia Low Woodland or Tall Shrubland	Similar to AWL(1), but mostly occurs on the southern side of the Fortescue Valley on better developed alluvial fans. Vegetation banding is evident but less distinct that AWL(1). Major species include *Acacia aneura* (complex), *Acacia synchronicia* and *A. tetragonophylla. E. victrix* present as scattered trees (low density).
*A*WL(3): Acacia Low Woodland	Functionally similar to AWL(1) and AWL(2); but has a more restricted distribution. Occurs on broad drainage lines, drainage basins and hardpan and stony plains.
*AxAs*SL: Acacia Tall Shrubland	Principally associated with the Hooley Land System (west of the proposed mining areas), occurs mainly on hardpan and stony plains. Characterised by fine textured (clayey) soil types. Water sources include direct rainfall and redistributed runoff. Tall Sparse Shrubland of *A. xiphophylla* and / or *A. synchronicia* with a mixed Sparse Chenopod Shrubland. These are generally regarded as shallow rooted, drought tolerant species.
*Bpo*FL: Bergia Forbland	Occurs in valley areas where surface water inflows accumulate, pool and persist. Claypan landforms mostly bare of vegetation but with scattered *Bergia perennis* subsp. *obtusifolia* and mixed tussock grasses mainly of *Eriachne benthamii* and *Sporobolus mitchellii. E. victrix* and *A. stenophylla* sometimes present as scattered trees (low density). The samphire *Tecticornia verrucosa* is a notable subordinate species.
*EfEb*TG: Eriachne Tussock Grassland	Occurs in valley areas where surface water inflows accumulate, on slightly raised portions of claypans. Dominated by tussock grassland of *Eriachne flaccida* and *E. benthamii. E. victrix* present as scattered trees (low density).

Vegetation Type	Key Ecohydrological Characteristics
*Ev*WL: Eucalyptus Low Open Woodland	Similar to *AdEv*WL but is restricted to areas where the river flow line is more defined. *E. victrix* occurs in open woodland formations.
Mosaic of *AdEv*WL / *Bpo*FL	*E. victrix* occurs in patchy open woodland formations within this mosaic.
MSL (1): Mixed Mid Shrubland	Occurs on low rises within the Fortescue River and surrounds and has been divided into two subunits: MSL(1) is interspersed within vegetation type AdEvWL and areas of MSL(1) that are higher in the landscape are dominated by *Triodia epactia*, while those in lower areas are dominated by tussock grasses. *E. victrix* present as scattered trees (low density). Subject to infrequent flooding.
MSL (2): Mixed Tall Shrubland	
MTG (1): Mixed Tussock Grassland	Occur on alluvial plains adjacent to major drainages feeding into the Fortescue Valley. Characterised by fine textured soils. *E. victrix* present as scattered trees (low density) in MTG(1) and MTG(2).
MTG (2): Mixed Tussock Grassland	
MTG (3): Mixed Tussock Grassland	
THGB: Triodia Hummock Grassland on Basaltic Terrain	Occurs on level to very gently inclined basaltic plains in the Chichester Range. Characterised by gilgai microrelief and clay soils.
*T*HG (1): Triodia Hummock Grassland	Occur on hillslopes in the Chichester Range. Rainfed, shallow rooted vegetation growing on stony soils.
*T*HG (2): Triodia Hummock Grassland	
*Tv*HG: Triodia Hummock Grassland	Has a restricted distribution on low rolling hills and undulating stony plains with a surface layer of shale in the Chichester Range. Rainfed, shallow rooted vegetation growing on stony soils.

7.8 2023 Site Inspection Observations

Figure 7.8 presents the area covered by the 2023 site inspection, together with the locations of selected observations / photographs referenced below.

7.8.1 Geomorphology

The major geomorphic units in the 2023 AOI include:

- The foothills of the Chichester Range (slope > 1%).
- The gently sloping alluvial fans between the foothills and the Fortescue Valley (slope approx. 0.3%).
- The Fortescue Valley flats (slope <0.1%).

Note that terrain slope is an important discriminator and major determinant of landscape hydrological behaviour in the AOI.

Within the major geomorphic valley units, further segregation can be made on the basis of surface drainage type (channelised flow vs sheet flow), surface roughness (affecting rainfall storage) and surface infiltration behaviour. Patterns of vegetation and soil are related to these characteristics consistent with the following principles (Ross et al. 2021; Nouwakpo et al. 2016; Pierson and Williams 2016; Tongway and Hindley 2004):

- Water arriving at the ground surface during rainfall events either evaporates, ponds at the soil surface, is stored in the litter layer, infiltrates into the soil, or is transferred downslope as runoff.
- By virtue of the rainfall storage characteristics of the land/vegetation surface, runoff generation exhibits threshold behaviour. Runoff only occurs when surface storage is exceeded.
- Surface storage is not a static parameter; rather at any point in time it constitutes a dynamic equilibrium between water inputs, storage and outputs. This makes the prediction of runoff behaviour complex and difficult. Key parameters affecting runoff are rainfall depth, rainfall intensity and antecedent conditions affecting surface storage at the time of rainfall (e.g. soil moisture).

