Hydrobiology

NSE PER INLAND WATERS – POOLS CHARACTERISATION

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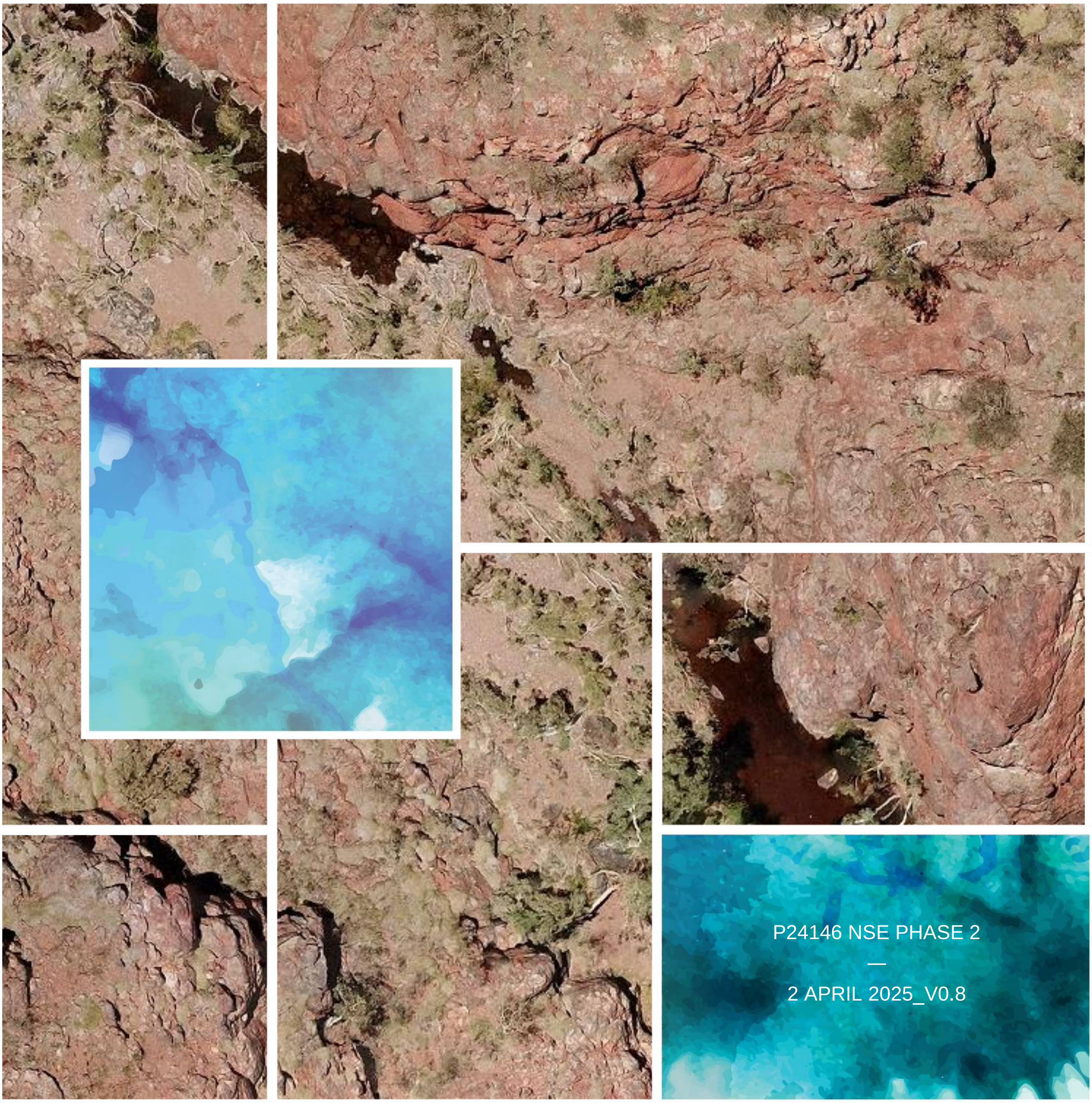

P24146 NSE PHASE 2

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1. INTRODUCTION

This report presents the results of a systematic identification and classification of the Inland Waters – Pool features of the North Star Extension (NSE) project area.

1.1 BACKGROUND

Fortescue Metals Group (Fortescue) is seeking to expand the current North Star Magnetite Project to the south of the existing mine development envelope. This expansion requires environmental approvals from the Environmental Protection Authority (EPA) and the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to enable development of new mine pits, a waste rock dump (WRD) extension and associated infrastructure. This new development is called the North Star Extension (NSE).

Several pools have been identified along creek lines within the North Star Stage 2 and NSE mine development area which are associated with hydrological and hydrogeological (Inland Waters) regimes. The DCCEEW issued PER Guidelines in December 2023, which included the need to identify and classify pools, then assess the risks associated with the NSE development.

Hydrobiology (as a sub-consultant to Worley) was engaged by Fortescue to identify and classify pools within the North Star Extension (NSE) area of influence. This report presents the results from a systematic identification and classification of the Inland Waters – Pool features of the NSE development area.

1.2 SCOPE

The objective of this study is to support the information requested to be provided by the PER Guidelines issued by DCCEEW as part of their assessment of the NSE under the EPBC Act 1999, relating to the identification and classification of pools in the NSE development area.

The scope of this report is to complete the systematic identification and classification of pools within the potential impact area (surface and groundwaters) of the NSE development. This is scope of work forms part of a pool impact assessment process as outlined in Figure 1-1. The impact assessment and subsequent risk assessment phases are being conducted separately to this scope of work.

The classification of pools is to be based on an assessment of whether the pools are permanent or ephemeral and whether they are surface water or groundwater fed, or both, with reference to the paper *A hydrological framework for persistent pools along non-perennial rivers* (Bourke et al, 2023) when conceptualising each pool's setting within the landscape.

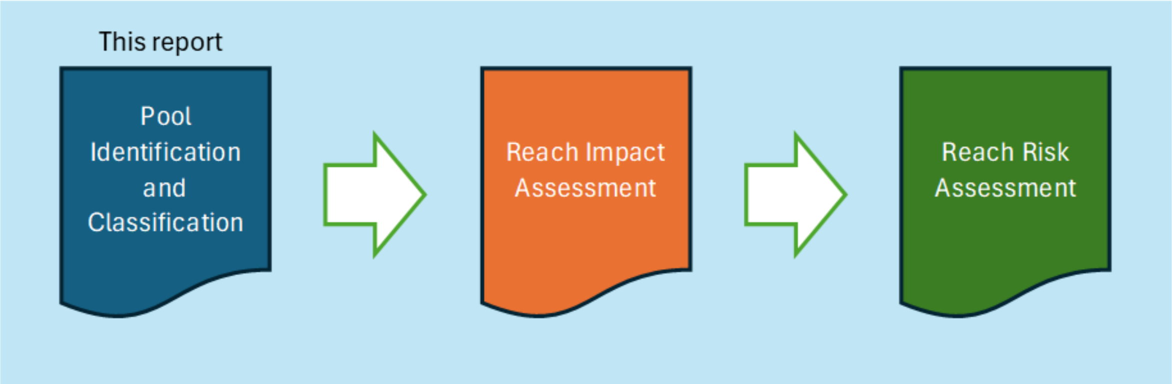


Figure 1-1 Schematic of workflow including the current report (Pool Identification and Classification).

2. METHODOLOGY

2.1 STUDY AREA DELINEATION

The Study Area applicable to this study was based on the combined extent of the estimated surface and groundwater impacts associated with the NSE project development. The delineation of these zones is discussed in the following sections. The eastern boundary of the surface water impact area was extended to ensure all named pools were included in the assessment. The extent of surface and groundwater impacts were then combined to define the Study Area.

2.1.1 DEFINITIONS

The following definitions have been adopted for this assessment:

- Baseline conditions**:** currently approved NS Stage 2 mining conditions, and
- Developed conditions**:** approved NS conditions plus the proposed NSE development conditions.

2.1.2 POTENTIAL GROUNDWATER IMPACTED AREA

Fortescue estimated groundwater drawdown extent associated with its proposed mine plan using a groundwater numerical model developed in Groundwater Vistas. Various scenarios were modelled to assess the impact that variations in groundwater recharge may have over the life of mine.

It was agreed with Fortescue that the 'reduced recharge' scenario would be adopted to inform the impact assessment, as it represents the most conservative approach. Fortescue provided estimated drawdown extents associated with the proposed NSE development (developed conditions), and the 2 m drawdown contour was used to set the boundary of the potential groundwater impact area, shown in Figure 2-1 (black polygon).

2.1.3 POTENTIAL SURFACE WATER IMPACTED AREA

Impacts to surface water flows and waterways were assessed as part of the *North Star Magnetite Project Extension Hydrological Impact Assessment Report: Waterways* (Document number: 311012-02916-HYD-REP-002-0) and the *Site 12 Pool Catchment Waterways Assessment – North Star Extension* (Fortescue 2025). The outcomes of this study were used to inform the extent of the impact assessment for surface water dependent pools. The boundary for the impact assessment area for surface water dependent pools was selected as the point at which the surface water peak flow rates under developed conditions are predicted to be within 10%-15% of baseline conditions surface water peak flow rates (Figure 2-1; light green dashed polygon). The eastern boundary of the surface water impact area was then extended by up to 500m to ensure all named pools were included in the assessment. There were no additional named pools to the western, northern or southern extent of the study areas and therefore it was not extended any further.

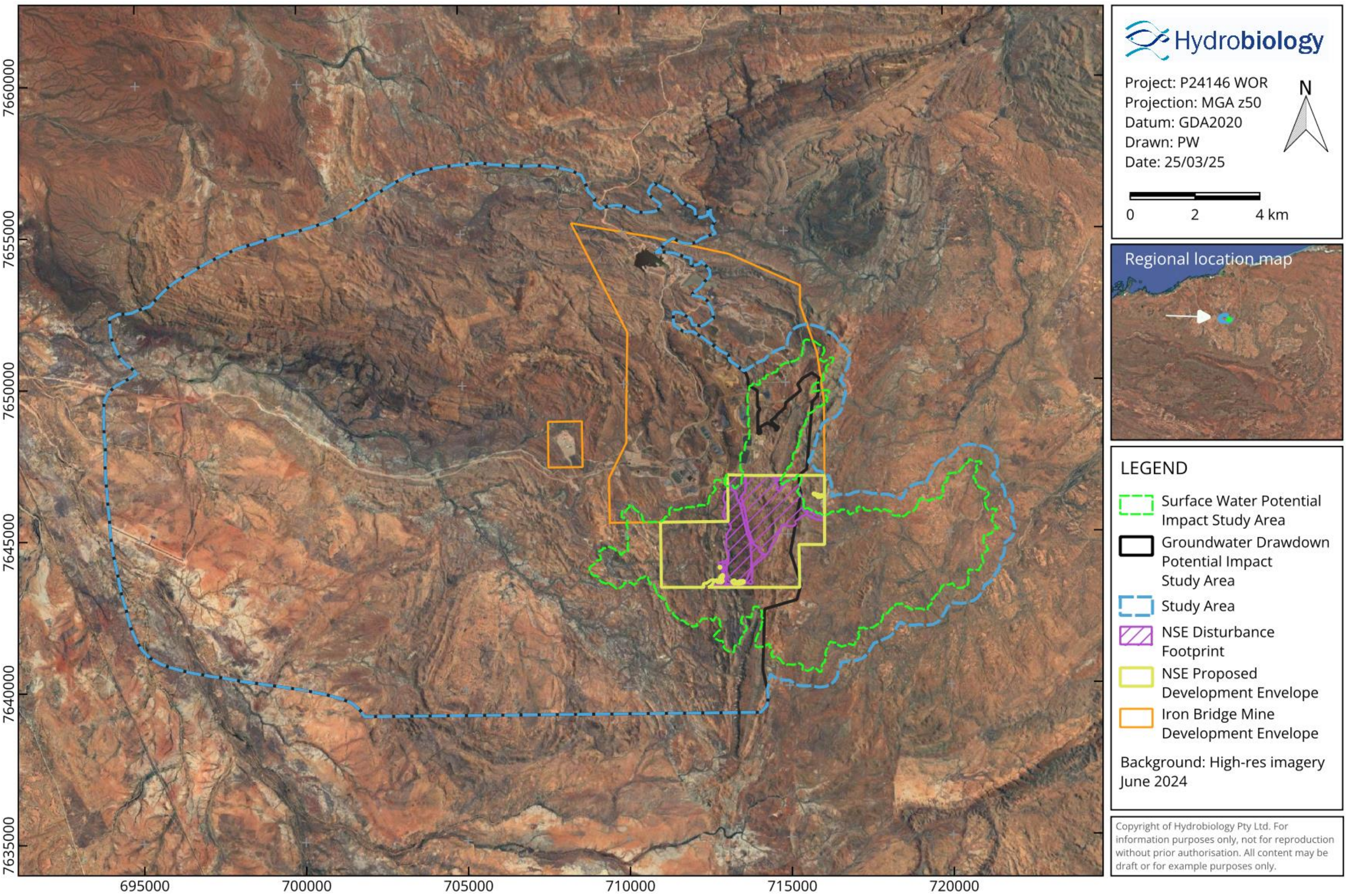


Figure 2-1 NSE surface water and groundwater potential impact areas.

2.2 DATA SOURCES

A range of data sources, described in the following sections, were analysed and assessed for the purposes of identifying and classifying pools within the study area. These data sources were targeted at completing a water permanence and source assessment following the method of Bourke et al. (2023); see Section 2.4.

2.2.1 AERIAL IMAGERY

Aerial imagery was supplied by Fortescue covering the period from August 2011 to June 2024. A total of 43 images were assessed with most images covering only part of the study area (Figure 2-2). A complete list of the image file names and dates is provided in Appendix A.

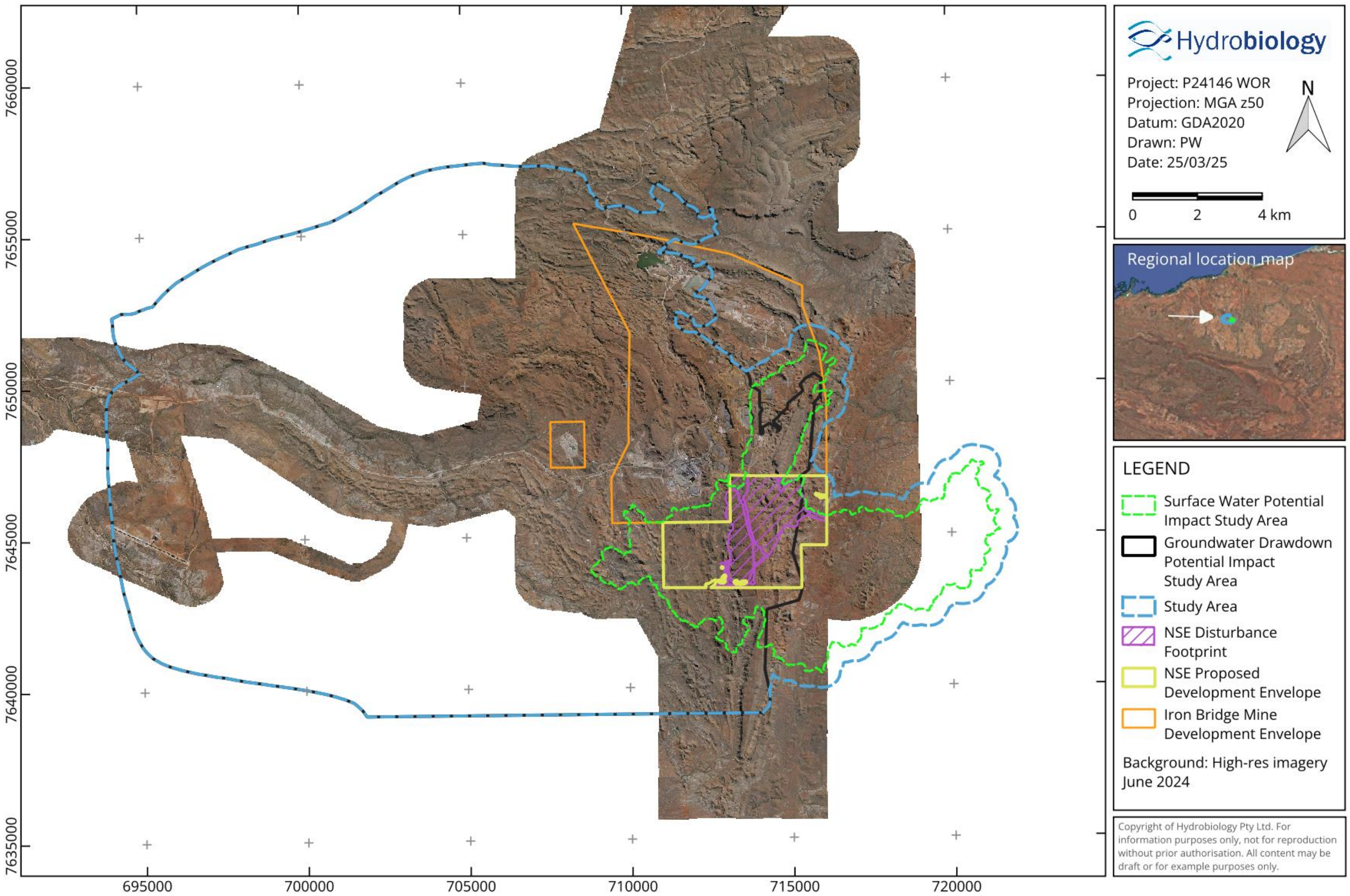


Figure 2-2 Example of aerial imagery capture area with study areas overlay – June 2024

2.2.2 SATELLITE IMAGERY

2.2.2.1 TRUE COLOUR COMPOSITE

Sensors on the Sentinel-2 satellite can image the Earth in different regions of the electromagnetic spectrum, called bands, with Sentinel-2 possessing 13 bands. True colour composite uses visible light bands, red, green and blue in the corresponding red, green and blue channels, resulting in a natural-coloured image that represents the Earth as it would naturally by seen by the human eye.

2.2.2.2 NORMALISED DIFFERENCE VEGETATION INDEX (NDVI)

The presence of denser vegetation and maintenance of high levels of vegetation vigour in the late dry season (October/November) are potential indicators of groundwater dependent vegetation (GDV). As a supporting line of evidence for water permanence and pool source classification, late dry season vegetation health was assessed across the study area using multi-spectral satellite data from the Sentinel 2 satellite array.

The two Sentinel 2 (S2) satellites captured 10 m resolution data across the study area every five days since October 2016. The Normalised Difference Vegetation Index (NDVI; B8-B4/B8+B4) was used to identify dense and healthy vegetation areas within the study area across the late dry season (October/November). The wet season in the study area is typically from December to May each year, with the April-May period being considered "late wet season". June to August is a period of drying of the landscape with increasing temperatures. September to November is the typical dry season, with late October/November (and occasionally early December) being the "late dry season".

Where pools were identified from true colour aerial or satellite imagery as being potentially permanent or semi-permanent, an assessment of the vegetation within the immediate vicinity of the pool was used to support the water permanence classification.

2.2.2.3 MOISTURE INDEX

As with the NDVI analysis (see Section 2.2.2.2), the S2 satellite data derived Moisture Index (B8A-B11/B8A+B11) was used as a line of evidence to support the classification of pools where imagery analysis had identified them as potentially permanent or semi-permanent. The Moisture Index provides a map of the soil and vegetation moisture content and can identify areas with non-meteoric (non-rainfall derived) water source such as groundwater and perched hyporheic water.

2.2.2.4 GOOGLE EARTH IMAGERY

The timeseries function in Google Earth was used to assess water presence for pools outside of the higher resolution aerial imagery capture area (see Section 2.2.1). The following Google Earth image dates were available and assessed for the study area:

- Sep-2006
- Feb-2007
- May-2011
- Sep-2011
- Jul-2013
- Sep-2013
- Nov-2015
- Jun-2018
- Mar-2020
- Jan-2021
- Dec-2022
- Apr-2023
- Mar-2024

2.2.3 LIDAR AND PHOTOGRAMMETRY

A site-wide digital elevation model has been captured using Light Detection and Ranging (LiDAR) at a 1 m resolution. In addition, drone-based photogrammetry was used to capture high-resolution imagery and elevation data for the Site 12 pool area in November 2024. This data was used to support the assessment of elevation for comparison to other datasets such as the modelled regional groundwater level contours.

For areas outside of the site wide 1 m LiDAR, SRTM data (NASA, 2024) and the Geoscience Australia elevation dataset (ELVIS; https://elevation.fsdf.org.au/) were used to obtain elevation data for the pools. When compared with LiDAR, the SRTM and ELVIS datasets are of much lower resolution and accuracy and provide less reliable estimates of pool elevation and water levels.

2.2.4 SITE PHOTOS AND INSPECTIONS

For many of the identified pools, physical inspection and collection of site photos was achieved during surface water monitoring[1] from December 2019 to November 2024. These photos were used to confirm water presence, substrate type and other hydrologic/hydrogeological features (such as seeps and vegetation changes). For difficult to access areas, helicopter overflight was conducted during routine surface water monitoring surveys in some cases.

2.2.5 CONCEPTUAL MODELS

Fortescue have developed conceptual models for several of the identified potentially permanent or semi-permanent pools in the study area. These conceptual models have been previously reported in environmental approvals submission documents (e.g., Fortescue, 2023).

2.3 HYDROLOGY / HYDROGEOLOGY

2.3.1 REGIONAL GROUNDWATER LEVELS

Fortescue provided modelled pre-mining regional groundwater level (mbgl) contours for assessment against pool elevations and landscape setting. The relative position of the groundwater table to estimated pool surface water levels is a key component of the pool classification method adopted from Bourke et al (2023; see Section 2.4.2).

2.4 POOL IDENTIFICATION AND CLASSIFICATION

2.4.1 IMAGERY ANALYSIS

Aerial and satellite imagery were accessed in a variety of GIS software platforms depending on functionality and format. Manifold GIS v8.0.34 was used to load .ECW (compressed wavelet image files) provided by Fortescue for the study area (see Section 2.2.1 and Appendix A) in Map Grid of Australia zone 50 projection, Geodetic Datum Australia 1994 (MGAz50, GDA94; EPSG:28350). Google Earth was used to generate pool register points (pool locations) for sites outside of the high-resolution aerial imagery capture areas. QGIS was used to format SHP files and some processing steps.

An initial pool register (points of pool locations) was developed from a combination of the following:

- Pools within the existing North Star project surface water monitoring program;
- Pools identified during site monitoring surveys (from 2019 to 2024) including helicopter overflights;
- Systematic visual review of satellite imagery (Google Earth) from the late dry season (Oct-Nov);
- Systematic visual review of aerial imagery provided by Fortescue for the late wet season period (Feb-April);

The location of late wet season pools observed in images from particularly wet years (surface water presence widely observed across the study area drainages) was recorded into a GIS layer (SHP file). Where there were strings of pools within the same reach that were clearly ephemeral (i.e. only present under recent rainfall conditions), a selection of the larger representative pools was chosen for assessment of those pool “reaches”.

This was most common in the lower elevation drainages that were supported by alluvium flow-through during active flow periods (e.g., Figure 2-3). In addition to true colour visual identification of pools, the NDVI and moisture index for the late dry season (October 2023) was interrogated from the Sentinel 2 (ESO) satellite datasets to identify any wet/moist areas that persisted into the dry season. These areas were then interrogated in the high-resolution true colour aerial imagery for the presence of pools.

The pool persistence or water presence classifications were adapted from the Australian National Aquatic Ecosystems (ANAE) toolkit (Aquatic Ecosystems Task Group, 2012). This system does not provide quantitative ranges or detailed guidance on water permanence classification except for a suggestion of calling pools with water present over 70% of the time as “Commonly Wet”. The other categories (see Table 2-1) were quantitatively defined for the purposes of this project.

Table 2-1 Water presence classification

Classification	Description
Permanently Inundated	Water always present (within the imagery analysed).
Commonly Wet	Water present >70% to 99% of the imagery analysed (may vary depending on the wet season, though the pool is known to dry out occasionally). This category is derived from the ANAE method.
Seasonally Inundated	Water present 50-70% of the imagery analysed. Mostly over the wet season. Relates to pools that routinely dry out over the dry season and are not likely to provide dry season refugia.
Periodic Inundation/Ephemeral	Water present <50% of the imagery analysed. Pools that dry out over the wet season, receding after flow events over a period of days to weeks and which do not tend to persist into the dry season.