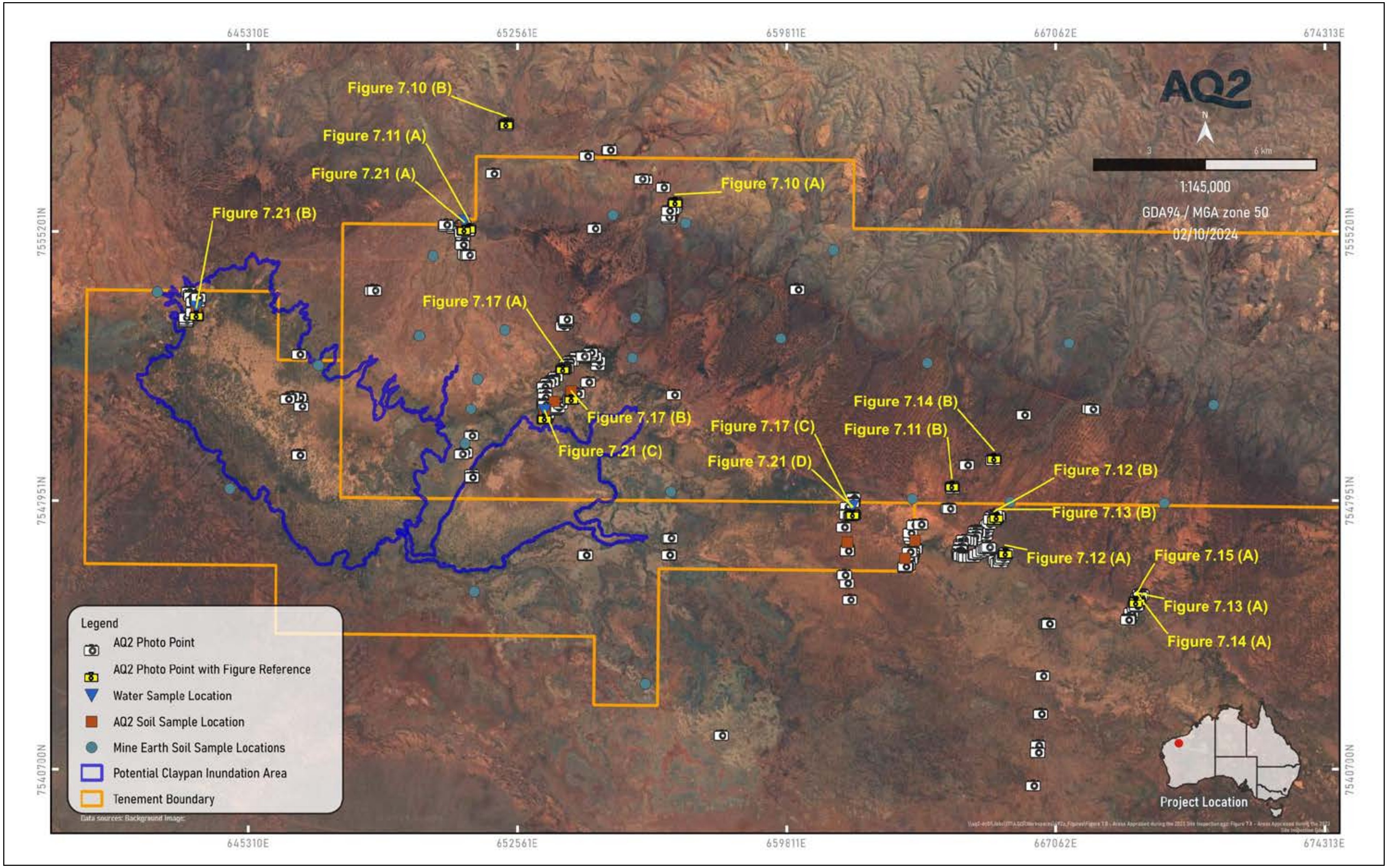


Figure 7.8 Areas Appraised during the 2023 Site Inspection

- Runoff occurs more rapidly after the onset of rainfall in sparsely vegetated interspaces than in vegetated zones, because vegetated areas generally have greater rainfall storage capacity. Factors contributing to this include:
  - Higher storage – by virtue of 3-dimensional structure, vegetated surfaces have a greater surface area facilitating physical entrapment of rainfall.
  - Infiltration losses in vegetated and litter covered areas are generally higher due to increased organic matter and biological productivity. Organic contributions and soil fauna activity contribute to lower soil bulk density, increased macropore development and other soil physicochemical properties associated with enhanced infiltration.
- Collectively, interception and enhanced infiltration in vegetated areas commonly results in two- to more than 20-fold less event runoff relative to bare or sparsely vegetated areas across point to patch scales. As a consequence, water and nutrients tend to translocate from bare (source) areas to adjacent vegetated (sink) areas. In water limited environments, this gives rise to vegetation patchiness that is re-enforced by a positive feedback of rainfall redistribution to sink areas.
- Vegetation degradation tends to reduce flow path tortuosity and increase runoff connectivity, with an associated increase in erosive energy and soil loss. Where pronounced, this can lead to a transition from sheet flow dominated to focused (i.e. channelised flow path) dominated water movement.