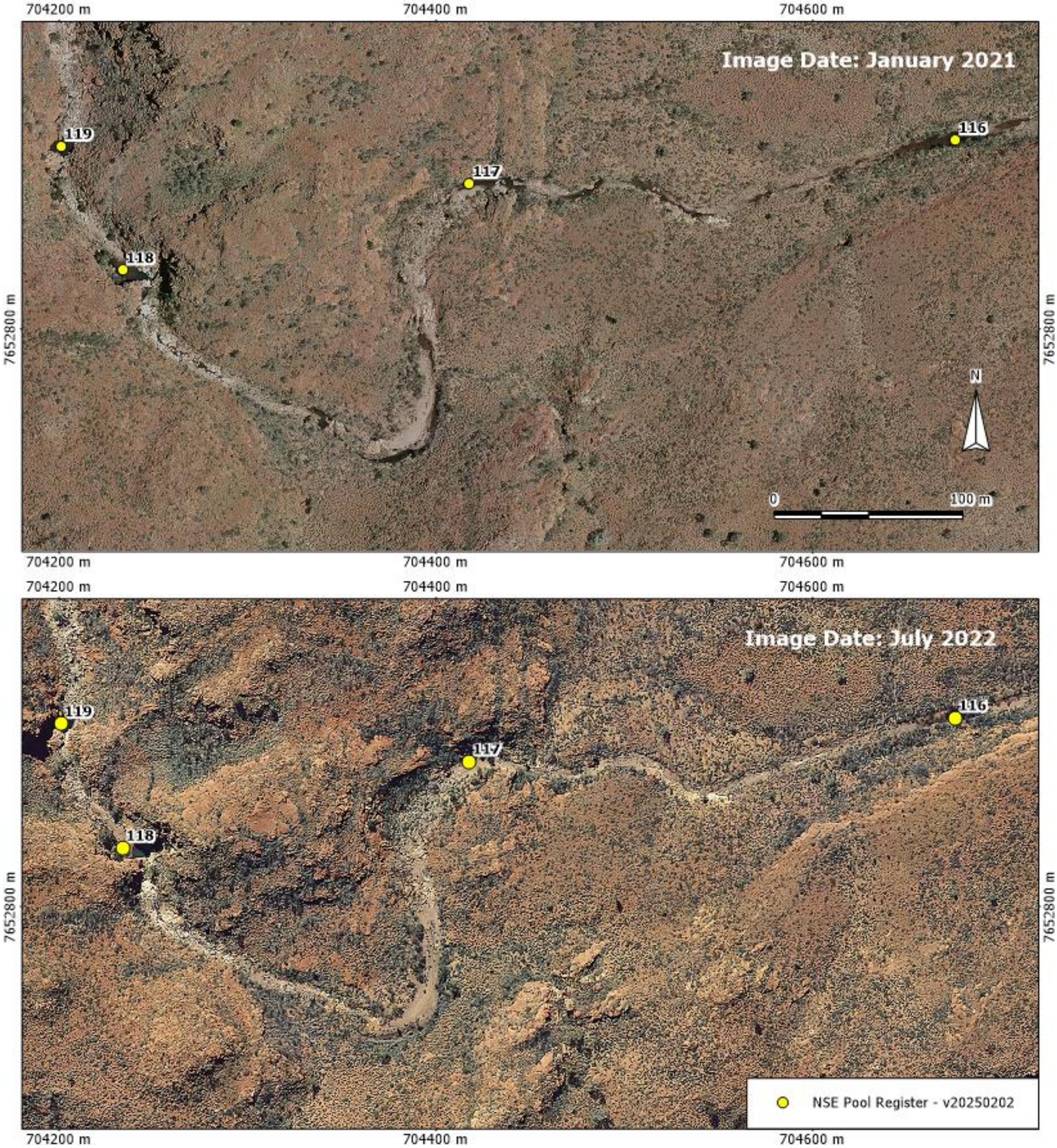


Figure 2-3 Example of a lower elevation drainage reach with a string of pools during the wet season (top: Jan 2021) and selection of the deeper/more persistent pools for the pool register assessment (yellow points; bottom).

Each identified pool was given a unique ID attribute (site name/number) and attribute columns generated for each image date.

Processing steps included:

1. Loading the data layers (image and pool register points files) into Manifold GIS;
2. For each image, the pool points register was overlaid, and the location of each individual pool was interrogated (zoomed into) and visually assessed for water presence as follows:
    a. A score of 0-5 for water presence (Table 2-2) was recorded in an excel spreadsheet against each pool in a separate column for each image. The percentage full assigned to each score in was based on visual assessment of the channel morphology and the maximum extent of water observed for each pool (i.e., where recent rains/flow had occurred):
    b. Where there was shadow over the pool, it was not clear if water was present or the image did not extend over the pool area, a null value was indicated.
3. The overall water presence classification for each pool (Table 2-1) was calculated based on the percentage of images with identifiable water present (score 1 to 5; Table 2-2). An additional metric of pool "fullness" was generated from the average water presence score (Table 2-2; Appendix B) across all images, though this was not used in classification, other than as a line of evidence to establish the hydrologic conceptual model for the pool (Appendix C).

Table 2-2 Water presence score

Score	Description
0	Dry
1	<10% full (small remnant puddle)
2	10-25% full
3	25-50% full
4	50-75% full
5	>75% Full - flowing reach

The Study Area features multiple pools that exist within narrow crevices/gorges and/or at the bottom of cliffs. For four of these sites, it was assessed that sufficient certainty over water presence could not be achieved from the available imagery (i.e., the pools were mostly in shadow or under overhangs in the imagery). It was assumed for reporting and assessment purposes that, as the pools had been named, they were conservatively classified as "Commonly Wet" (water present over 70% of the time). This applied to Astrid Bee Cave, Dingo Lair Pool, Craig's Pool and Zane's Gorge Pool. These pools are described and discussed further in Section 3.2.3.2.

2.4.2 BOURKE ET AL., 2023 METHODOLOGY

A recent published peer-reviewed scientific paper titled *A hydrological framework for persistent pools along non-perennial rivers* (Bourke et al., (2023) was identified as providing a suitable basis for categorising the pools identified for the NSE study area based on their hydrologic and hydrogeological characteristics. This paper specifically used Pilbara pools for the case studies of the application of its methodology and therefore was particularly relevant to the NSE study area. Bourke et al. (2023) proposed a framework for the classification of the key hydraulic mechanisms that support the persistence of river pools.

The three main hydraulic mechanisms identified by Bourke et al. (2023) are:

- **Perched surface water**;
  - "*Perched surface water can persist in topographic lows that retain rainfall and runoff during the dry season but are disconnected from the (regional) groundwater system*."
- **Throughflow of alluvial groundwater**;
  - *"During rainfall events, increases in water levels in rivers result in water storage and flow within the unconsolidated alluvial sediments in the beds and banks of stream channels (Cranswick and Cook, 2015). As the streamflow recedes after a flood, continuous surface flow ceases, resulting in isolated pools along the river channel. Some vertical thickness of the alluvial sediments that line the stream channel will remain saturated with water beyond the period of surface water flow; this water is hereafter referred to as alluvial groundwater.*"
- **Groundwater discharge**;
  - Geological contacts and barriers to flow: "*Two subtypes: (i) catchment constriction across ridges, or (ii) aquifer thinning due to geological barrier intersecting topography. Presence of waterfalls or surface geological features (hard-rock ridges). Hydraulic head step changes across pool feature*".
  - Topographically controlled seepage from regional aquifer: "*Topography intersects (i) water table or (ii) preferential flow from… aquifer. Standing water persists during dry season due to groundwater discharge in absence of rainfall*".
  - A third groundwater discharge mechanism has been added to the above classifications for the purposes of the current study. In discussions with Fortescue and Worley hydrogeologists, a conceptual mechanism of localised "perched" groundwater supported by a geological structure (intrusion/fault/aquitard) has been proposed. The NSE study area contains several permanent or semi-permanent (commonly wet) pools that appear to be situated above the regional groundwater table (based on groundwater levels from regional monitoring bores or on inferred pre-mining water level from groundwater modelling). Given that water persistence in these pools is greater than would be expected if they were perched surface water supported (i.e., due to losses to evaporation), a localised or discrete source of groundwater "seepage" could be responsible for supporting these pools into the dry season.

The Bourke et al. (2023) method does not provide any classification system for water persistence, only water source. However, the Australian National Aquatic Ecosystems (ANAE) classification framework does have broad guidance on classifying water persistence (see Section 2.4.2.2).

Bourke et. al. (2023) also suggests diagnostic tools for mapping and classifying persistent pools including:

- Regional-scale Tools:
  - Remote sensing and image analysis
  - Landscape position and geological context
  - Hydrogeological context
- Pool-scale tools:
  - Pool hydrography and water balance
  - Pool hydrochemistry
  - Stable isotopes of water
  - Temperature

These datasets were utilised within the current assessment and classification as available. Regional scale geology mapping, fault mapping, depth to groundwater, water quality and elevation data were attributed to the pool points using GIS layers of each dataset.

2.4.2.1 CONCEPTUAL MODELS

The following conceptual models for water source in persistent pools were adapted from Bourke et. al (2023) for the current study (Table 2-3):

Table 2-3 Summary of Conceptual Water Source Models used in the current study

Type #	Conceptualisation	Description	Potentially Sensitive to Surface Water Changes	Potentially Sensitive to Local Groundwater Changes	Potentially Sensitive to Regional Groundwater Changes
1a	Alluvium - perched throughflow	Alluvium throughflow, with scour holes and potential for localised perching due to presence of lower permeability units. Pool water primarily reliant on surface water flows, and pool levels higher than "regional" water table.	Yes	No	No
1b	Alluvium/bedrock - perched throughflow	Alluvium throughflow, with scour holes and bedrock expressions, resulting in localised perching of surface water. Pool water reliant on surface water flows, and pool levels higher than "regional" water table.	Yes	No	No
2a	Bedrock - perched surface water	Perched water high in bedrock catchment, pool situated within lower permeability units. Pool water reliant on surface water flows or interflow, and pool levels higher than "regional" water table.	Yes	No	No
2b	Bedrock fracture / regolith flow groundwater source	Pool fed by shallow and/or deep groundwater via flow in fractured bedrock or regolith. Fracture systems may be aligned with surface water drainage lines. Connection with regional water table is unlikely due to position of pool in the landscape, and the unique presence of the pool where adjacent drainages do not show pool features at the same elevation or lower.	No	Yes	No
3	Bedrock aquiclude - groundwater discharge	Groundwater discharge to surface due to catchment constriction across ridge line, presence of low permeability unit and lateral constraint on groundwater flow.	No	Yes	Yes
4	Topographically controlled groundwater outflow	Topographically controlled groundwater outflow either regional or local. These locations identified based on water presence, geomorphological and catchment setting.	No	Yes	Yes

Figure 2-4 to Figure 2-9 provide visual conceptualisations for each model applied in the pool classifications for the current study. These have largely been adopted from Bourke et. al. (2023) though with minor modifications as noted in the figure captions and markups on the figures.

The hydraulic conceptualisation Type 2b (Bedrock - fracture flow groundwater source) has been derived specifically for the NSE project and has previously been used by Fortescue (2023) to describe the hydraulic conceptual model for several North Star Project area pools. It is proposed that this type of pool is supported by dry season inflows from **local** groundwater, potentially hosted within fractured rock or regolith above and adjacent to the pool. These pools are not likely to be connected to the regional water table, based on their position in the landscape (relative to regional water table monitoring records) and the unique presence of the pool where adjacent drainages do not show pool features at the same elevation or lower.

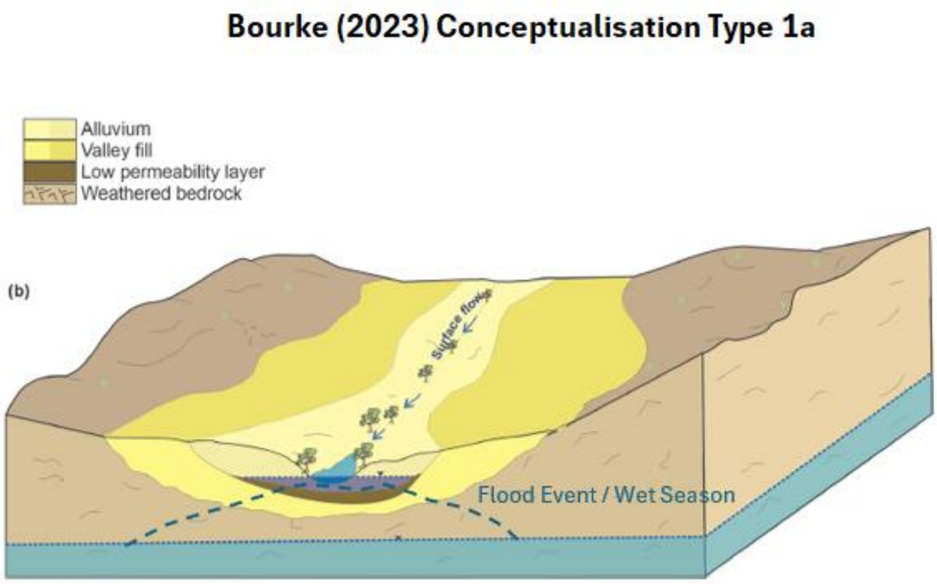


Figure 2. Schematic illustration of pools that are maintained by throughflow from the adjacent alluvial sediments. The water in these alluvial sediments can be either **(a)** connected to the unconfined aquifer, or **(b)** form a perched aquifer if the water is stored over a low permeability layer.

Figure 2-4 Hydraulic mechanism Type 1a: Alluvium - perched throughflow (adapted from Bourke et. al. (2023) Figure 2).

Bourke (2023) Conceptualisation Type 1b

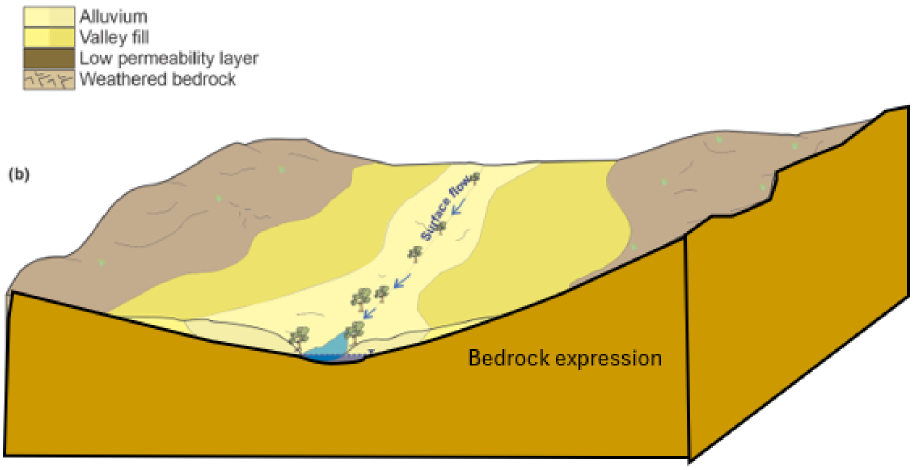


Figure 2. Schematic illustration of pools that are maintained by throughflow from the adjacent alluvial sediments. The water in these alluvial sediments can be either **(a)** connected to the unconfined aquifer, or **(b)** form a perched aquifer if the water is stored over a low permeability layer.

Figure 2-5 Hydraulic mechanism Type 1b: Alluvium/bedrock - perched throughflow (adapted from Bourke et. al. (2023) Figure 2).

Bourke (2023) Conceptualisation Type 2a

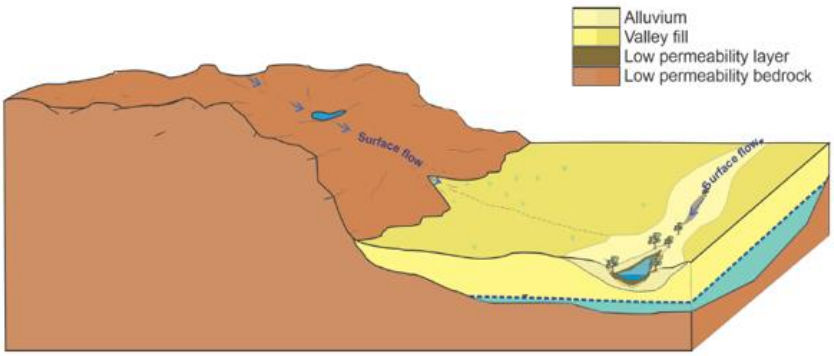


Figure 1. Schematic illustration of perched pools where rainfall–runoff collects in a depression that has morphology that limits evaporation, and/or low permeability lithology beneath the pool that limits infiltration, allowing water to be retained for an extended duration.

Figure 2-6 Hydraulic mechanism Type 2a: Bedrock - perched surface water (adapted from Bourke et. al. (2023) Figure 1).

Bourke (2023) Conceptualisation Type 2b

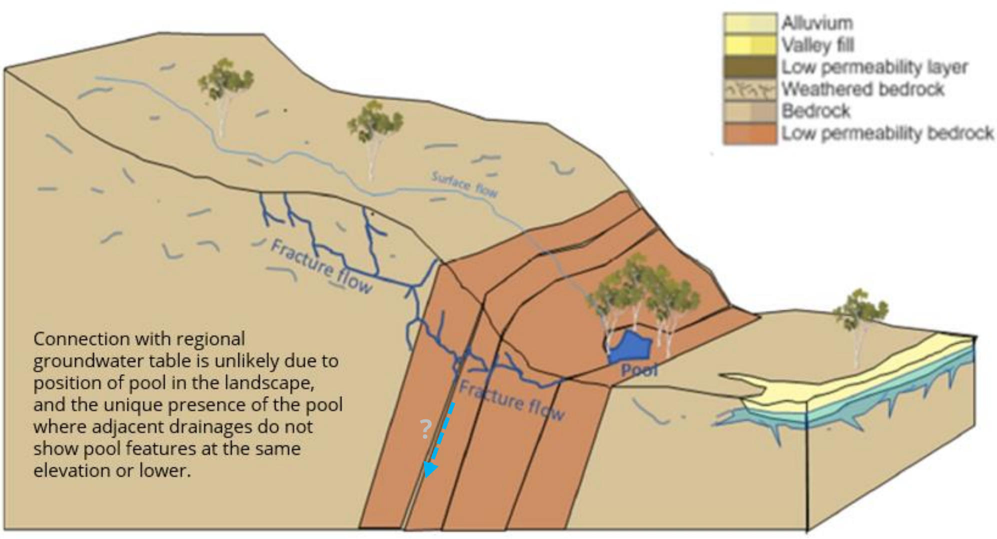


Figure 19: Schematic illustration of fracture flow groundwater source for Cow Spring and Fig Pool (adapted from Bourke *et al.* (2023)).

Figure 2-7 Hydraulic mechanism Type 2b: Bedrock fracture / regolith flow groundwater source (adapted from Fortescue (2023) Figure 19, after Bourke et. al. (2023).

Bourke (2023) Conceptualisation Type 3

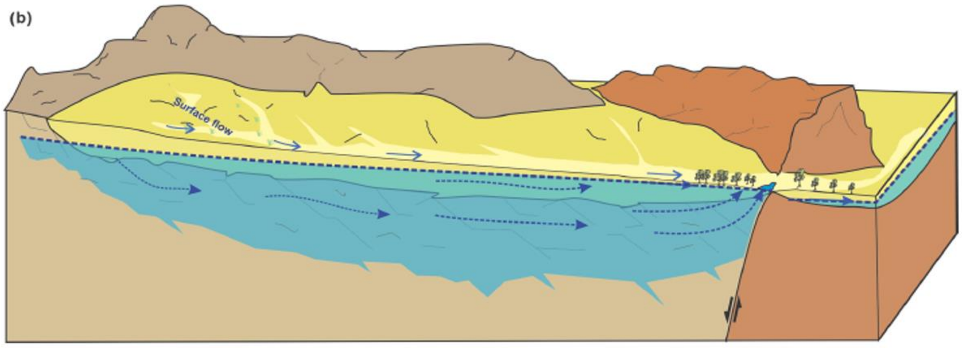


Figure 3. Schematic illustration of a groundwater discharge pools where surface water persistence is driven by geological barriers that **(a)** cause a regional aquifer to pinch out vertically or **(b)** form a lateral constraint on the catchment and underlying regional aquifer.

Figure 2-8 Hydraulic mechanism Type 3: Bedrock aquiclude - groundwater discharge (adapted from Bourke et. al. (2023) Figure 3).

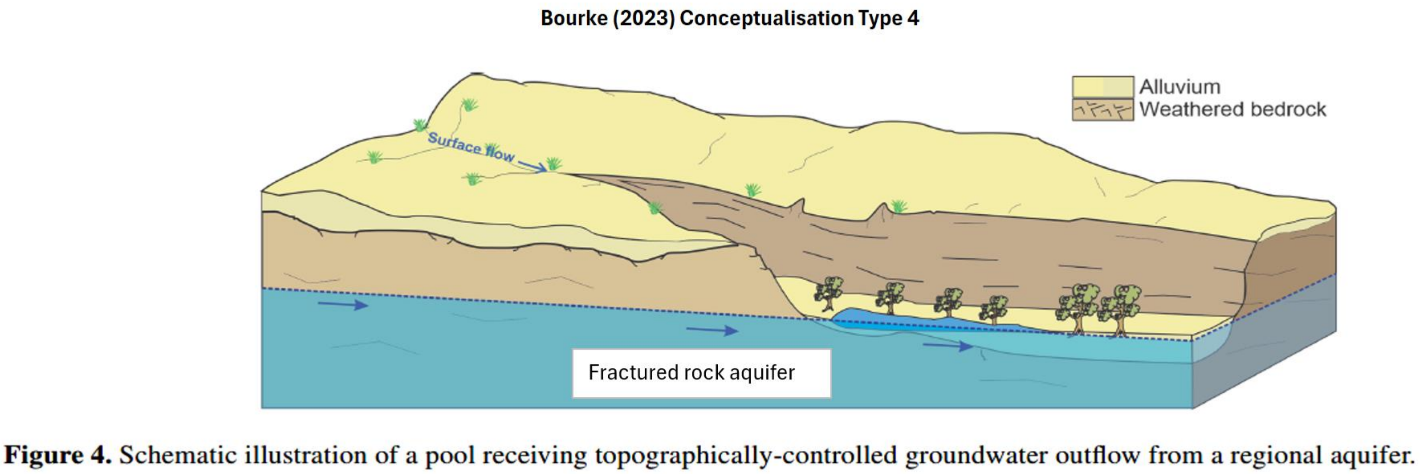


Figure 2-9 Hydraulic mechanism Type 4: Topographically controlled groundwater outflow (adapted from Bourke et. al. (2023) Figure 4).

2.4.2.2 AUSTRALIAN NATIONAL AQUATIC ECOSYSTEMS (ANAE) COMPARISON

The ANAE classification framework is a broad-scale, semi-hierarchical, attribute-based scheme, which provides a nationally consistent and flexible framework for classifying different aquatic ecosystems and habitats including rivers, floodplains, lakes, palustrine wetlands, estuaries, and subterranean ecosystems (Aquatic Ecosystems Task Group, 2012).

The ANAE framework consists of three levels which are designed to capture the broad spatial patterns and ecological diversity of aquatic ecosystems and habitat types. Level 1 is regional scale, Level 2 is landscape scale, and Level 3 is aquatic classes, systems and habitats.

Levels 1 and 2 are large scale, national regionalisations for landform, climate, hydrology, topography and water influence, which provide context relative to both the regional and landscape scales. Level 3 identifies the classes of aquatic ecosystems (surface water and subterranean), major aquatic systems (e.g. estuarine, lacustrine, riverine, and floodplain), and the pool of attributes used to classify those systems into habitats.

The water persistence classification within the ANAE toolkit (Aquatic Ecosystems Task Group, 2012) provides general classes of persistence as outlined in Table 2-4. These have been adapted to have numeric thresholds for the current NSE study to allow for pool classification using the water presence data obtained from imagery interrogation (see Section 2.4.1; Table 2-2).

Table 2-4 Water persistence classification framework taken from the ANAE toolkit (Table 2)

Attribute	Metrics and Thresholds	References
Water Regime: Water regime conditions have a major influence in determining the nature and persistence of aquatic ecosystems. For example, permanent systems are often highly important in providing refugia for plants and animals during dry/drought conditions, while the unique nature of ephemeral systems, especially those in arid areas, leads to interesting endemic and highly adapted flora and fauna. As such, water regime is a key attribute used to characterise and differentiate between different habitats and ecosystems. A range of metrics and thresholds have been identified which differentiate the range of influence water regime has on aquatic ecosystems.	Presence of water*: • Permanently inundated • Seasonally inundated • Aseasonally inundated • Waterlogged'*' OR** • Commonly wet (>70% of time) • Periodic inundation • Waterlogged'*' * This attribute may include sub-metrics to support environmental flow assessment where data is available. Potential sub-metrics for detailed flow regime include flow to achieve inundation/commence-to-flow, duration, 10-year representation of flow etc. available from records or modelling. ** Where data is limited. Based on remote sensing plus expert knowledge. *** Included to accommodate seasonally waterlogged areas in temperate Australia and Alpine bogs etc. that are generally not inundated.	Information for this category is often derived from remote imagery to identify extent over a range of wet and dry periods. The following information is derived from Boulton and Brock (1999): • Permanent - may be static or flowing, with varying levels, however is predictably filled. • Seasonally - covers intermittent with wet and dry periods on a regular basis according to season. Such areas often have a higher flora and fauna diversity than permanently inundated areas. • Aseasonal - captures areas that alternate between wet and dry but not on a predictable basis. This includes such regimes as: – Intermittent: alternating wet and dry periods but less frequently and regularly than seasonal. – Episodic: dry most of the time with irregular wet phases that may persist for months. Annual inflow is less than minimum annual loss in 90% of years. – Ephemeral: only filled after unpredictable rainfall and runoff. Surface water dries within days of filling and seldom supports macroscopic aquatic life. • Waterlogged must have hydric soils as a minimum (and associated wetland flora and fauna).

2.4.2.3 EVIDENCE MATRIX

Multiple lines of evidence were used to derive a hydraulic conceptualisation for each identified pool. Appendix C provides a results summary for each line of evidence as detailed in Table 2-5.

Table 2-5 Evidence Matrix description

Line of Evidence	Description
Evidence matrix based source	This field contains the general consensus on the likely water source based on the multiple lines of evidence listed below. This is either GW (groundwater), SW (Surface Water) or GW/SW (a combination of both).
EM - Water Presence	SW indicators include: • Water presence typically only after wet season rains (for days to weeks) • Receding water at or faster than evaporation rates after the last rainfall event • Water not typically present during the dry season GW indicators include: • Water presence in the pools for longer than would be expected/calculated based on evaporation and antecedent rainfall. • Water not receding after extended dry periods (months)
EM - Fullness Score	As for Water Presence, the average fullness of the pool (see Section 2.4.1) can indicate if inflows to the pool are related to rainfall or a more consistent source (i.e. groundwater). For example, pools that are reliant on surface flows will recede (become less full) with time from the previous flow event. Groundwater sourced pools will be more stable/persistent.
EM - Substrate	The substrate of a pool can provide an indication of the permeability and potential for the pool water being perched above an impervious geological layer (e.g., bedrock). Pools within deep alluvial sediments, particularly scour holes at bends (often against a rock-face), can indicate a surface water source of alluvial throughflow.
EM - Location	This line of evidence can be somewhat subjective though useful. For example, a pool located at the base of a cliff face, with a very small catchment above it, could be considered in a location that is likely to be supported by local groundwater derived from the elevated terrain adjacent to the pool (as the catchment would be too small for extended alluvial throughflows). Pools located within a similar setting to other pools, where more data might exist, can have "Location" line of evidence suggesting a likely similar water source.
EM - Elevation	The elevation can be relevant to the potential for regional groundwater to be a source (i.e., the pool is below the measured or inferred regional water table elevation). Similarly, if data exists that indicates groundwater surface expressions occur within a given elevation band, then this can be a potential line of evidence.
EM - Depth to regional GW	As with Elevation, the relative depth of the regional water table to the pool water surface can indicate if there is potential for the pool water to be from or in connection to this source. Pools with surface elevations above the regional water table (within a margin of error for topographically driven variability), can be attributed to a local aquifer or surface water source depending on the water persistence.
EM - Catchment Size	For alluvial throughflow to generate persistence of pools deep into the dry season, a relatively large catchment may be required to support this as a potential source. Where the catchment area is relatively small, and inflows exist in alluvial substrates or bedrock depressions (substrate) into the dry season, this may indicate that a groundwater source is present.
EM - Flow Regime	The measured flow-regime of a pool can indicate the dominant water source. For example, if a pool only fills with a rainfall event (as indicated by local rainfall records) and recedes at a rate consistent with alluvial throughflow/evaporation post surface water flow events, then a surface water source would be indicated. If the pool continues filling weeks after surface water flows have ceased within the drainage, and persists well into the dry season, this may indicate that a groundwater source is present.
EM - Vegetation	Groundwater near the surface can drive the presence of dense vegetation (groundwater dependent vegetation – GDV) dominated by wetland species (e.g. Melaleuca, Sedges, Typha etc.). If the vegetation vigour extends into the late dry season, relative to regional vegetation, then a groundwater source is likely to be present (e.g. as measured by NDVI). The absence of hydrophilic vegetation, or denser vegetation relative to the regional norm, can indicate that the groundwater table is not close to the root zone within the pools location and therefore the pool may be surface water sourced.
EM - Hydrochemistry	The most common hydrochemical indicator for groundwater inflows is a difference in dissolved ion content (as measured by electrical conductivity/salinity). Groundwater typically contains higher concentrations of dissolved ions than surface water inflows dominated by recent rainfall. In contrast, surface water inflows that have ceased and are perched on impervious substrates (such as in a bedrock depression) will increase in dissolved ion concentrations as the water evaporates into the dry season. A salinity above the local/regional groundwater concentration may indicate a perched surface water source.

2.4.3 REACH CLASSIFICATION

For the purposes of impact assessment, individual pools were grouped into local reaches along a connecting section of drainage line (generated from the site wide 1 m resolution LiDAR elevation model, e.g. Figure 2-10). Where there was only a single pool along a reach, a representative section of drainage line upstream and downstream of the pool "point" feature was included as the pool reach. The length of the reach upstream and downstream of the pool point was variable, based on the nearest intersection of tributaries to the main channel, though was typically on the order of 50-100m upstream and downstream of the pool "point".

The purpose of generating reaches was to provide a mechanism to group pools within close proximity (i.e. within several hundred meters along the same drainage line) where the same impact mechanisms and assessment could be applied across the reach. This reduced repetition where groups of pools would be similarly potentially impacted.

A buffer polygon of 10 m either side of the reach drainage line was generated for mapping and figure production purposes. This buffer polygon was also used to overlay pool points and transfer data attributes from the point layer to the reach layer from the pools within each reach.

The attributes from the pool register point file (SHP file) were overlaid onto the Reaches polygon SHP file. Where there were multiple pools within a reach, the water permanence classification of the most persistent pool was applied (i.e., if there was both an "ephemeral" and a "seasonally inundated" pool within the reach, then the "seasonally inundated" attribute was applied).

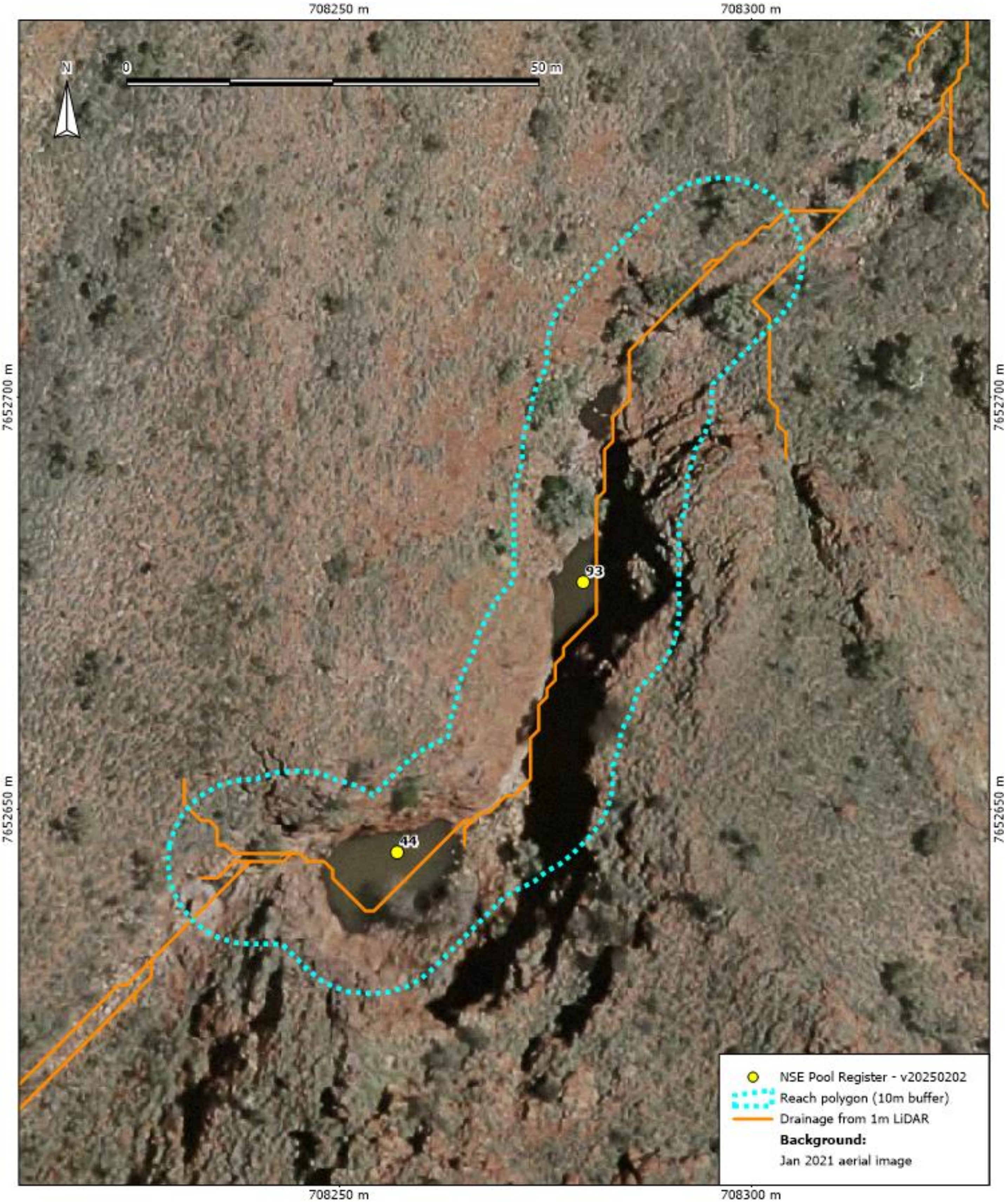


Figure 2-10 Example of two pools (#44 and 93) being combined into a single reach for impact assessment purposes.

3. RESULTS

3.1 POOL IDENTIFICATION AND CLASSIFICATION

A total of 102 pools were identified and assessed for water presence across the NSE Inland Waters study area (Figure 3-1). An average of 26 images (+- 10.7 st.dev; min. 0, max. 45) were available for the water presence classification of each pool. A total of 2,715 pool images across the 103 pools were assessed with water being present on average in 35% of the images.

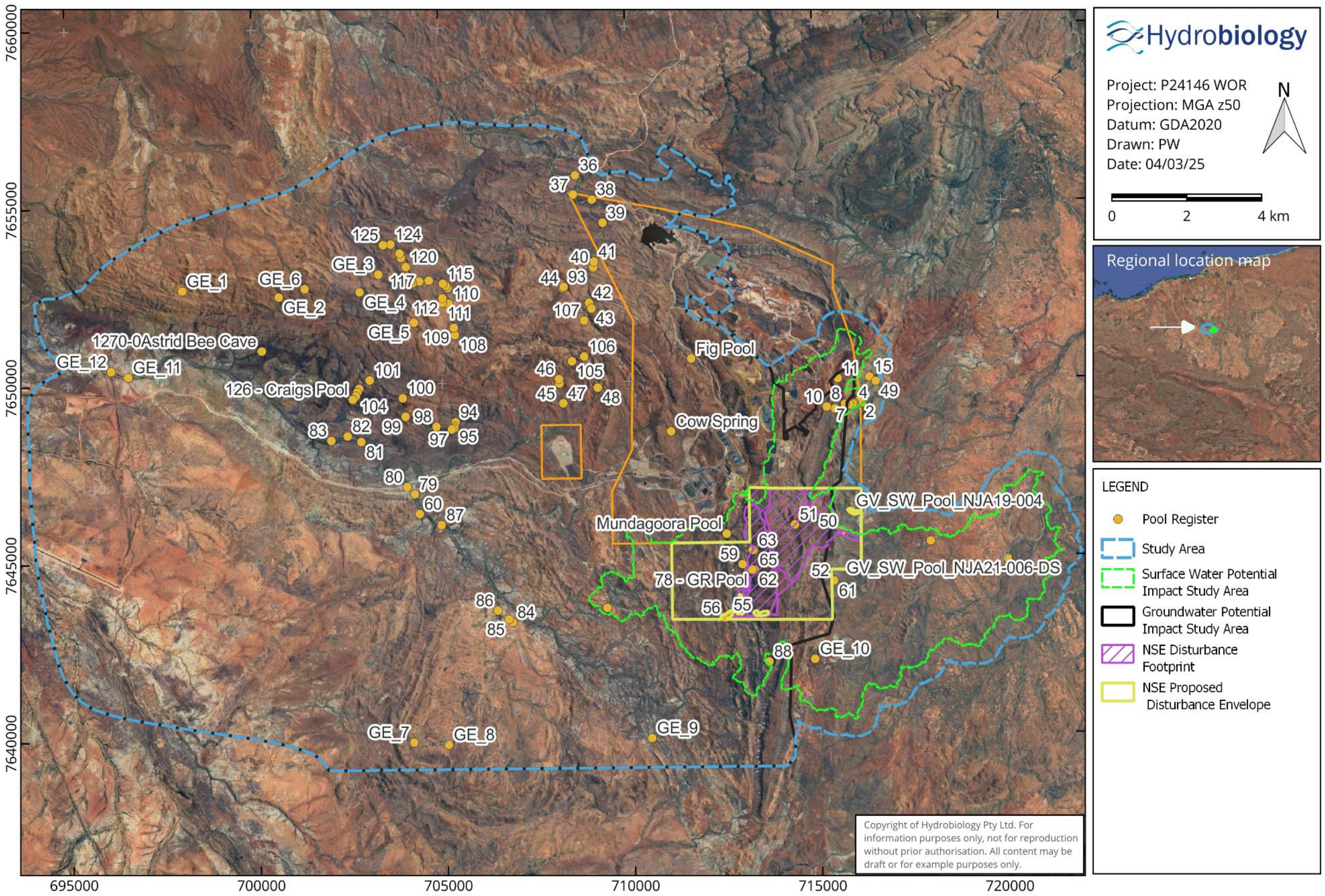


Figure 3-2 NSE Pool identification.

Water was most present in the mid-wet season (January; 79%) and least present in the late dry (November; 15%) as would be expected (Figure 3-1). Note that the May dataset had only 7 data points and therefore is not representative.

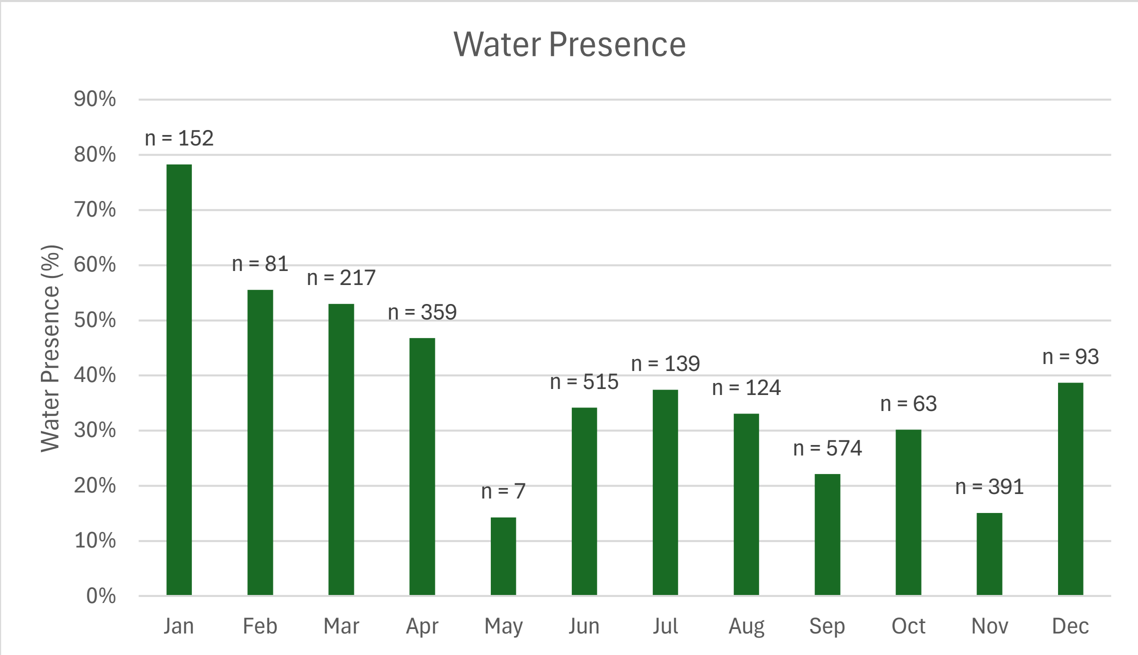


Figure 3-3 Percentage of pools containing water by month across all images

Table 3-1 provides a summary of the number of pools identified within the NSE Inland Waters study area within each water presence category. Seven pools (7%) were identified as permanent (having water present in all imagery) and 14 pools (14%) as Commonly Wet (having water present in over 70% of imagery). The vast majority were either Seasonally Inundated (11%; water present during the wet season) or had Periodic Inundation/Ephemeral (69%; water present for a shorter period after rainfall events).

Table 3-1 Pool water permanence classification summary

Permanence Classification	Fraction of images in which water was present	Count	Percentage of Total Count (%)
Permanent	1	7	7%
Commonly Wet	0.7 <> 1	14	14%
Seasonal Inundation	0.5 <> 0.7	11	11%
Periodic Inundation/Ephemeral	<0.5	70	69%
	Total	**102**	**100%**

Figure 3-2 presents the point location of all pools assessed within the current study area across both the potential groundwater impact and surface water impact areas. The pool points are thematically coloured by their respective water presence categories. As described in Section 2.4.3, a section of the drainage line upstream and downstream of each pool was selected as the pool "reach" for the purposes of impact assessment. Where multiple pools were located within close proximity, a single reach was created containing these adjacent pools, for the purpose of subsequent impact assessment. Note that impact assessment is not within the scope of this report and will be covered by subsequent reporting by Worley and Fortescue. Appendix D provides detailed maps of the pools including pool name labels for reference.

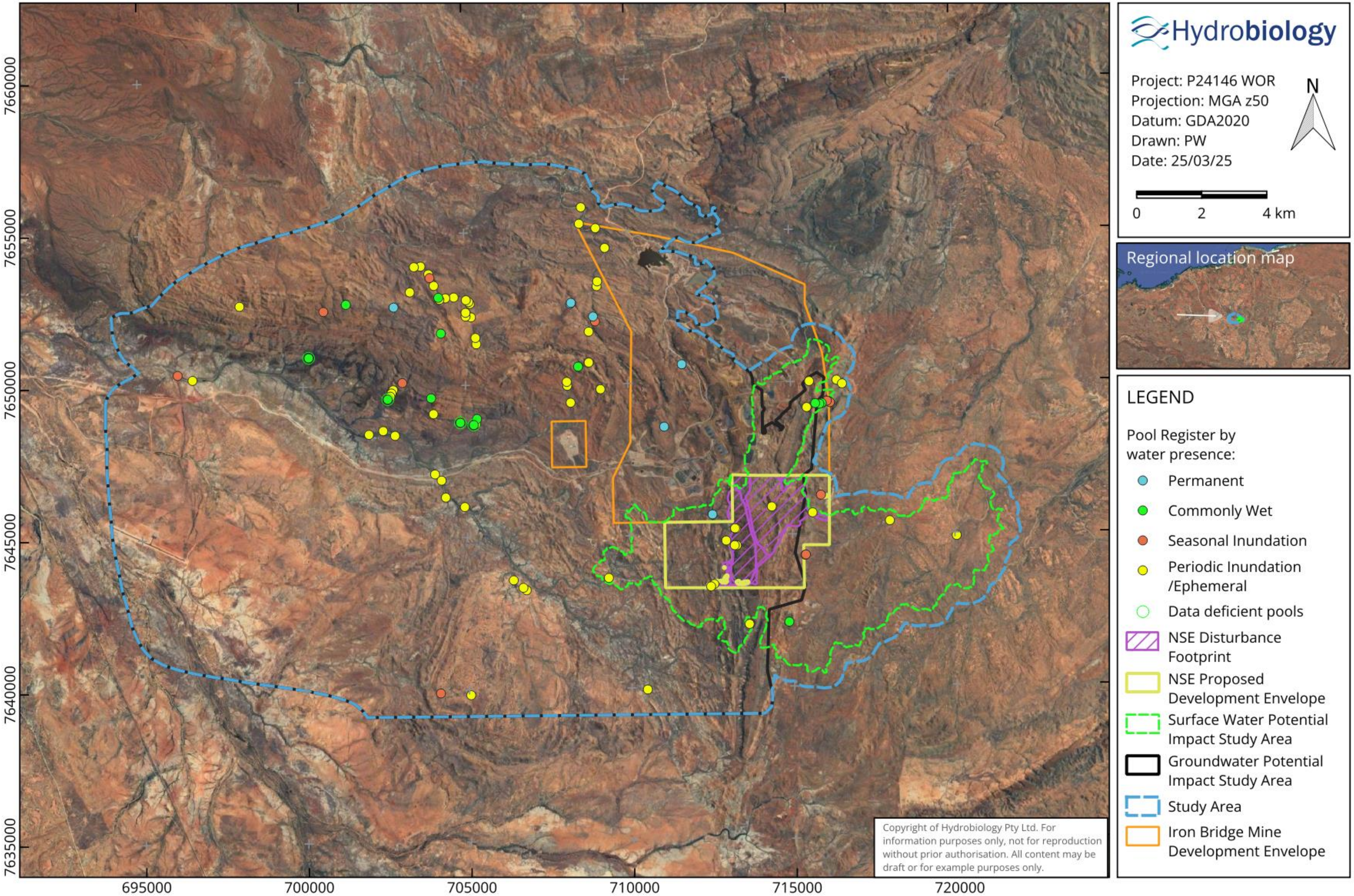


Figure 3-4 NSE Pools by water presence category

3.2 APPLICATION OF HYDROLOGICAL FRAMEWORK FOR PERSISTENT POOLS ALONG NON-PERENNIAL RIVERS (BOURKE ET AL., 2023)

The application of a hydrological conceptual model to each identified pool within the NSE study area was undertaken using a range of lines of evidence. These included data sources described in Section 2.2 and the approach outlined in Bourke et. al. (2023). While impact assessment is not within the scope of this report, the identification and classification of pools was primarily to inform the impact assessment process being completed by Worley. Therefore, the conceptual hydrologic models attributed to each identified pool were focused on the source of the sustaining waters for each pool. This included if each pool was supported by groundwater inflow, surface water inflow or, a combination of both (see Section 2.3).

Alluvial flowthrough was treated as a surface water source for the purposes of classification, although it is recognised that groundwater is part of alluvial flows. Further, groundwater can be sourced from a local aquifer (e.g., perched aquifer, fractured rock, or fault zones) or the regional aquifer (major aquifer with relatively high intra-aquifer hydraulic connection, allowing for equilibration of water levels on a sub-decadal timescale across the relevant region).

Pools fed by regional groundwater, have higher potential to be impacted by drawdown of the regional aquifer. Local aquifers are unlikely to be affected by drawdown in the regional aquifer although, the area is host to a complex interaction of faults and geological structures that may affect connectivity between the mining area and individual pools.