Considering these principles, the key geomorphic elements observed in the AOI were as follows:

- The Chichester Range Uplands comprising:
  - Rocky hilltops and slopes – water source areas characterised by skeletal soils vegetated with spinifex.
  - Infill valleys – areas between the rises where alluvium/colluvium has accumulated. The deeper soils provide for increased plant available water storage and thus support denser vegetation (typically *Acacia* shrublands).
- Drainage channels – ephemeral river channels that receive inputs from the surrounding uplands and transmit flows onto the alluvial fans. The upland drainages conform with the 'unconfined/semi-confined single thread cobble channel' geomorphic type, as described by Flatley et al. (2022; 2023) for Pilbara headwater streams. Gravel bars were prominent in the channels, which provide resilience to flood disturbance by increasing hydraulic roughness. Channel migration is ultimately confined by basement highs, and many of the channels are skewed to one edge of their host valleys.
- The Alluvial Fans comprising:
  - Wide, gently sloping interfluves with stony surfaced soils and banded vegetation formations. Water redistribution processes are dominated by localised sheetflow, transferring from sparse intergroves to adjacent vegetated groves. In small to medium sized rainfall events, rainfall is likely to be retained within this element. In large rainfall events, excess water may be delivered into adjacent drainage tracts.
  - Drainage tracts characterised by small low flow channels (circa 1 to 3 m wide and 30 to 50 cm deep) and narrow vegetated floodplains. These are principally fed by the drainage channels existing the Chichester Range uplands, transmitting flows through to the valley flats which otherwise bypass the alluvial fan geomorphic unit. In general, channel depths are constrained by hard, high bulk density subsoils. Flows within these drainage channels progressively lose energy moving from alluvial fan apex to toe, and completely dissipate where they enter the Fortescue Valley flats.

- The Fortescue Valley Flats comprising various units chiefly distinguished by surface soils / microtopography:
  - Stony flats – these areas are most prominent on the outer flanks of the Fortescue Valley. Near the drainage termini from the alluvial fans, the stony flats are commonly blanketed with a veneer of fine sediments. This fine sediment accumulation is probably a natural process but may have been exacerbated by a prolonged history of cattle grazing causing erosion on the alluvial fans. Infiltration is impeded, resulting in periodic waterlogging and near surface salt accumulation in small depressions within a wider micro-topographical mosaic. The vegetation is generally sparse, attributable to limited infiltration and soil water replenishment.
  - Loamy flats – these areas are associated with the better developed *E. victrix* woodlands and tussock grasslands of the Fortescue Valley. Soil characteristics are inferred to be influenced by organic matter accumulation; the surficial soils exhibit a high degree of macropore development and variable shrink-swell behaviour associated with clay content. Functionally, the loamy flats can be regarded as 'mega-groves' within a patched vegetation landscape, which receive runoff from either the adjacent alluvial fan geomorphic unit or calcrete rises within the Fortescue Valley itself. The density of trees and grasses is variable and appears to correspond with soil type and runoff delivery niches.
  - Calcrete flats and rises – these comprise benches or rises of calcrete formed in the Fortescue Valley in the Neogene (late Tertiary) period. The calcrete sometimes outcrops, but otherwise is overlain by shallow loamy soils formed in-situ and/or blanketed by shallow layers of valley alluvium. The upper surface of the calcrete has been generally softened by weathering and becomes harder and massive with depth.
  - Calcrete is commonly found in paleovalleys of arid Australia, and forms within valley sediments by precipitation of carbonate near the water-table and upward displacive growth (Chen et al. 2002). In the Pilbara region, valley calcretes typically comprise thick and expansive hardpans associated with groundwater systems upgradient of throughflow impediments such as basement pinch points or intrusive barriers. Calcrete has been intersected in all hydrogeological drilling in the valley of the AOI and, given the relationship between calcrete formation and groundwater, calcrete would be expected to extend across the full width of the Fortescue Valley Flats (i.e. beyond the AOI, to the south).
  - Ponding flats – these areas are formed in topographic depressions with high clay content soils that restrict infiltration, resulting in periodic waterlogging and near surface salt accumulation. The ponding flats are largely non-vegetated. Ponding water is derived from direct rainfall augmented by runoff inputs. Source catchments are difficult to define owing to lack of defined drainage and overall flatness of the Fortescue Valley. The most prominent examples are the Gnalka Gnoona and Koodjeepindarranna claypans; however, in the AOI smaller claypan features that function similarly are scattered throughout the valley.

Landscape relationships between these geomorphic units are schematically described in Figure 7.9. Photographic examples of each geomorphic element are provided in Appendix N.