Within the current study, it was assumed that any pool which persisted into the dry season, beyond what would be likely supported by alluvial throughflow (taking into account evaporative losses), was likely to be groundwater supported to some extent. The source of this groundwater could be either a local aquifer (e.g., perched, fractured rock / regolith), or regional groundwater (i.e., the pool surface is at or below the regional groundwater table). Conversely, pools that were seasonally inundated or periodically inundated/ephemeral were likely to be supported by surface water inflows (runoff) including shallow aquifer inflows into channels and alluvial throughflow. These pools would be unlikely affected by regional aquifer drawdown, though may have potential impacts from any catchment alteration and flow velocity changes due to the NSE project.

Appendix B provides information on which pools were identified as being within the potential groundwater and surface water impact areas.

3.2.1 EVIDENCE MATRIX

For each identified pool, a conceptual model of the potential water source was assigned based on a range of evidence. An evidence matrix for the various lines of evidence for assigning a groundwater or surface water source to each pool, and subsequent hydraulic conceptual model assignment (as outlined in Section 2.4.2.3) is provided in Appendix C.

As an example of the role of elevation as a line of evidence, Figure 3-3 provides a cross-plot of the elevation data and pool fullness score (see Section 2.4.1) for the NSE study area. There is a clear correlation between the fullness or persistence of pools and elevation with pools within the 280-320 m elevation range (ELVIS ground elevation dataset is used to include areas for which Lidar is not available) having a greater representation within the more persistent pools categories. This is not an exclusive relationship, in that pools of low persistence also exist within this elevation band and, some pools with high persistence exist outside this band. For this reason, it is important to consider multiple lines of evidence when assigning a potential conceptual hydrological model to each pool.

Section 2.4.2.3 provides further information on how these lines of evidence were defined and applied.

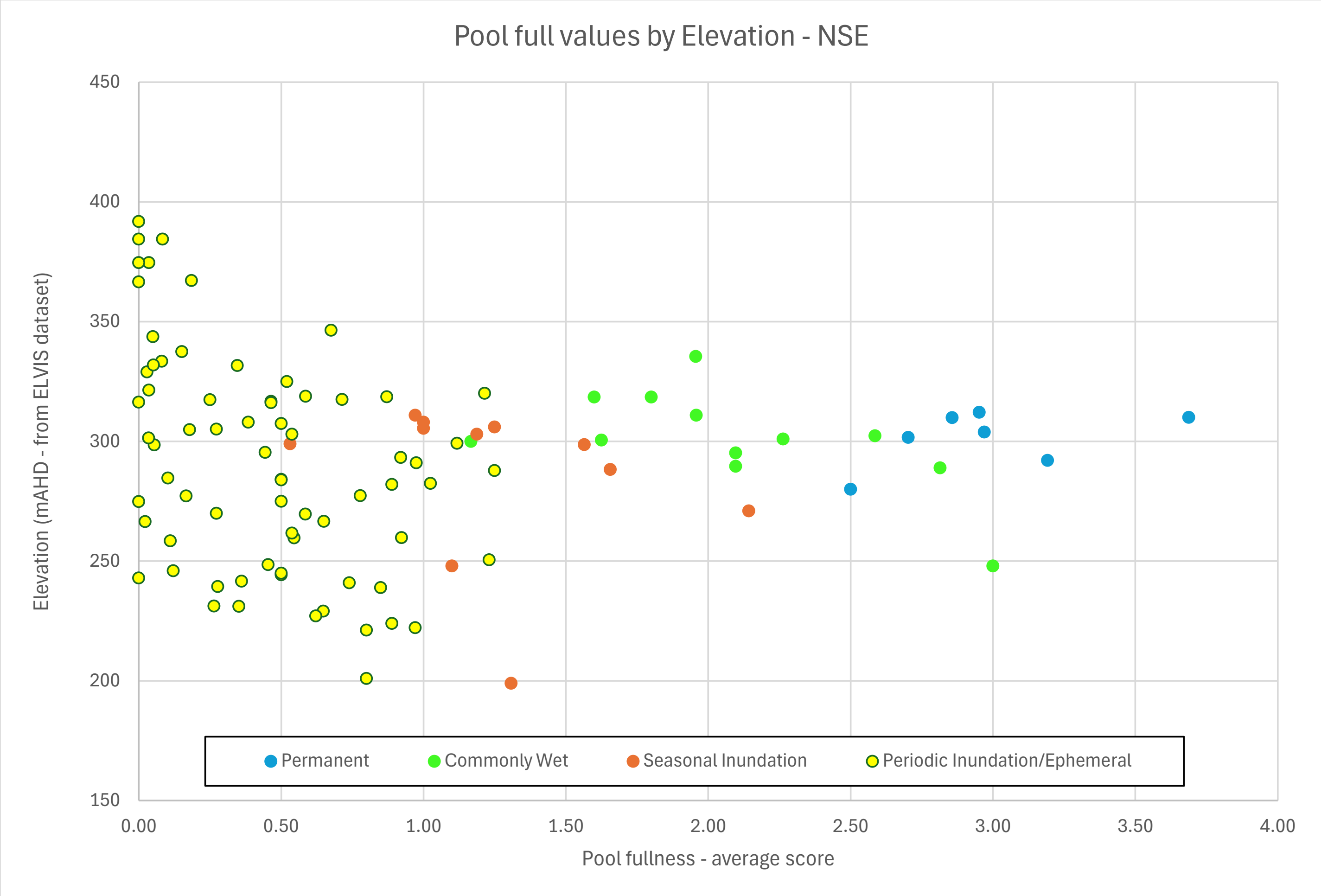


Figure 3-5 Pool fullness score by elevation for NSE study area pools

3.2.2 REACH IDENTIFICATION AND CLASSIFICATION

As described in Section 2.4.3, for the purposes of impact assessment, the individual pools were included within a "reach". The majority of the reaches had only one pool (72 of 82 reaches). Six reaches included 2 pools, 3 reaches included 3 pools, 1 reach had 4 pools and 1 reach had 8 pools (the Site 12 Pool string of pools; Figure 3-4).

Table 3-2 provides a summary of the number of reaches within each water persistence type identified within the potential groundwater and potential surface water impact assessment areas respectively

Figure 3-6 Site 12 string of pools showing individual pools and assessed reach

Table 3-2 Count of reaches by water persistence type within the Groundwater and Surface Water Impact areas.

Water Persistence Type	Within Groundwater Impact Area	Within Surface Water Impact Area
Permanent	7	1
Commonly Wet	11	2
Seasonal Inundation	*6*	1
Periodic Inundation/ Ephemeral	*50*	11
Total	**74**	**15**

Table notes:

- *Pools with only seasonal inundation or periodic inundation/ephemeral water persistence types (greyed italic text) were considered unlikely to be groundwater fed.*

Table 3-3 provides a summary of the number of reaches within each identified hydraulic conceptualisation type (after Bourke et. al. 2023). The majority of reaches were identified as being sourced by 1a - alluvium throughflow (35) with the second most common water source being 2a - perched surface water (21) within bedrock features of low permeability (i.e. scoured rock-holes within creek beds). A thematic map of the reaches by hydraulic conceptualisation type presented in Figure 3-5.

As the pool identification and reach allocation was completed largely in GIS software, the primary data repository for this dataset is in the form of electronic shapefiles (SHP). Interrogation of the data at an individual pool or reach level is best achieved within a GIS system, allowing for viewing of attribute information and providing geographic context. Therefore, individual pool maps/images have not been included within this report. The appendix data does include pool coordinate information and therefore can also be converted to GIS format(s) if required.

Table 3-3 Count of reaches within each hydraulic conceptualisation type

Hydraulic Conceptualisation Type	Primary Water Source	Count of Reaches within Study Area	Count within Groundwater Impact Area	Count within Surface Water Impact Area
1a	Alluvium - perched throughflow	34	32	**5**
1b	Alluvium/bedrock - perched surface water throughflow	9	7	**1**
2a	Bedrock - perched surface water	21	19	**6**
2b	Bedrock - fracture flow groundwater source	9	9	0
2a/2b	Potentially either 2a or 2b	7	5	**1**
3	Bedrock aquiclude - groundwater discharge	2	**2**	**2**
4	Topographically controlled groundwater outflow	0	**0**	0
	Total	**82**	**74**	**15**

Table notes:

- *Some reaches are within both the surface water and groundwater impact assessment areas. Therefore, the total number of reaches within the Study Area is less than the sum of the reaches within the combined surface water and groundwater columns.*

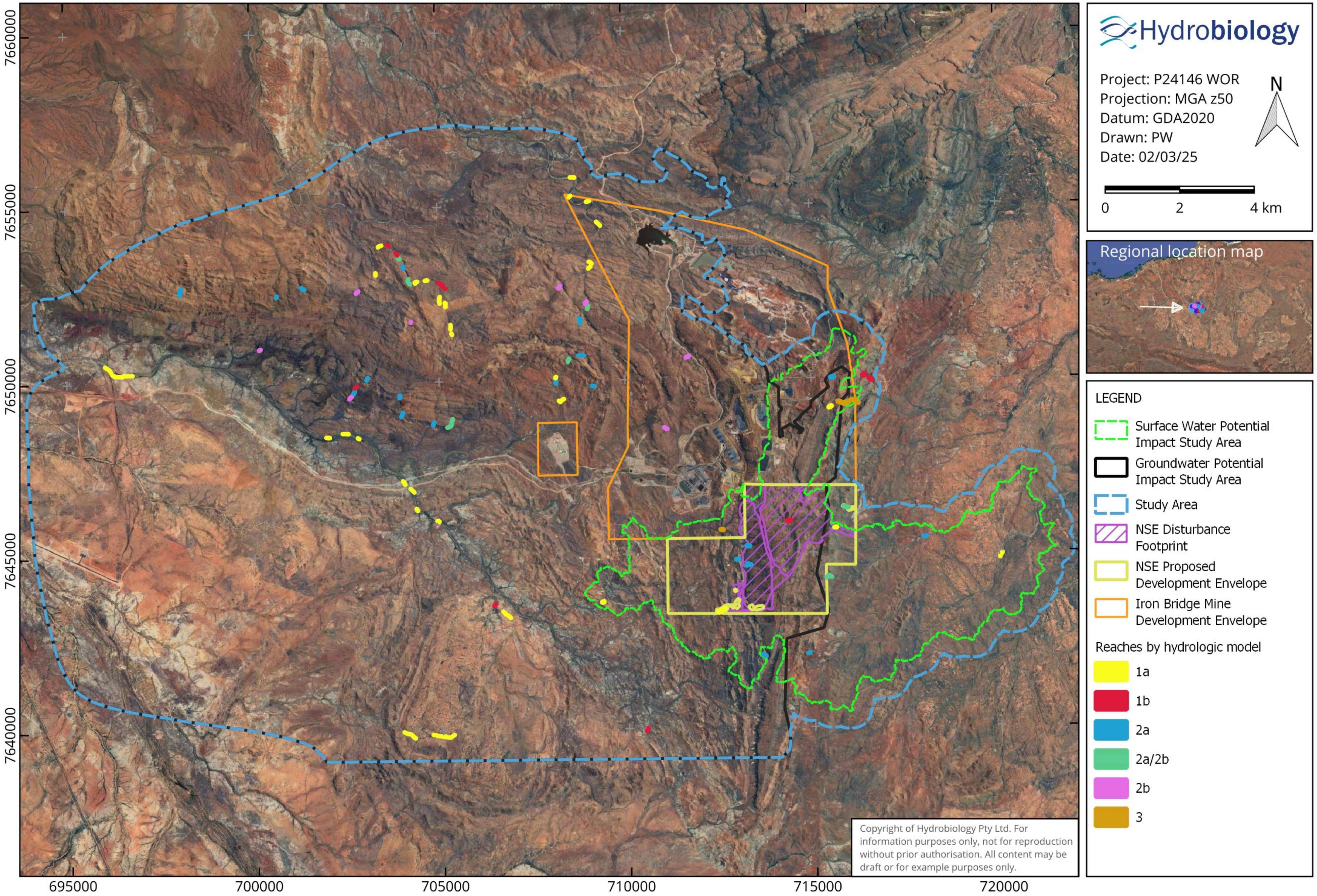


Figure 3-7 Map of reaches by hydraulic conceptualisation type

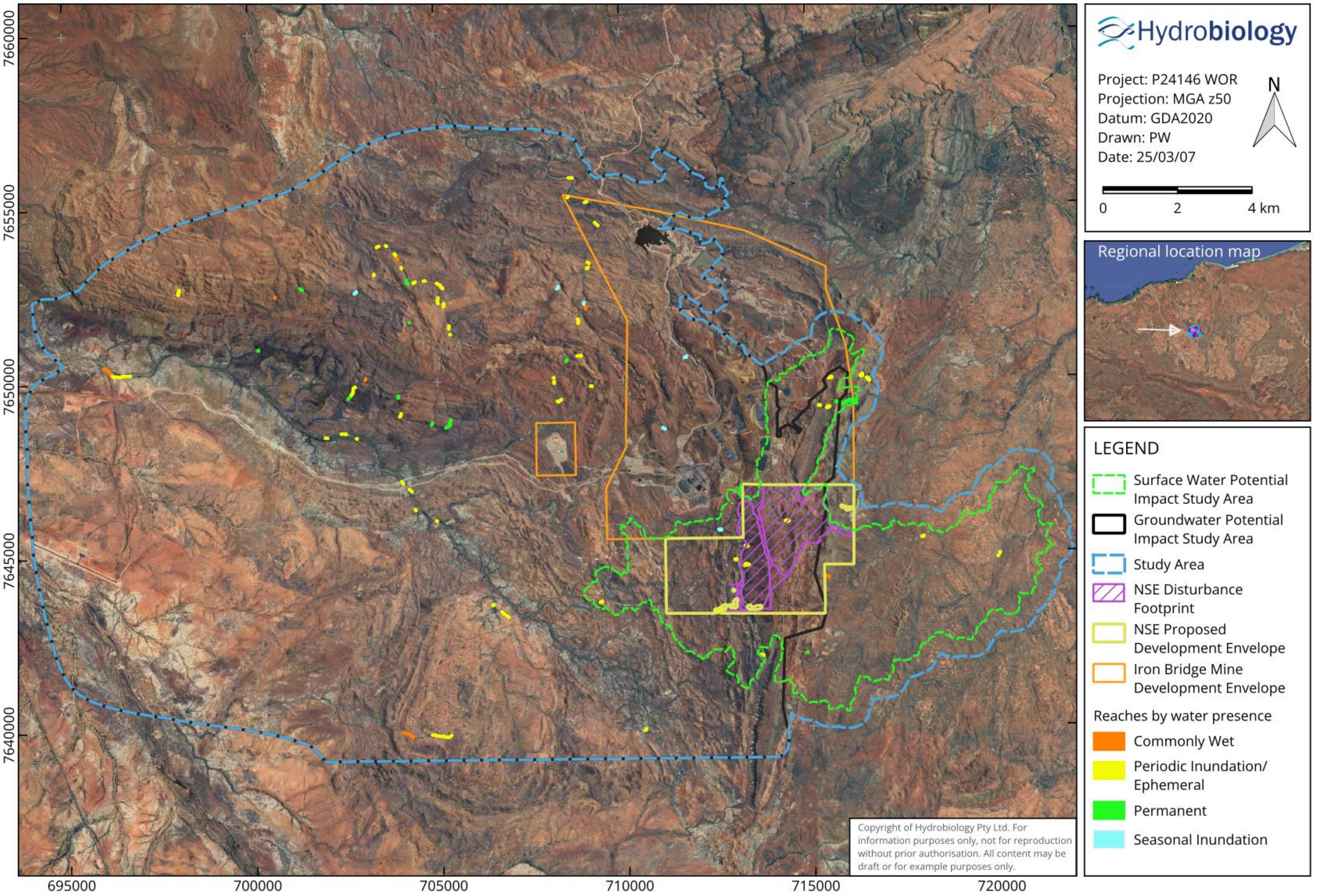


Figure 3-8 Map of reaches by dominant water presence type

3.2.3 CONCEPTUAL MODELS FOR SELECTED POOLS/REACHES

To avoid repetition, we have not provided individual visual conceptual models for every pool identified as potentially impacted within the groundwater and surface water impact assessment areas. However, this section provides conceptual models for previously reported pools (Fortescue, 2023) and newly identified permanent pools, drawing on multiple lines of available evidence to support the hydraulic conceptualisations following Bourke et. al. (2023). Appendix C provides a complete listing of the hydrologic conceptualisation for every pool identified within the current study.

Monitoring data indicates shallow depths to groundwater occur in areas of mapped potential groundwater dependent vegetation which coincide with drainage features in the landscape. Recharge and discharge mechanisms imply a cyclical connection between surface water and groundwater systems. The conceptual interrelationship between these aspects of the environment is illustrated in Figure 3-7.

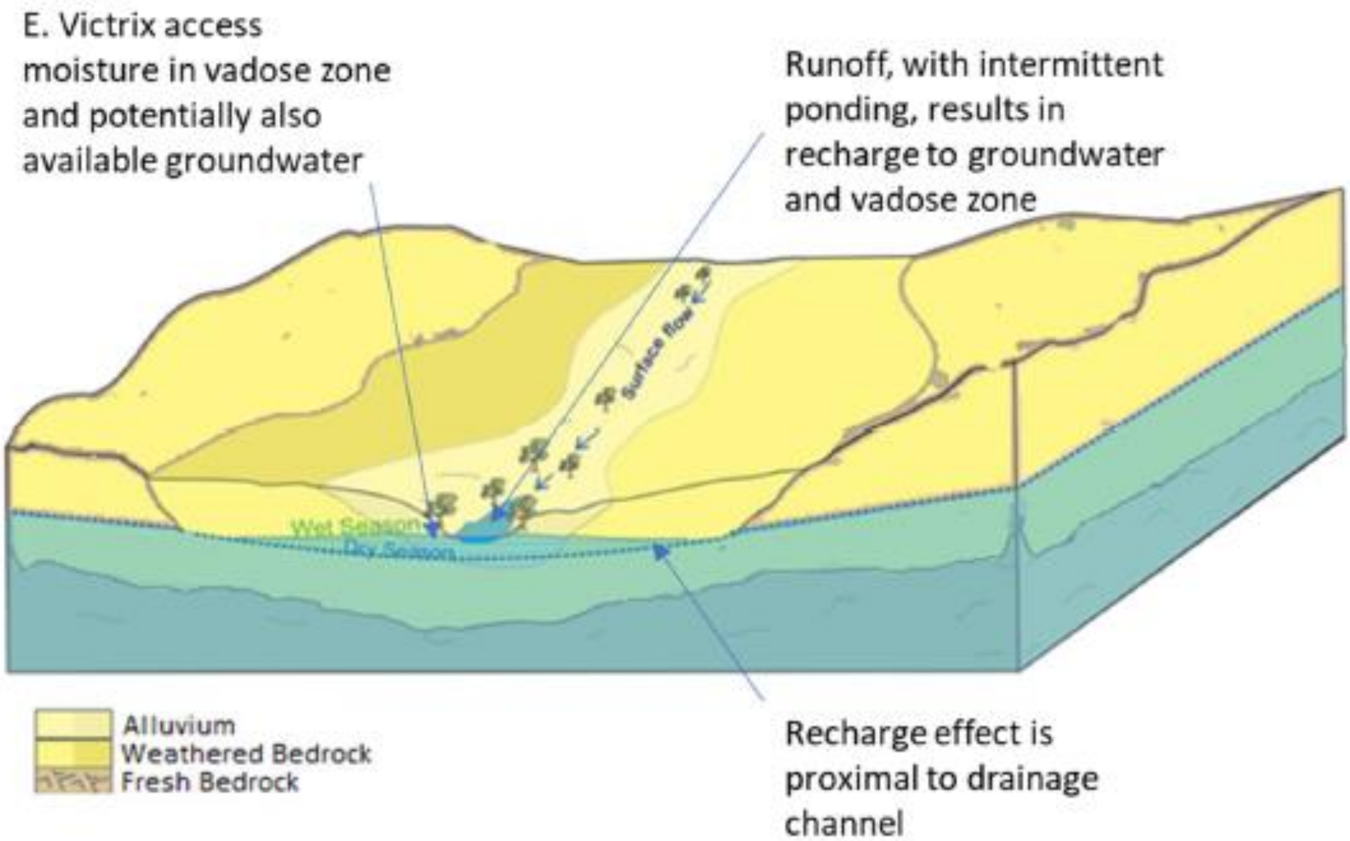


Figure 3-9 Conceptual schematic of generalised groundwater, surface water and vegetation interaction at Iron Bridge Mine (adapted from Bourke et al. [2023]) (Fortescue, 2023).

3.2.3.1 TYPE 1A - ALLUVIUM - PERCHED THROUGHFLOW

Central Creek Pool

The conceptual hydrological model for Central Creek Pool is representative of the majority of the pools within the NSE study area (Type 1a). This pool is within deep alluvium material and has been formed by scouring of the alluvium on a bend in the drainage channel where the flow meets a rock outcrop (Figure 3-8).

The pool forms after the first flow event for the wet season within the creek and typically persists for most of the wet season. The pool recedes between flow events and early in the late wet season/early dry season. The pool does not persist into the dry season and is routinely dry for much of the year. Central Creek pool is classified as “Periodic inundation/Ephemeral” based on water presence data at this site.

The conceptual mechanism is one of filling by alluvial throughflow and receding as the alluvials drain to lower elevations over time (Figure 3-9). There may be some loss to the deeper vadose/groundwater zone vertically, as the pool is perched above the regional groundwater table at this location. It is considered unlikely that there is connection to regional groundwater, other than through losses.

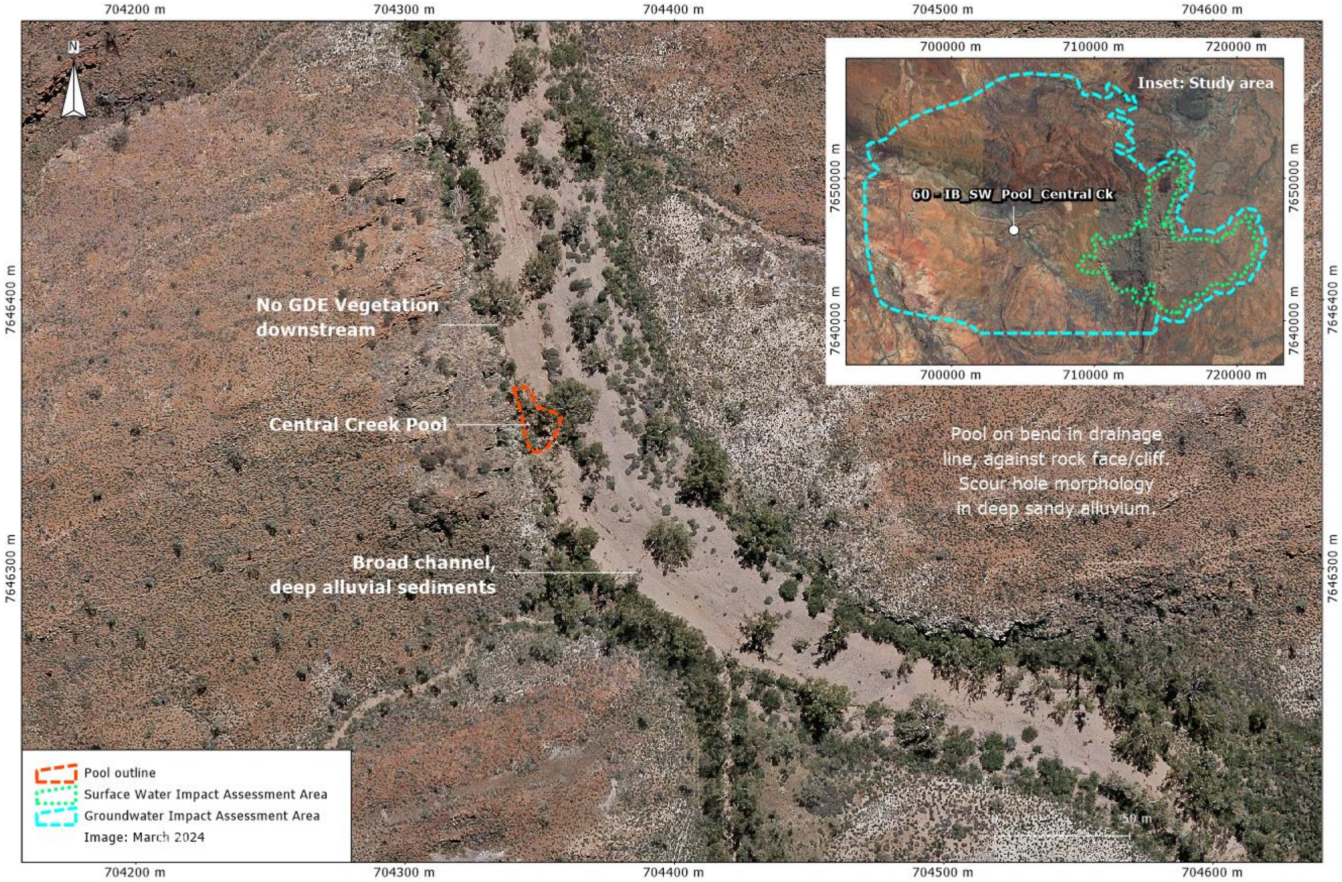


Figure 3-10 Map of Central Creek Pool showing hydrological features.

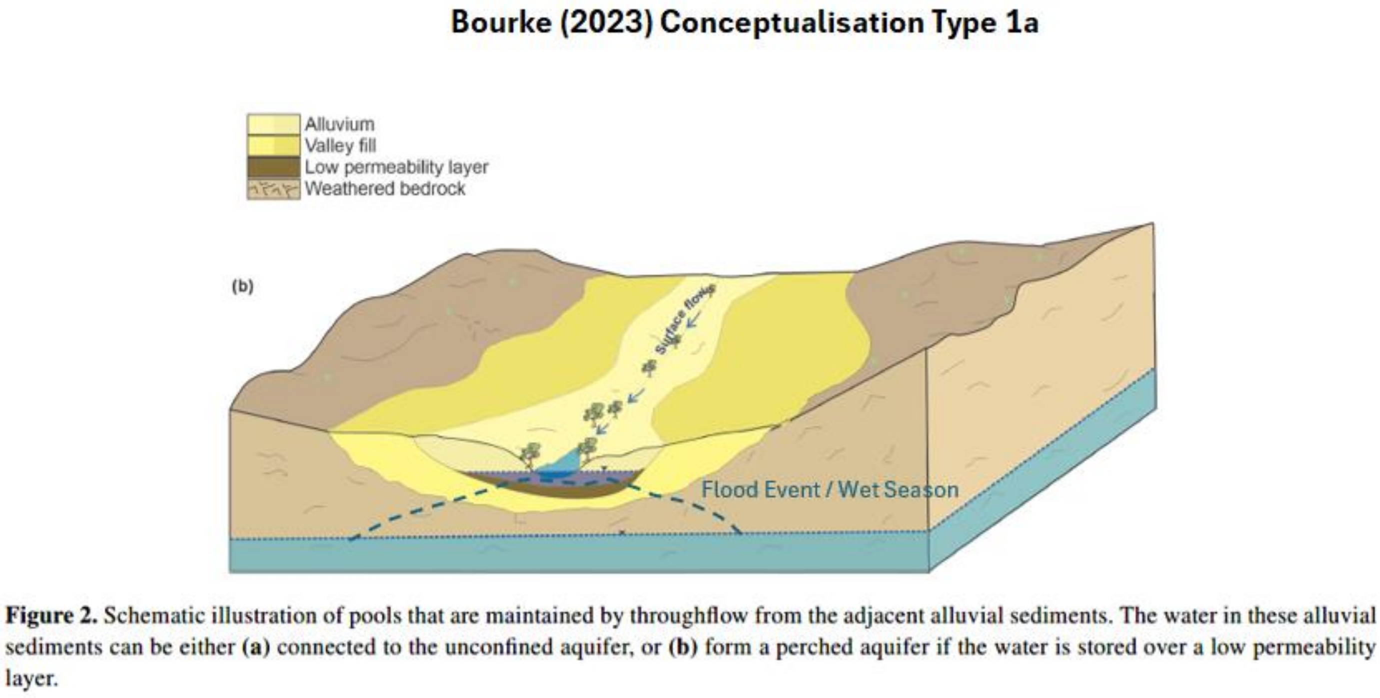


Figure 3-11 Conceptual hydrologic model for Central Creek Pool, Type 1a - Alluvium - perched throughflow

3.2.3.2 TYPE 2B - BEDROCK FRACTURE / REGOLITH FLOW GROUNDWATER SOURCE

Fig Pool

Fig Pool is a small, isolated pool that lies at the base of a rockface with a small catchment area (Figure 3-10). The water level is stable as it is maintained by fresh groundwater and is periodically flushed with fresh surface water flows after rainfall events (Figure 3-11). There is no obvious inflow channel for surface waters and therefore the conceptual model is one of localised shallow groundwater inflow with rainfall entering a fractured rock or regolith material and driving local groundwater within the elevated terrain above the pool to discharge.

The water within this pool is typically of low pH and low in dissolved solids (mean EC is ~200 µS/cm, varying between 20 and 606 µS/cm), indicative of a shallow subsurface circulation source with leached aquifer material (possibly chert). While the dissolved solids (as measured by EC) drop with rainfall events, indicating a surface water inflow connection, the levels increase to a stable ~250-260 µS/cm within days-weeks, indicating replacement by a local groundwater source (i.e., the typical EC within Fig Pool is significantly lower than regional groundwater).

The conceptual model of localised groundwater inflows is supported by the fact that there are large mature melaleuca trees (GDV) immediately downstream of the pool.

Based on the above, Fig Pool has been assigned a “permanent” water persistence classification and a Type 2b hydrologic conceptual model - Bedrock fracture / regolith flow groundwater source (Figure 3-12).

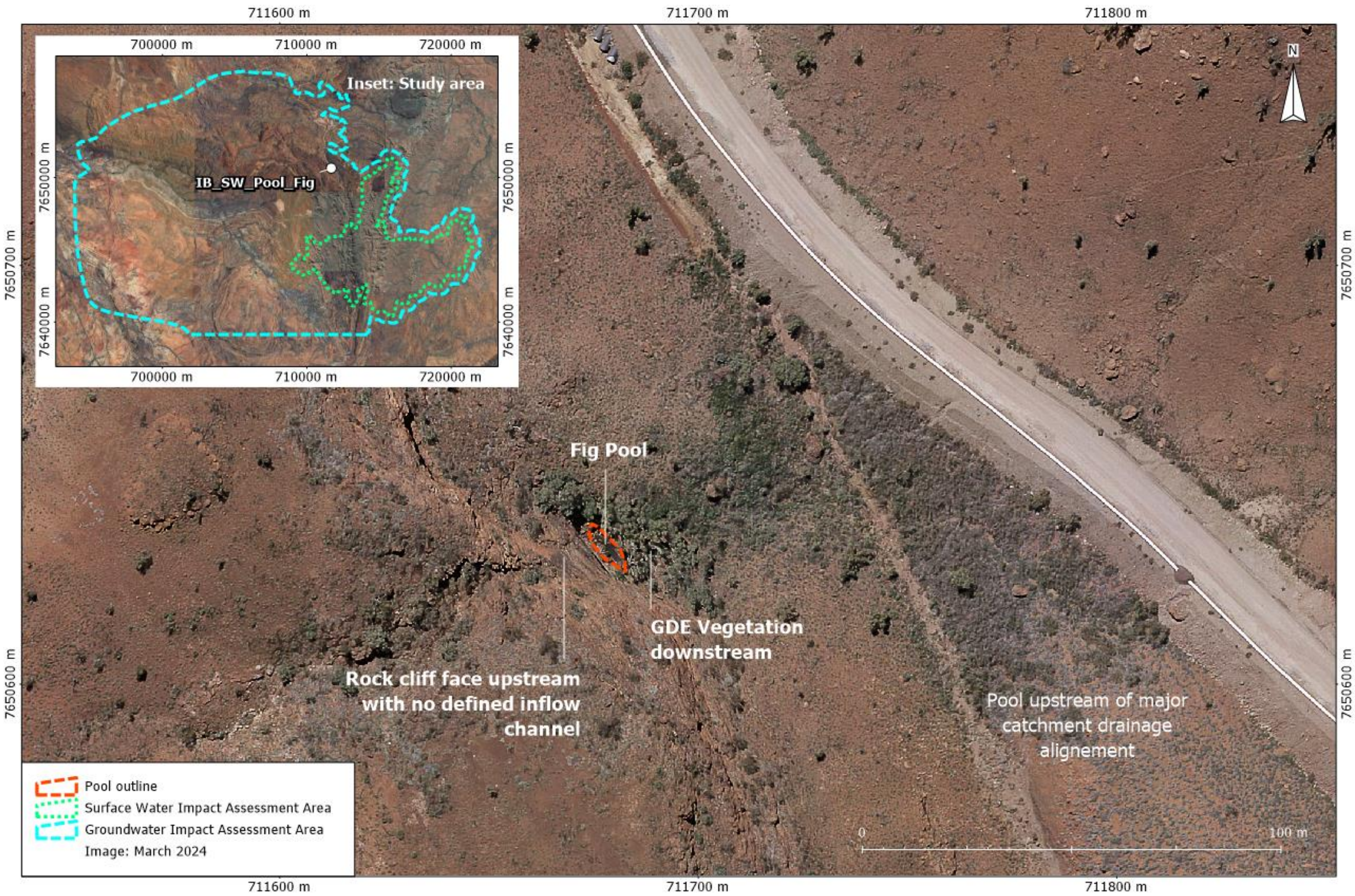


Figure 3-12 Map of Fig Pool showing hydrologic features

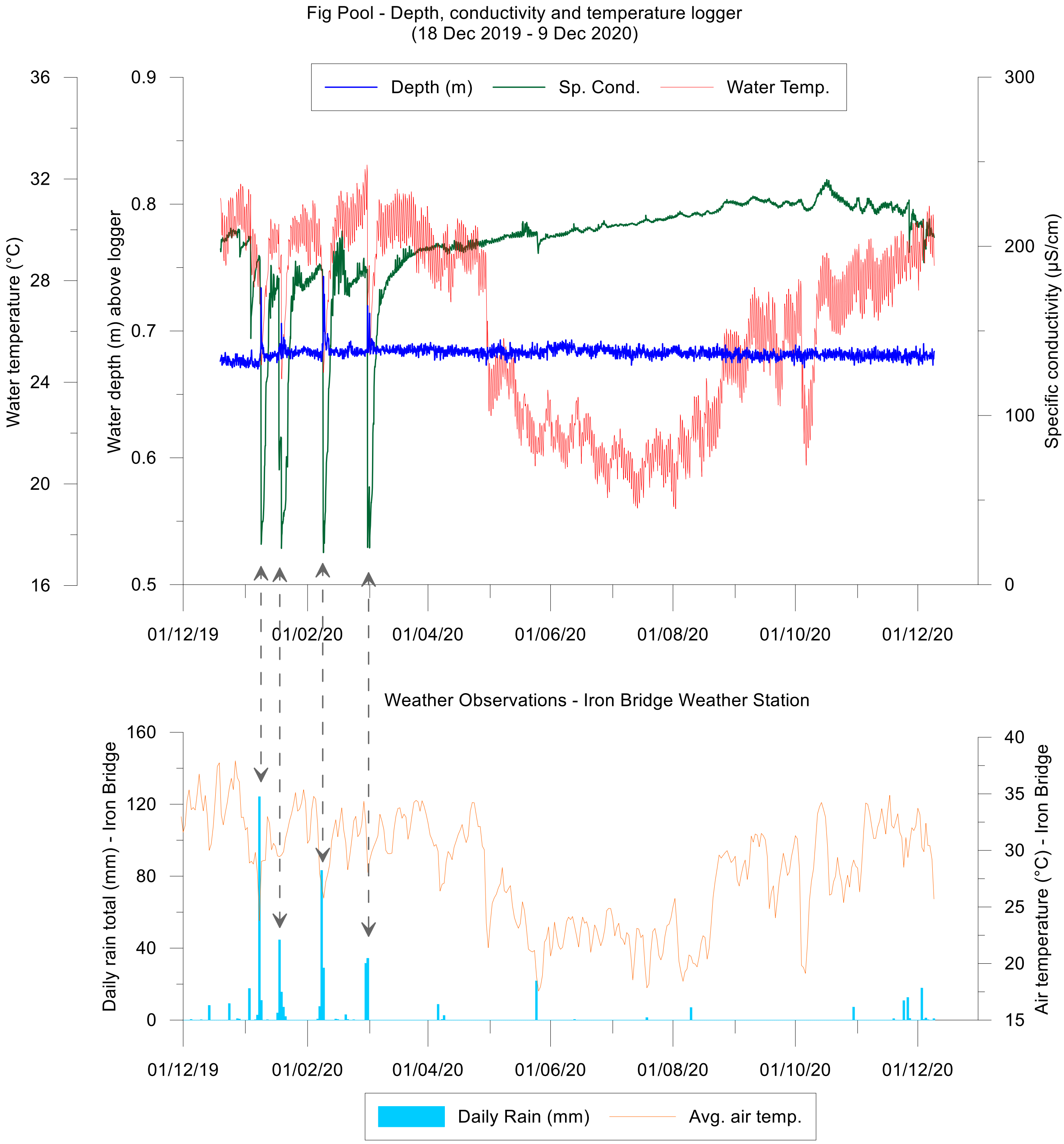


Figure 3-13 Water level, specific conductivity, temperature logger data from Fig Pool over an annual cycle in relation to inflow events – Dec 2019 to Dec 2020.

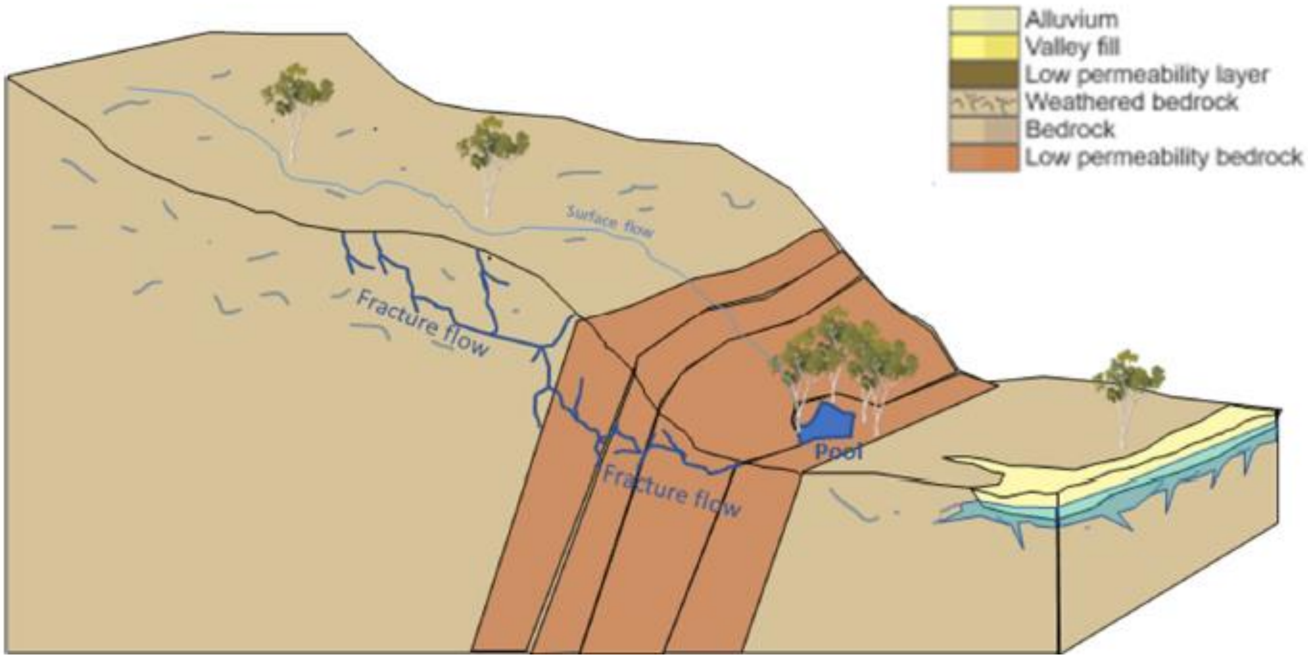


Figure 3-14 Schematic illustration of fracture flow groundwater source for Fig Pool (adapted from Bourke et al. [2023]) (Fortescue 2023).

Cow Spring Pool

Cow Spring is a small pool confined by bedrock habitat that is likely to be sustained by groundwater (Figure 3-13). There is a waterfall above the pool that flows during rainfall events and temporarily replenishes the pool with lower salinity surface waters. These are replaced over days to weeks with a constant inflow of groundwater, as indicated by the overflow from the pool supporting GDV for ~50 m downstream year-round (Figure 3-18). The water level within the pool is constant with only small variations during flow events and in response to vegetation dams downstream being flushed out (Figure 3-14). The mean EC value is 450 µS/cm, varying within a range of 278 to 595 µS/cm. This is fresher than the regional groundwater, indicating a local groundwater source.

Cow Spring pool has a constant fish population, constant water levels and submerged macrophytes. The Pilbara Olive Python has also been observed within this pool, indicating elevated ecological values.

Cow Spring pool has been classified as having a Type 2b hydrologic conceptualisation - Bedrock fracture / regolith flow groundwater source with a “permanent” water persistence category (Figure 3-15).

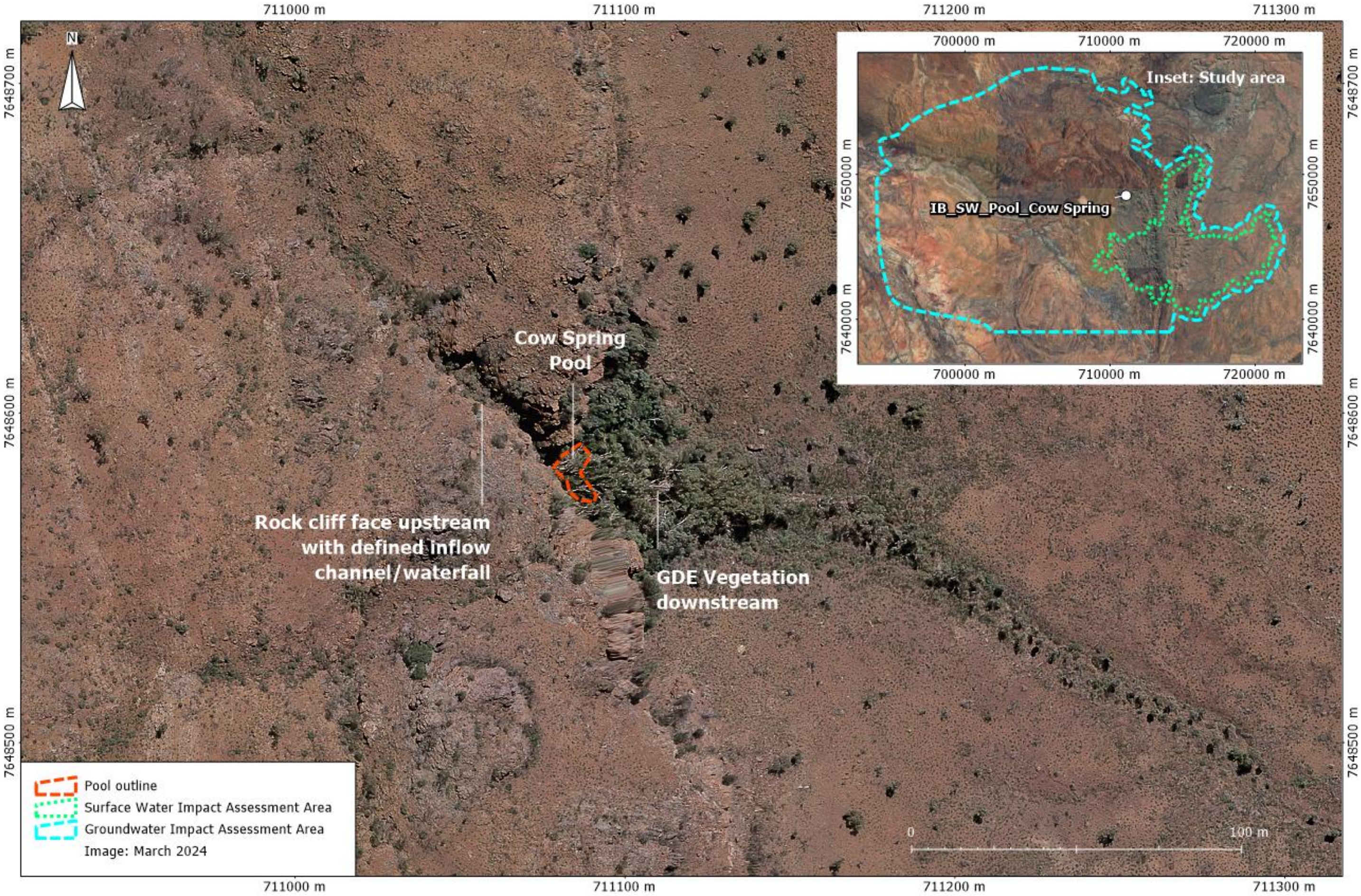


Figure 3-15 Map of Cow Spring Pool showing hydrologic features

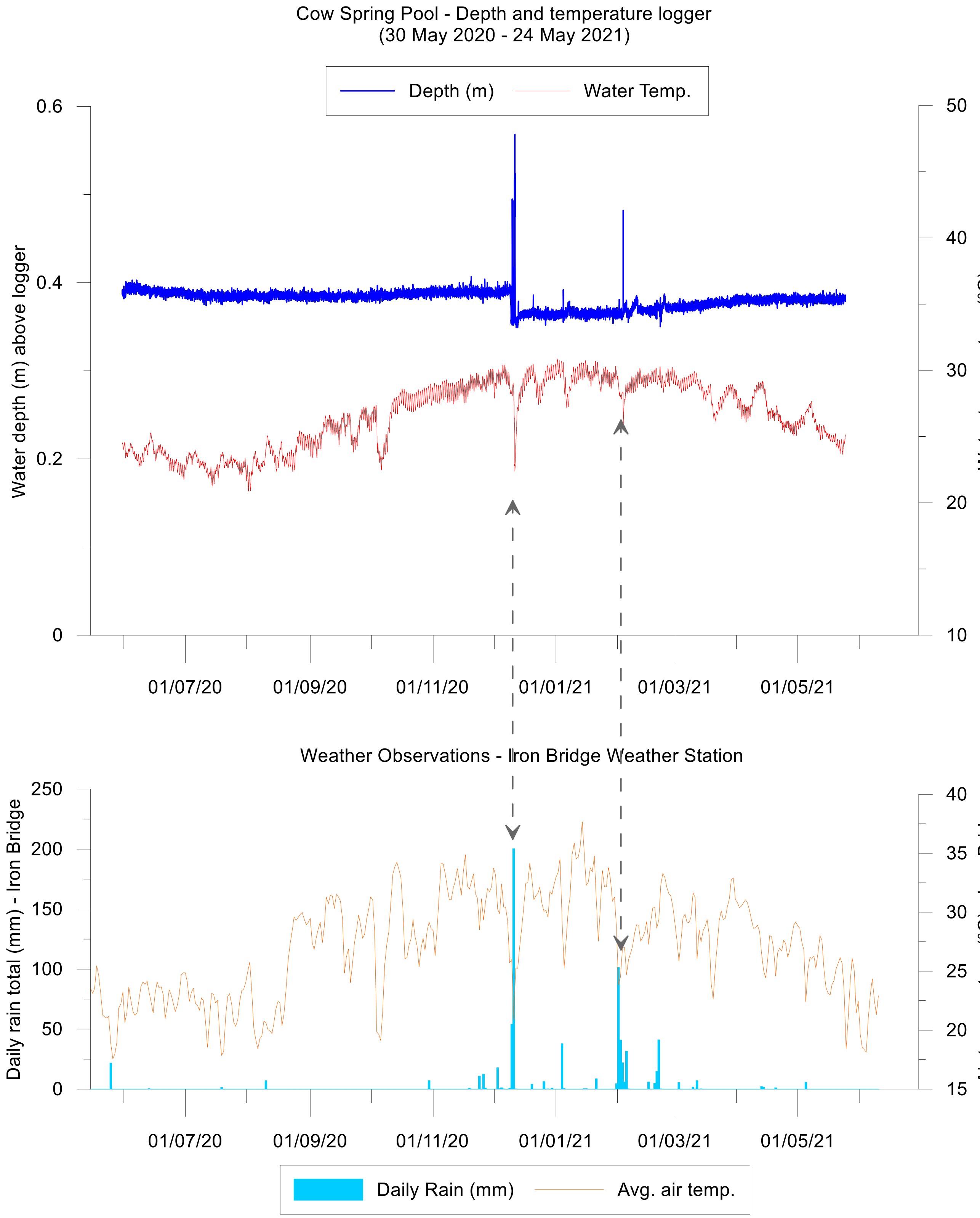


Figure 3-16 Water level and temperature at Cow Spring Pool in relation to rainfall and air temperature – May 2020 to May 2021

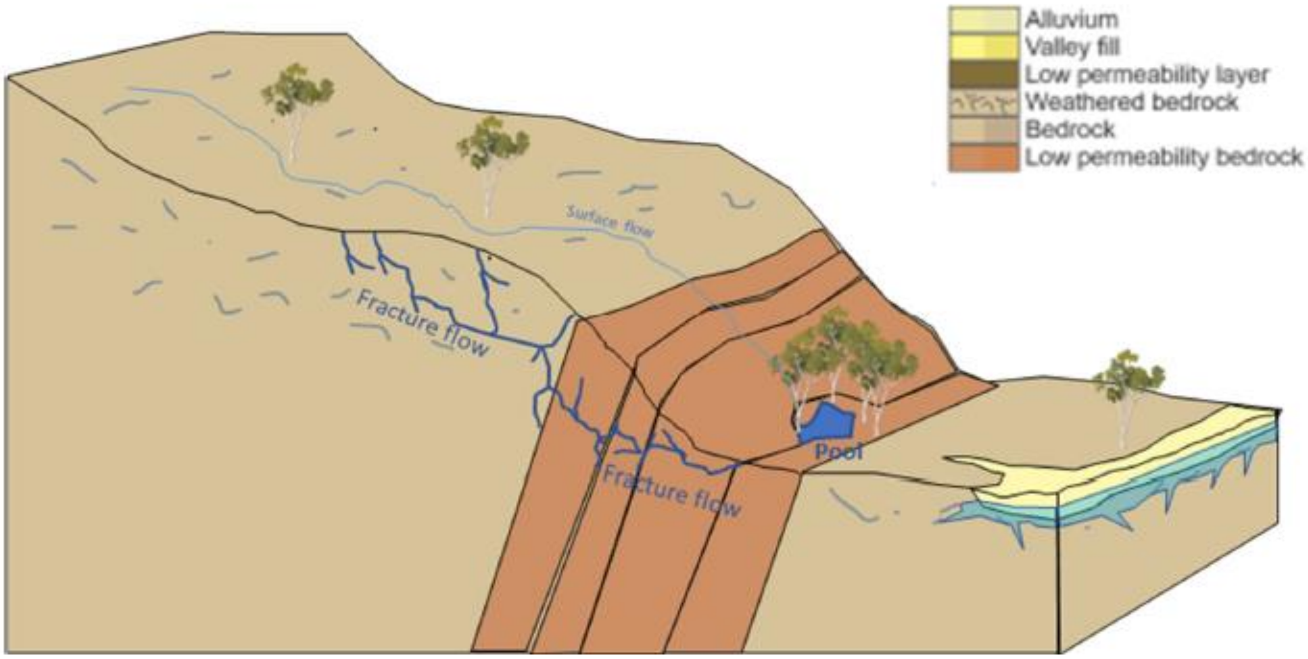


Figure 3-17 Schematic illustration of fracture flow groundwater source for Cow Spring (adapted from Bourke et al. [2023]) (Fortescue 2023).

Pools 93, 44 and 42

Four newly identified pools (from the current pool identification process) have been classified as potentially having permanent water presence and therefore a groundwater source. Three of these pools exist in close proximity to each other to the north of the project area (Pools 93, 44 and 42; Figure 3-16). The fourth pool (GE_4) is discussed separately below. These pools are classified as "Permanent" as water has been present in all available imagery.

Of these three pools, only Pool 44 has been accessed (Figure 3-16). During a site inspection in October 2024, it was noted that there were fish (Spangled Perch) present at Pool 44 and that the water was fresh (149 µs/cm), oxygenated (88% saturation), clear (<1 NTU) and near-neutral pH (6.84). The presence of water and fish at this site during the late dry season, in a relatively dry year, indicates that a groundwater source is present. The low EC (149 µS/cm) indicates this is likely a local groundwater source due to being fresher than regional groundwater (~800 to 1500 µS/cm). Pool 44 had an active seep in the rockface below Pool 93 in October 2024, about 0.5m above the waterline (Figure 3-17, Figure 3-18) indicating inflow from the local aquifer.

Pool 42 is located approximately 800 m to the south-east of Pools 44 and 93 and is within a similar setting within the landscape (273 m elevation, steep elevation drop, constricted channel and bedrock substrate). Note that Pool 93 is at the essentially the same elevation as Pool 42 (274 m). Pool 42 also has a small seasonally inundated pool ~180 m upstream (Pool 43; 307 m elevation) within a similar bedrock setting (Figure 3-19).

These pools (42, 44 and 93) have been classified as Type 2b - Bedrock fracture / regolith flow groundwater source based on their position in the landscape and the indicative geochemistry from Pool 44. All of these pools are classified "permanent" within the water persistence category.

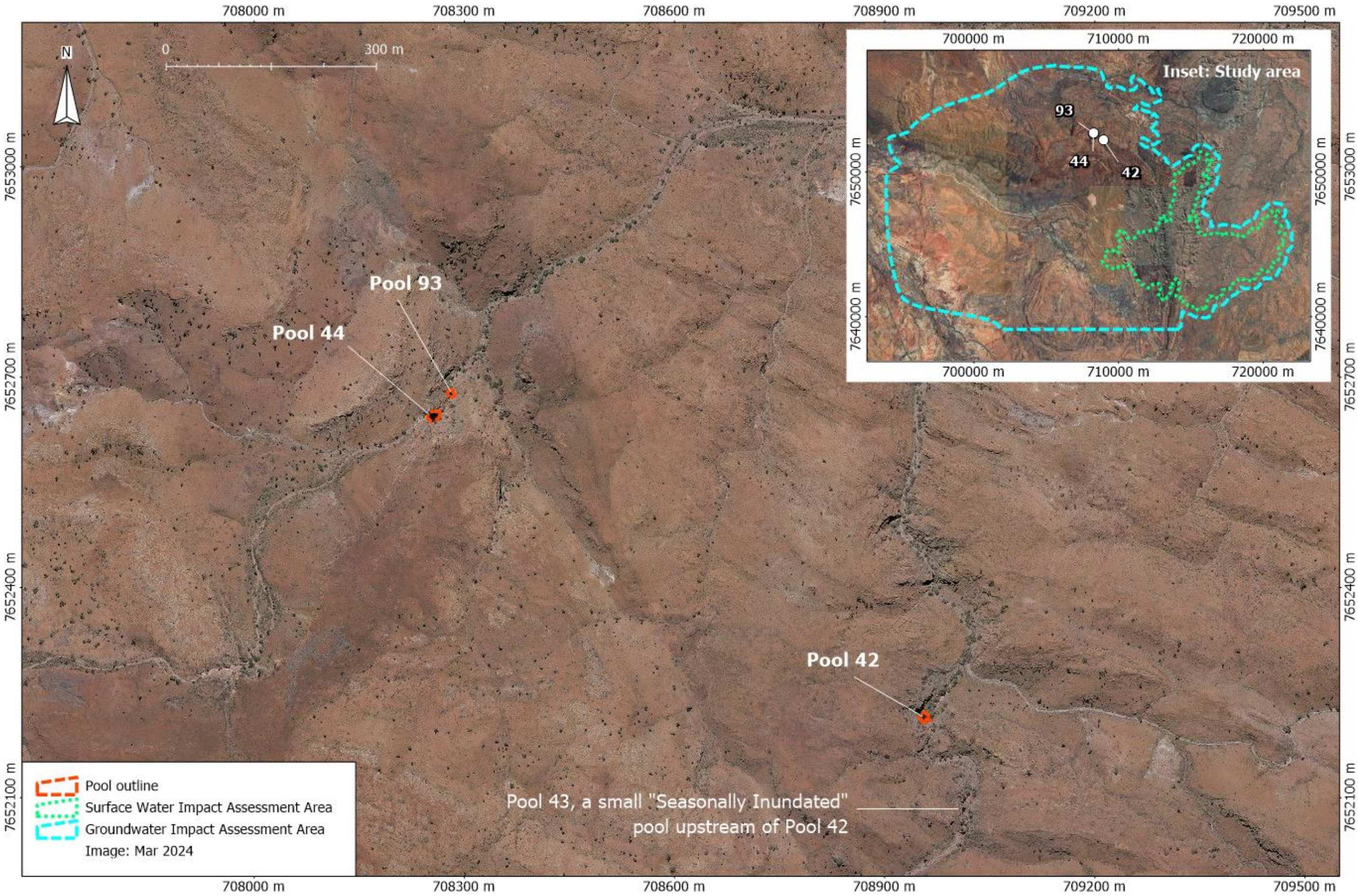


Figure 3-18 Map of Pools 42, 44 and 93.

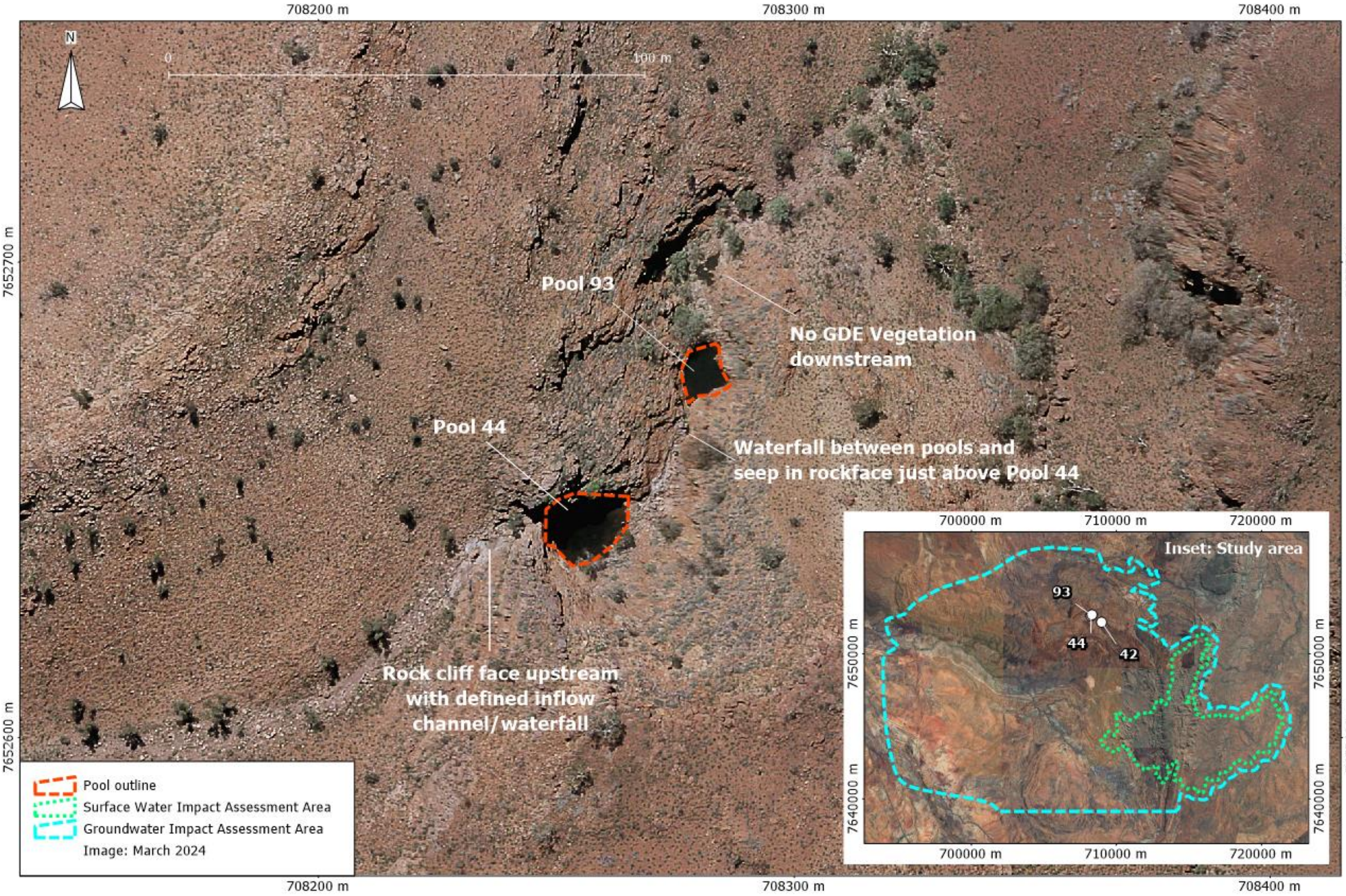


Figure 3-19 Map of Pools 44 and 93 showing hydrologic features.

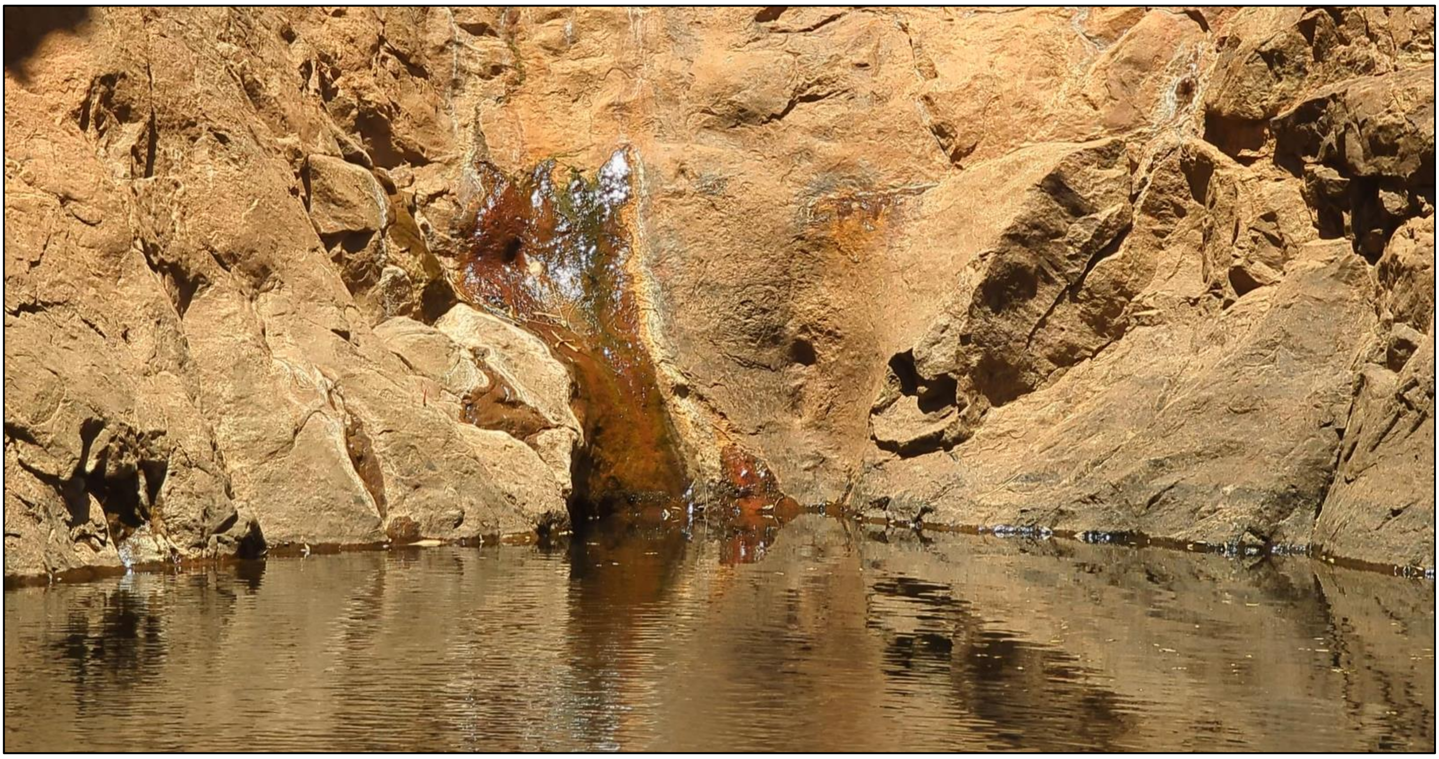


Figure 3-20 Active seep at the upstream end of Pool 44 in October 2024 – 0.5 m above the water line.

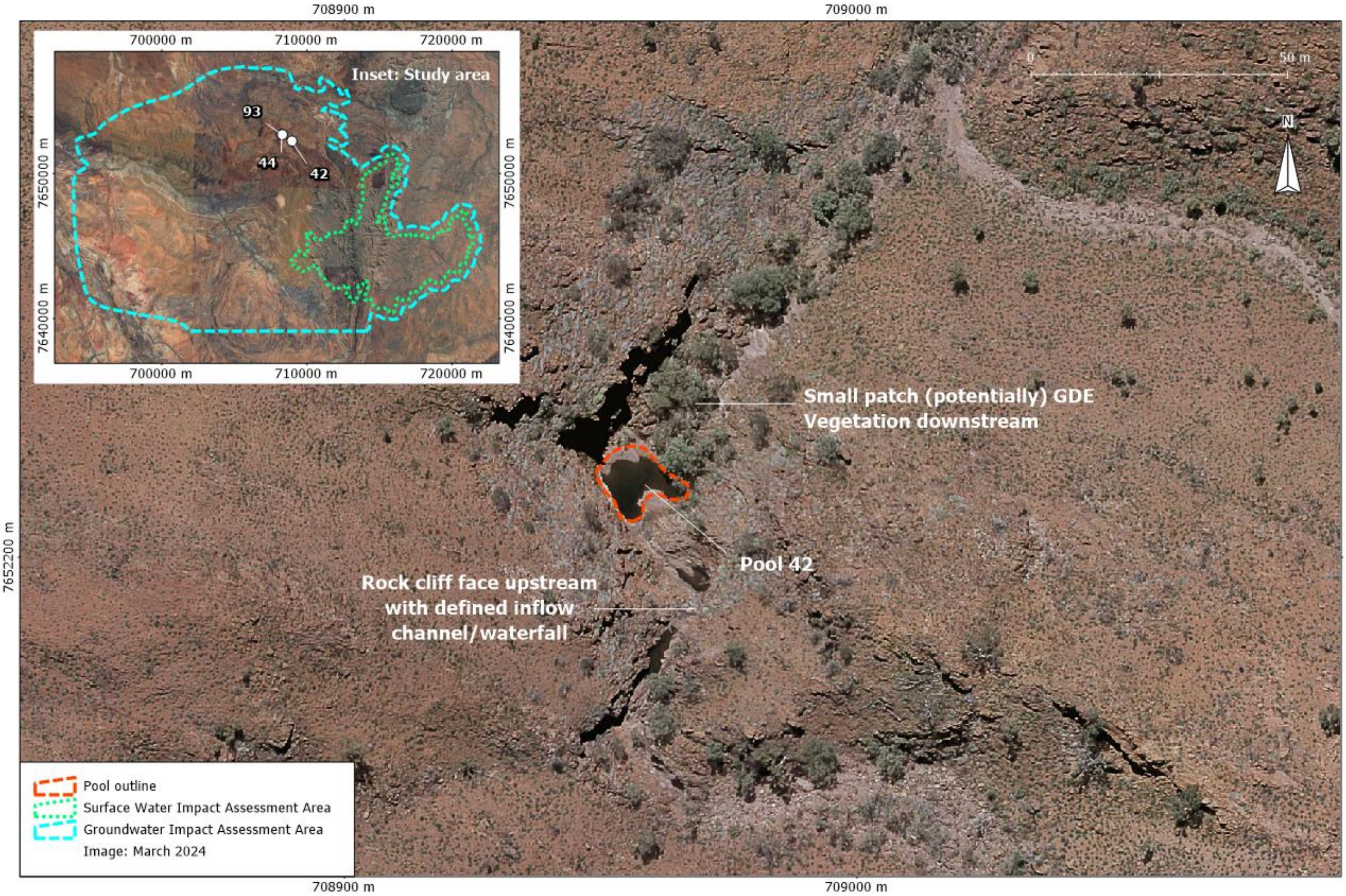


Figure 3-21 Map of Pool 42 showing hydrologic features.

Astrid Bee Cave; Craig's Pool; Dingo Lair Pool; Zane's Gorge Pool.

Whilst no data exists for these pools, their position in the landscape is considered a strong indication of conceptual similarity to Cow Spring and Fig Pools. Figure 3-20 provides an overview map of the location of these pools.

These pools all exist at the base of steep elevation changes (cliffs) and are situated at a similar elevation. As the pools were typically within the shadow of the cliff and their exact location/morphology has not been determined, the water presence and persistence could not be estimated using the aerial imagery provided. Based on their location in the landscape, there is a strong potential for these pools to be supported by a groundwater source. Therefore, as a conservative measure, it has been assumed that these pools are commonly wet and have some groundwater dependency.

Figure 3-21 presents a map figure of the Zane's Gorge string of pools. These pools do not show a GDE vegetation signature though are located within a similar geographic setting to other permanent or semi-permanent pools within the study area. There was water present on 26th October 2024 (late dry season) based on a helicopter overflight undertaken at that time. A Type 2a/2b conceptual hydrologic model (2a - Bedrock - perched surface water; 2b - Bedrock fracture / regolith flow groundwater source) has been applied to this pool based on its position in the landscape and limited available data.

Figure 3-22 presents a map figure of the Dingo Lair pool. This pool did not have high-resolution imagery coverage and was characterised based on publicly available satellite imagery (Google Earth and Virtual Earth), as well as vegetation (NDVI) and elevation datasets. A Type 2a conceptual hydrologic model (2a - Bedrock - perched surface water) has been applied to this pool based on its position in the landscape and limited available data.

Figure 3-23 provides a map figure of Craig's Pool, which has a series of semi-permanent pools on top of the escarpment and a pool of unknown permanence at the base of the cliff face (Figure 3-24). If any GDE vegetation exists adjacent to this pool it is likely to be of limited extent, based on the oblique aerial imagery. A Type 2b conceptual hydrologic model (2b - Bedrock fracture / regolith flow groundwater source) has been applied to this pool based on its position in the landscape and limited available data.

Figure 3-25 provides a map figure of the Astrid Bee Cave pool area. The exact location of this pool is not known, due to the shadow present in satellite/aerial imagery. To date, this pool had not been inspected by the surface water monitoring team on-site due to access difficulty. A Type 2b conceptual hydrologic model (2b - Bedrock fracture / regolith flow groundwater source) has been applied to this pool based on its position in the landscape and limited available data.

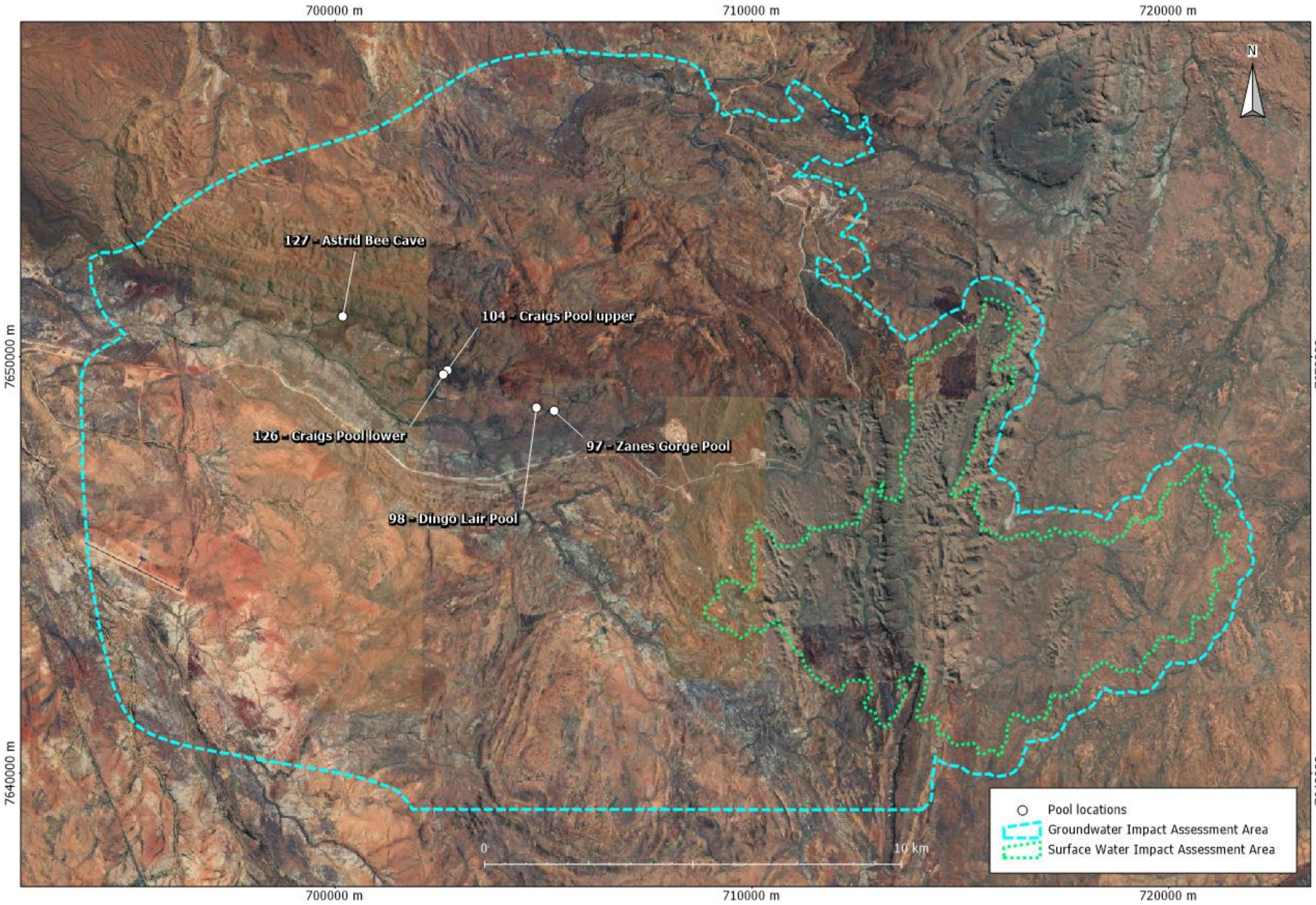


Figure 3-22 Map location of Astrid Bee Cave, Craig's, Zane's Gorge and Dingo Lair pools

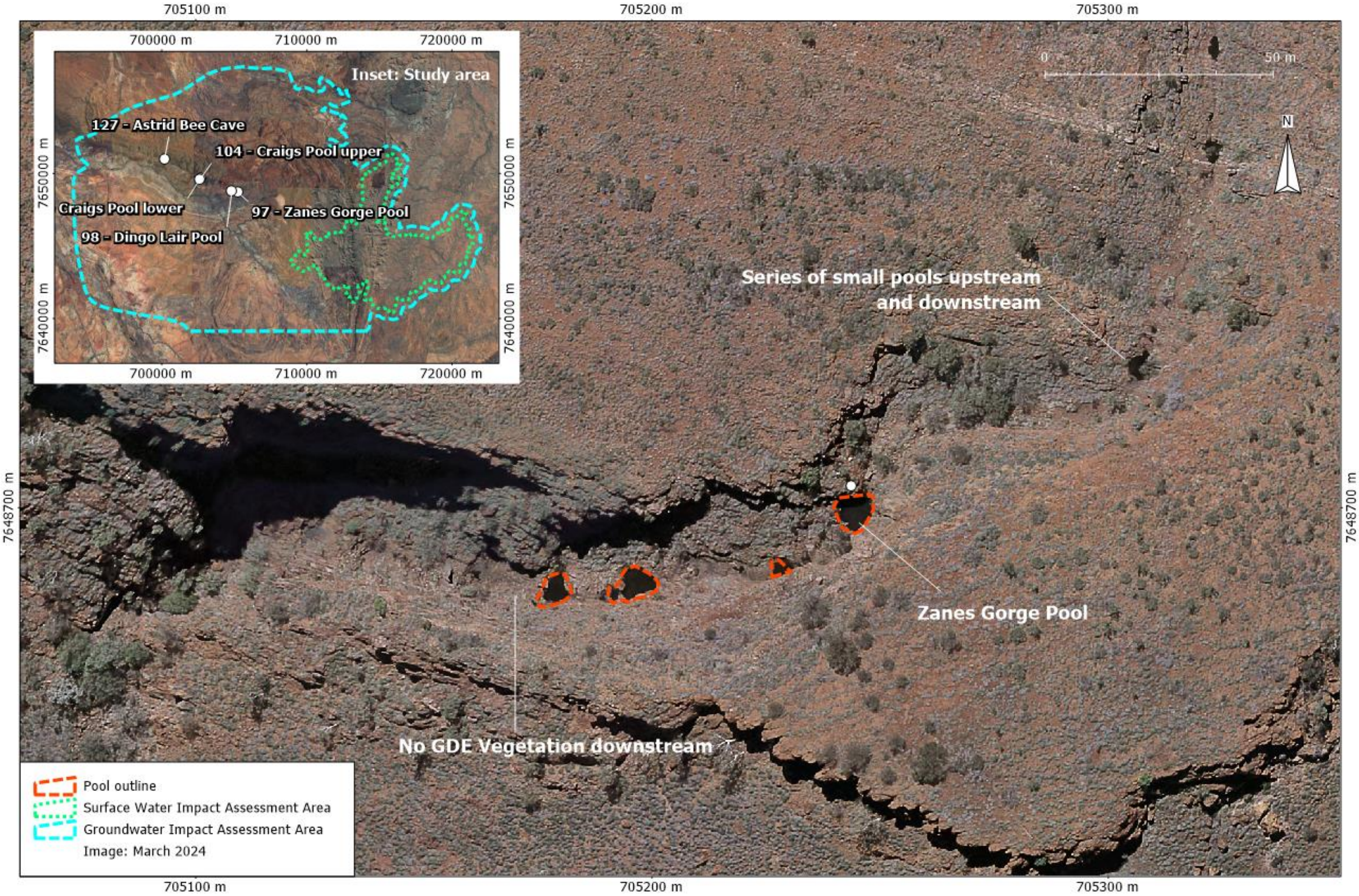


Figure 3-23 Map of Zane's Gorge Pool showing hydrologic features

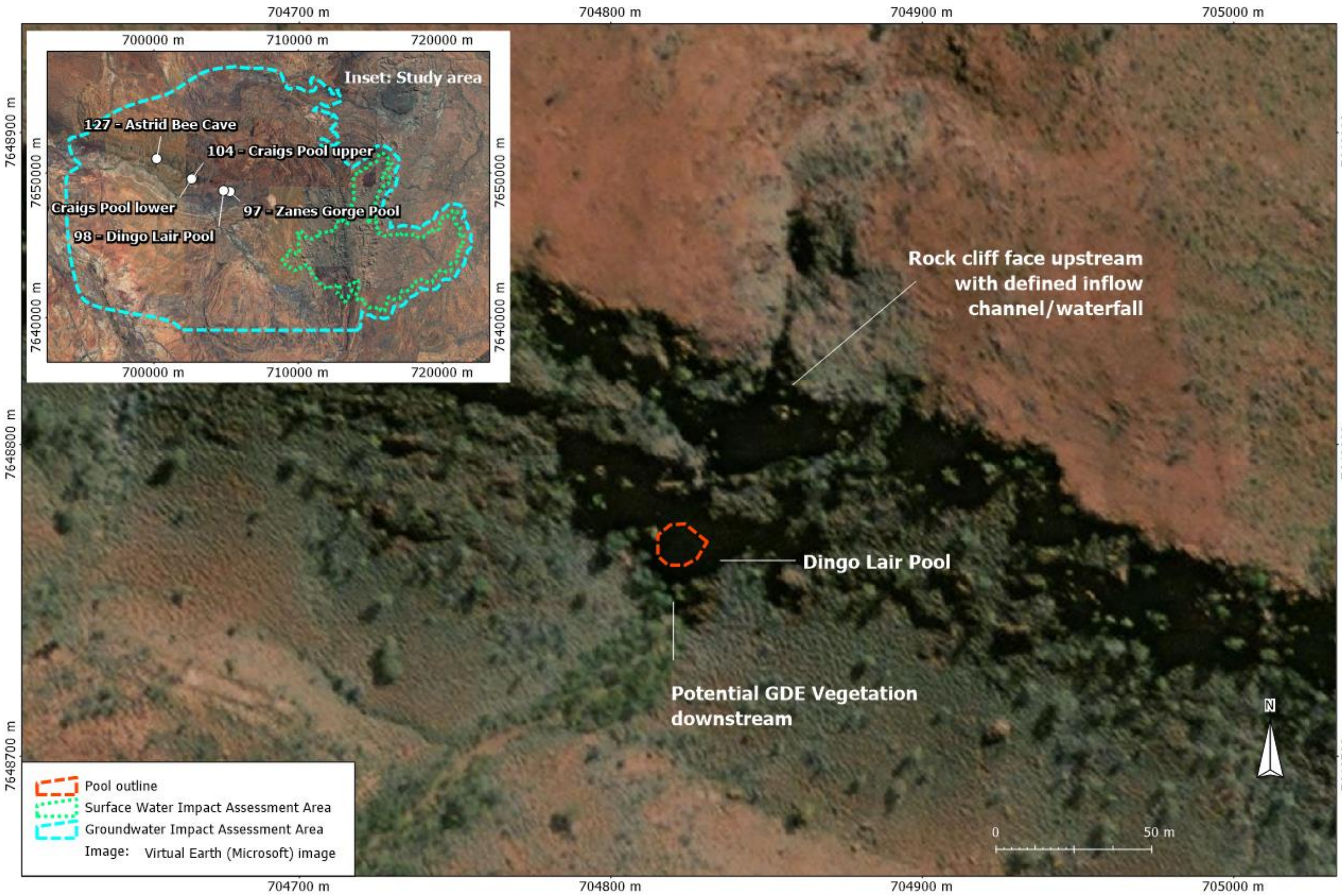


Figure 3-24 Map of Dingo Lair Pool showing hydrologic features.

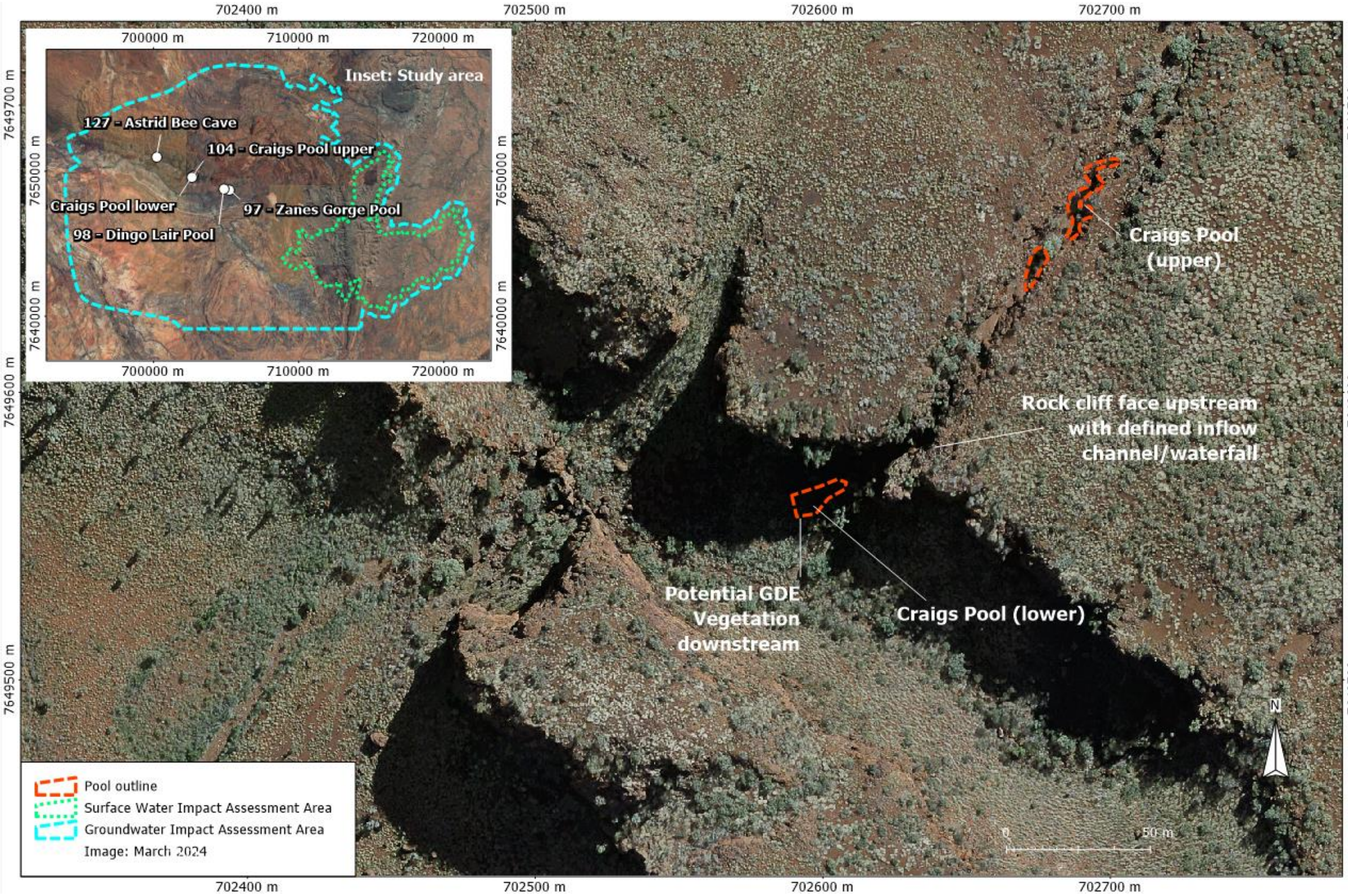


Figure 3-25 Map of Craig's Pool showing hydrologic features.

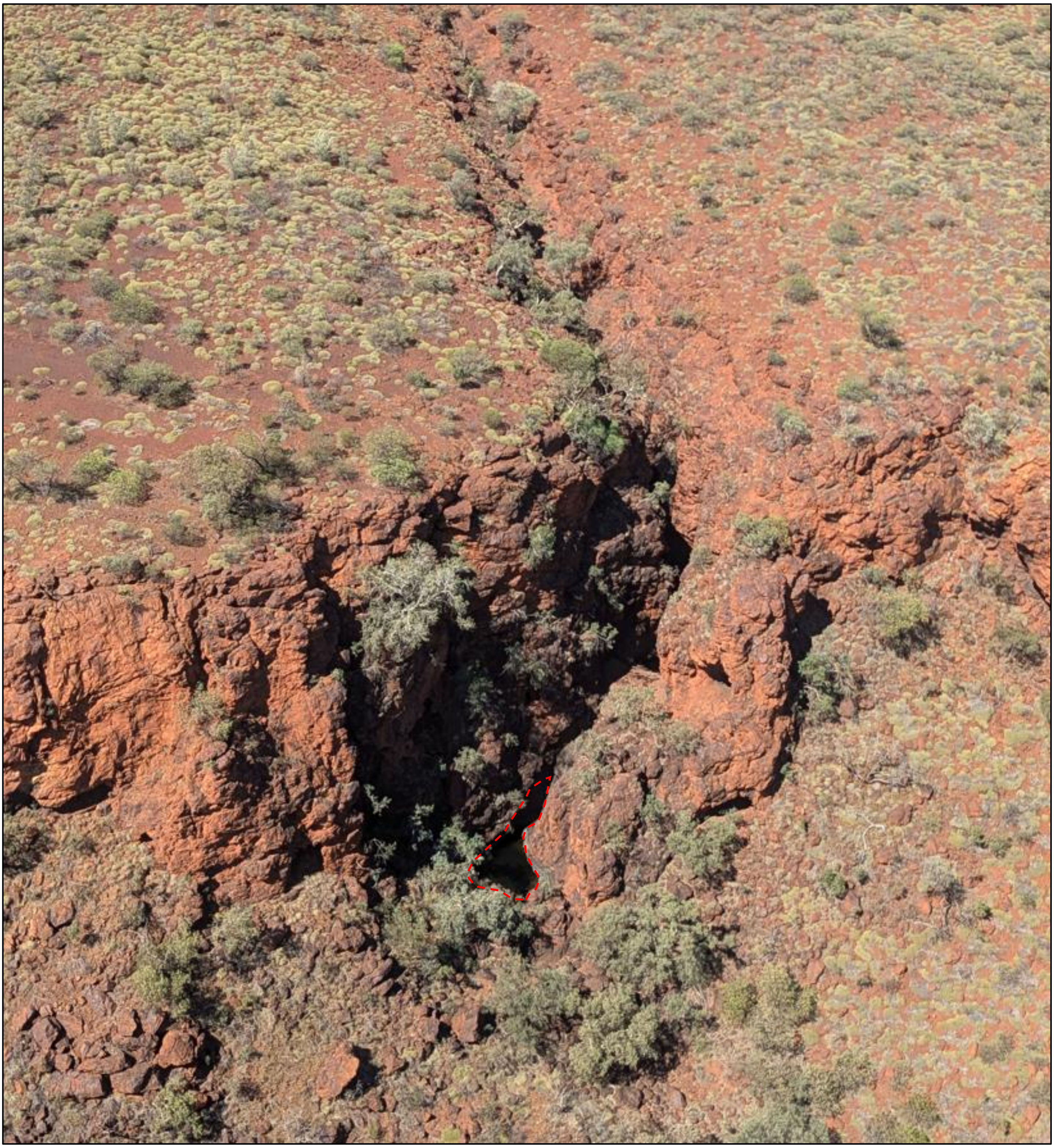


Figure 3-26 Oblique aerial photograph of Craig's Pool (lower) on 26th October 2024 showing water presence (red dash polygon)

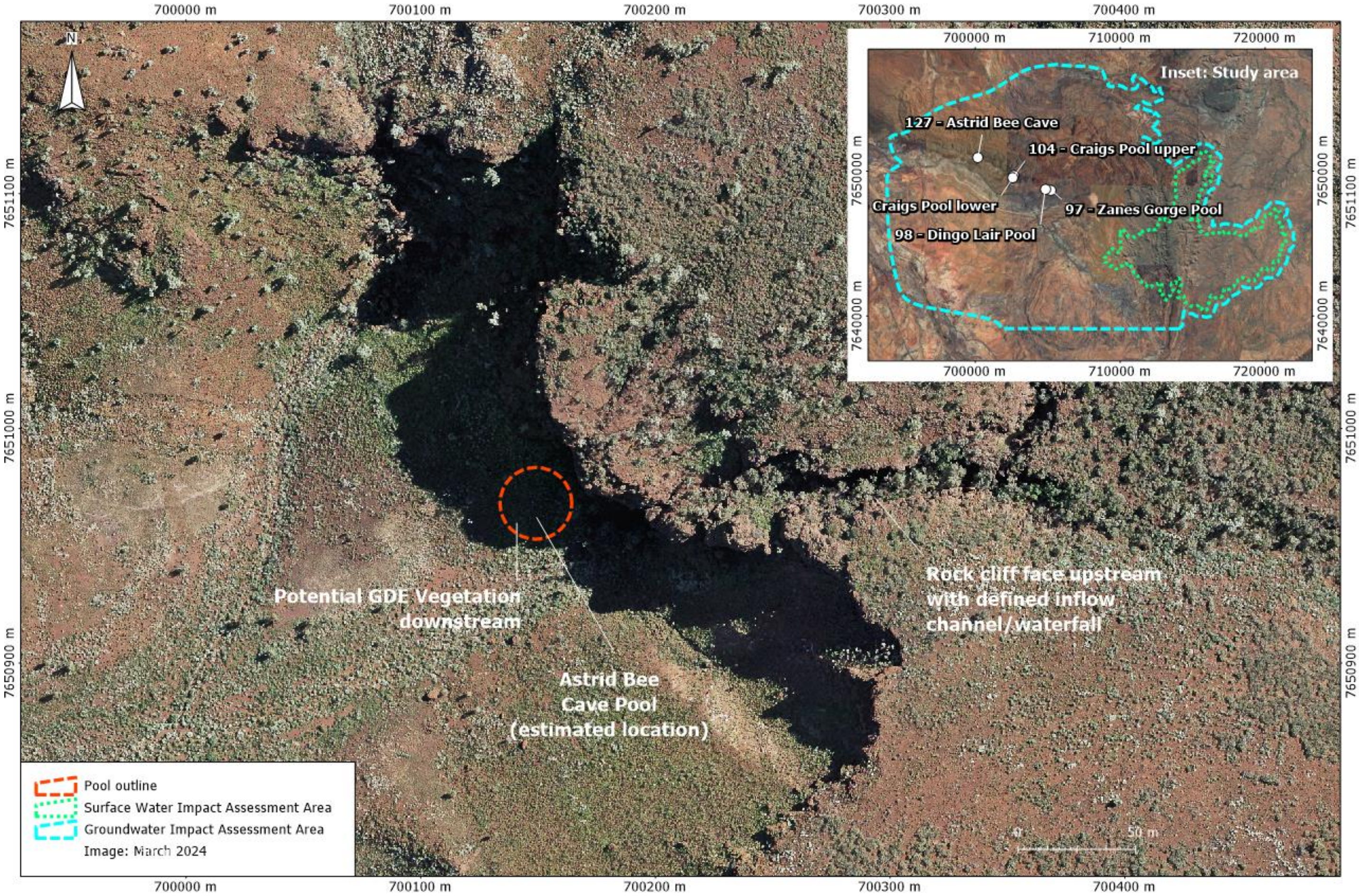


Figure 3-27 Map of Astrid Bee Cave Pool (estimated location) showing hydrologic features.

GE_4 Pool

As part of the review of pools outside the high-resolution imagery capture area for the NSE project, a set of pools were identified based on Google Earth imagery. One pool, GE_4, had water present on all nine images available in Google Earth (ranging from September 2011 to March 2024). GE_4 is located at the base of a rockface/cliff, similar to many other study area permanent pools, and has evidence of thicker vegetation adjacent to the pool suggesting potential GDE. This pool has two smaller pools immediately above it (on top of the cliff) and one small pool adjacent to the east (Figure 3-26). There appears to be a seep (from staining) on the rockface above the pool, which maybe a source of groundwater inputs (and/or drainage from the pool above it). In this respect it potentially has a similar arrangement to the Pool 44/93 hydrology.

Investigation of the NDVI and moisture index (Sentinel 2 dataset) for the GE_4 pool area indicates a similar pattern to Cow Spring and Mundagoora Pool with a concentrated soil moisture area downstream of the pool and elevated dry season NDVI signature.

GE_4 Pool has been classified as a Type 2b - Bedrock fracture / regolith flow groundwater source based on its position in the landscape and supporting features. GE_4 has a “permanent” water persistence classification.

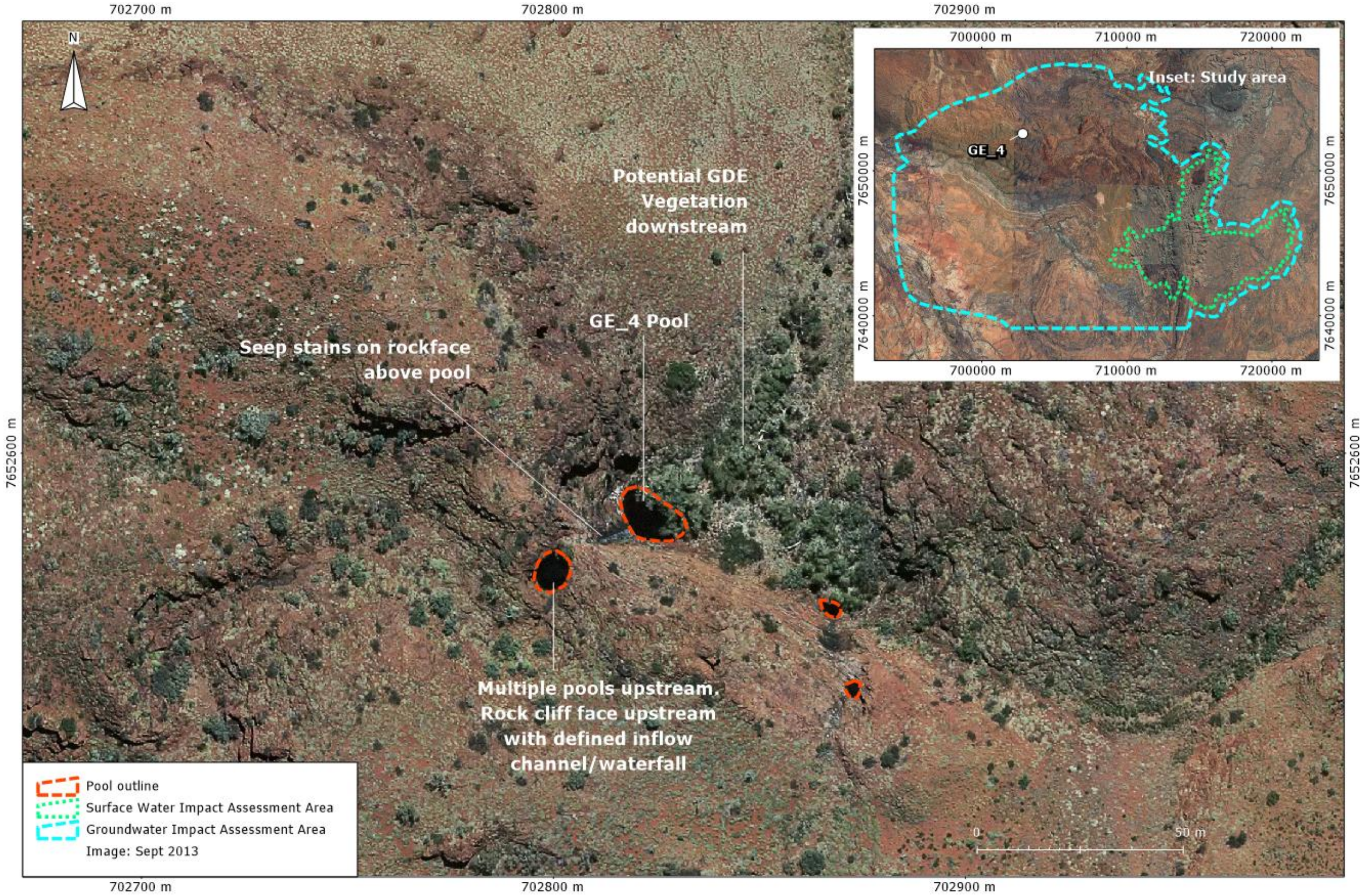


Figure 3-28 Map of GE_4 Pool showing hydrologic features.

3.2.3.3 TYPE 3 - BEDROCK AQUICLUDE - GROUNDWATER DISCHARGE

Mundagoora Pool

Mundagoora Pool is a relatively deep permanent pool located at the base of an intermittent waterfall, with surface water inflow only occurring during high rainfall events. The pool is located to the west of the NSE development area and south of the existing Operational Processing Facility (OPF; Figure 3-8). The pool water level is controlled by a sill at the downstream edge, with water levels remaining relatively consistent within the pool except for short duration peaks during high rainfall. Monitoring survey data indicates the pool is largely sustained by groundwater with periodic flushing of fresh surface water flows after rainfall events. The discharge or overflow from Mundagoora Pool supports a groundwater dependent ecosystem (GDE) downstream for a length of 150-300 m depending on the strength of the antecedent wet season and discharge rates (Figure 3-8).

The hydrochemistry of this pool shows that large rainfall events can flush the pool with surface water from once to several times per wet season (Figure 3-9). The fresher (less salty) surface waters are replaced by groundwater inflows (indicated by higher salinities) over a period of 2-3 weeks following these rainfall/flow events (pool's mean EC is ~900 µS/cm, within a range of 50 to 1000 µS/cm). The estimated groundwater inflow rate, based on the rate of salt replacement following a surface water flow event, is ~0.19 L/s.

This indicates that for the majority of the annual hydro-cycle, the pool is supported by groundwater inflows. The pool surface level is relatively constant throughout the year with fluctuations of <0.3 m from dry to wet season at a maximum depth of over 3 m. Over the monitoring period, flood peaks were observed to be limited to only ~0.6 m above the normal pool levels.

The permanent near-full status of the pool and, the dense groundwater dependent vegetation immediately downstream of the pool, indicates a groundwater source. The conceptual model applied to Mundagoora Pool is

Type 3 - Bedrock aquiclude - groundwater discharge (Figure 3-10). Appendix C provides a listing of all pool/reach conceptual model classifications.

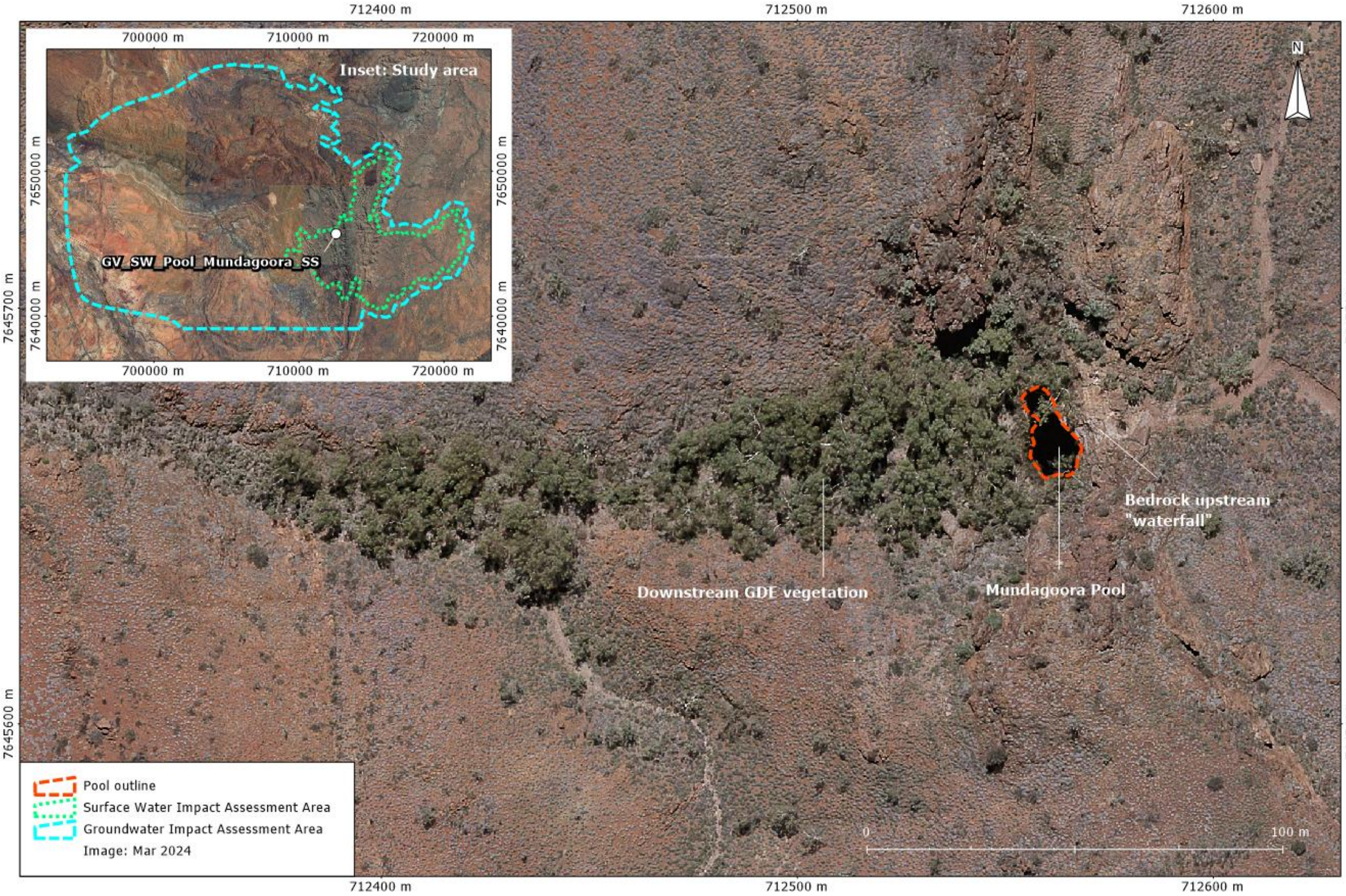


Figure 3-29 Map of Mundagoora Pool

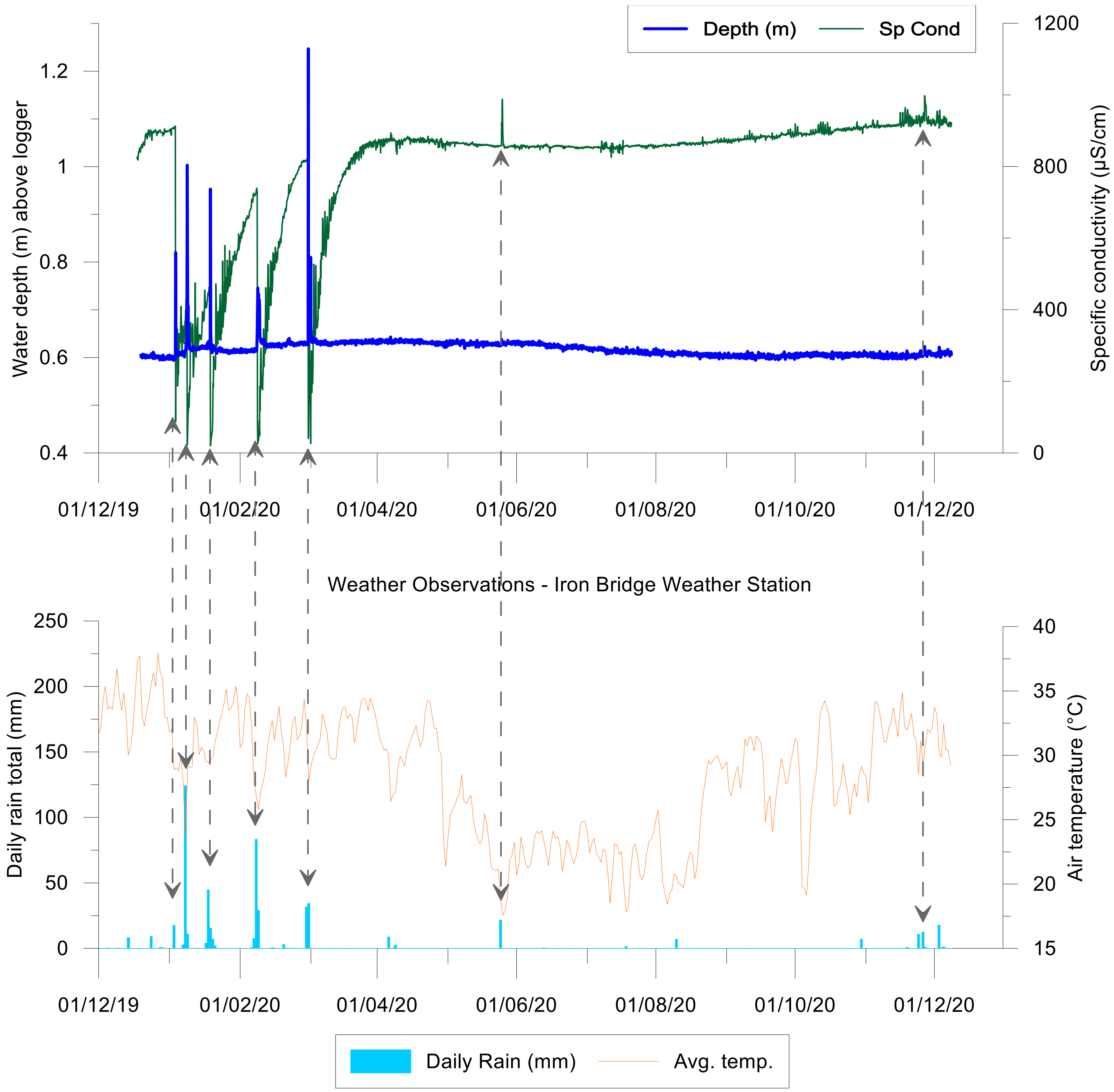


Figure 3-30 Annual water level and salinity (EC) at Mundagoora Pool in response to rainfall events (2019/20 season)

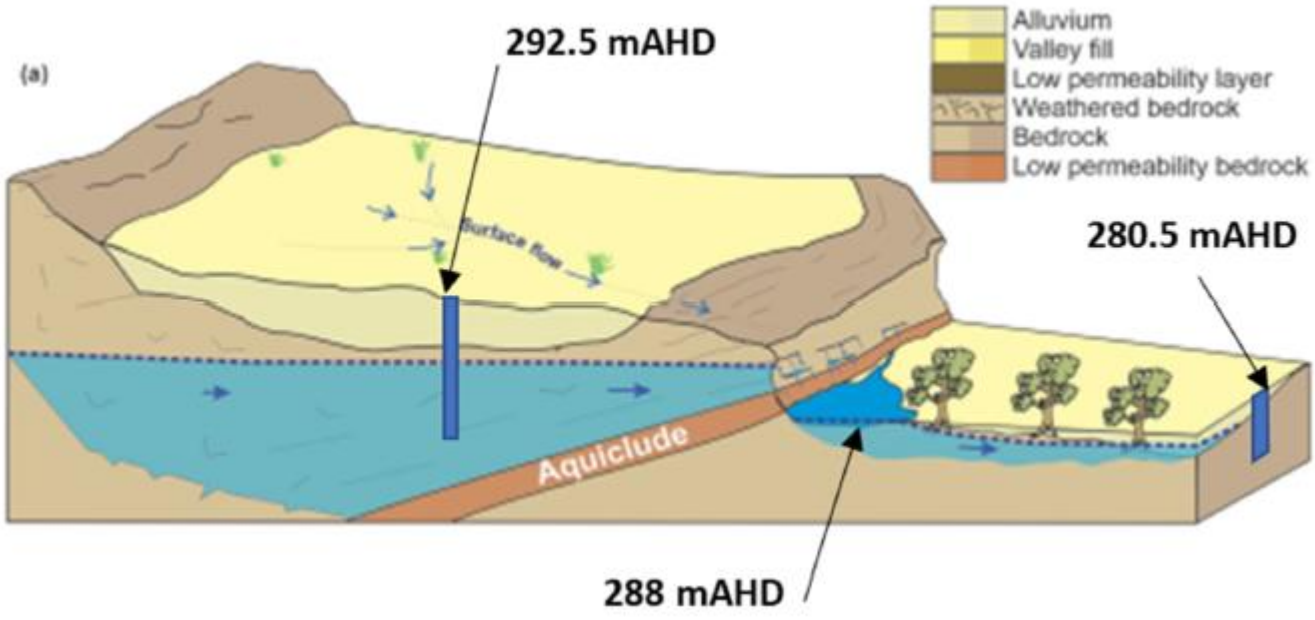


Figure 3-31 Conceptual schematic of Mundagoora Pool, showing relative water levels in upstream catchment, the pool and downstream (adapted from Bourke et al. [2023]) (Fortescue, 2023).

Site 12 Pool

Site 12 pool is part of a series of shallow pools that lie to the east of the active mining area, on a small tributary to the upper Six Mile Creek (Figure 3-11). The pool is connected to both surface water and groundwater until the local groundwater levels drops below the pool base level over the late dry season. The pool is frequently perennial though has been known to dry out following small wet seasons. What is referred to as "Site 12 Pool" is the lower or last pool within the string of pools, with the uppermost pool in the string is referred to by its monitoring site name "IB_SW_Pool12_01" around 400m upstream. The upper three pools in this string are "Commonly Wet" with the lower pools being seasonally inundated.

The hydrochemistry of this pool indicates that the upper pools in this reach are likely to be supported by regional groundwater, with very little change in water quality even when near dry (indicating that the water levels are receding to the subsurface rather than evaporation; Figure 3-12). The lower-lying pools in the string/reach, including Site 12 Pool, demonstrate a more fresh/surface water dominant signature and are likely to have less reliance/support from groundwater inflows than the upper pools (Figure 3-13; see also Figure 3-4 in Section 3.2.2) for context. Site 12 Pool in a poor wet season can recede faster than calculated for evaporation alone, indicating that loss to groundwater is likely to be occurring when groundwater levels are relatively low.

The Site 12 pools also contain significant environmental values including GDV, three fish species (the only pool in the NSE area to contain catfish), emergent and submerged macrophytes and, the Dinner Plate Turtle (*Chelodina steindachneri*). These indicators suggest water permanence or semi-permanence with common persistence into the late dry season.

There is a small wetland/waterlogged area upstream of the Site 12 pools which occurs immediately upstream of a bedrock outcrop within the drainage channel. The conceptual model for this site suggests that this rock outcrop within the drainage channel may be a sill or aquiclude behind which groundwater mounds and overflows, feeding the Site 12 pools (Figure 3-11).

The Type 3 - Bedrock aquiclude - groundwater discharge hydrologic model has been applied to Site 12 Pool, though it is noted that this applies most completely to the upper pool(s) in the string, which have more water persistence and a greater groundwater hydrologic and geochemical signal. While the Type 3 conceptualisation has been applied to all pools within the Site 12 string, the lower pools are less persistent and have a greater proportion of their persistence supported by surface water inflows (residual ponded surface waters, as indicated by salinity logger measurements). Appendix C provides a listing of all pool/reach conceptual model classifications.

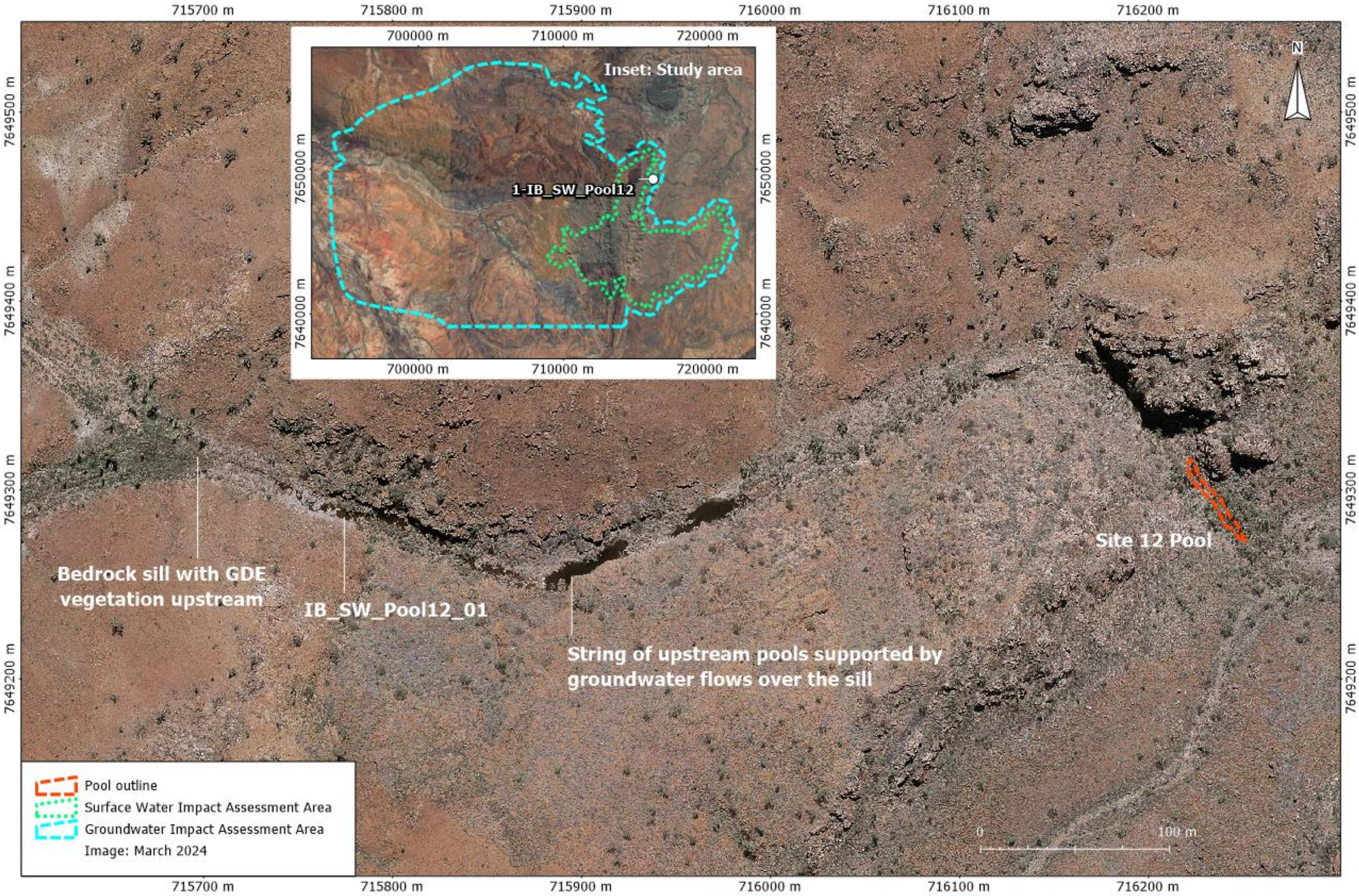


Figure 3-32 Map of Site 12 Pool showing hydrologic features

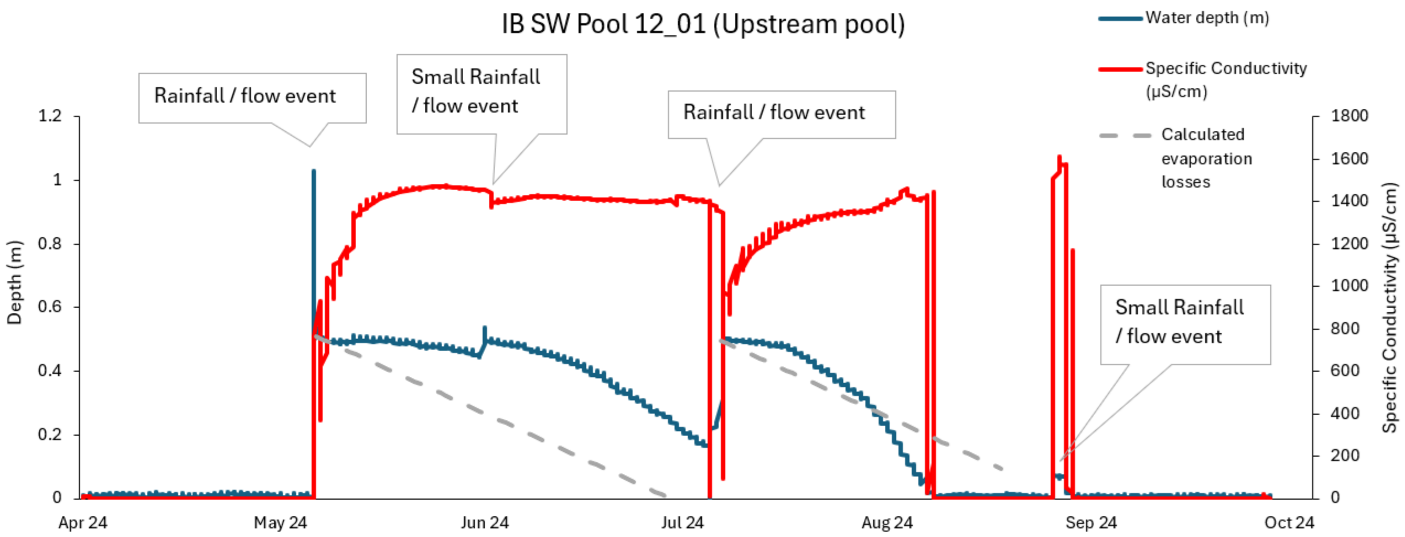


Figure 3-33 Water level and specific conductivity plot for IB_SW_Pool12_01 – April to Oct 2024

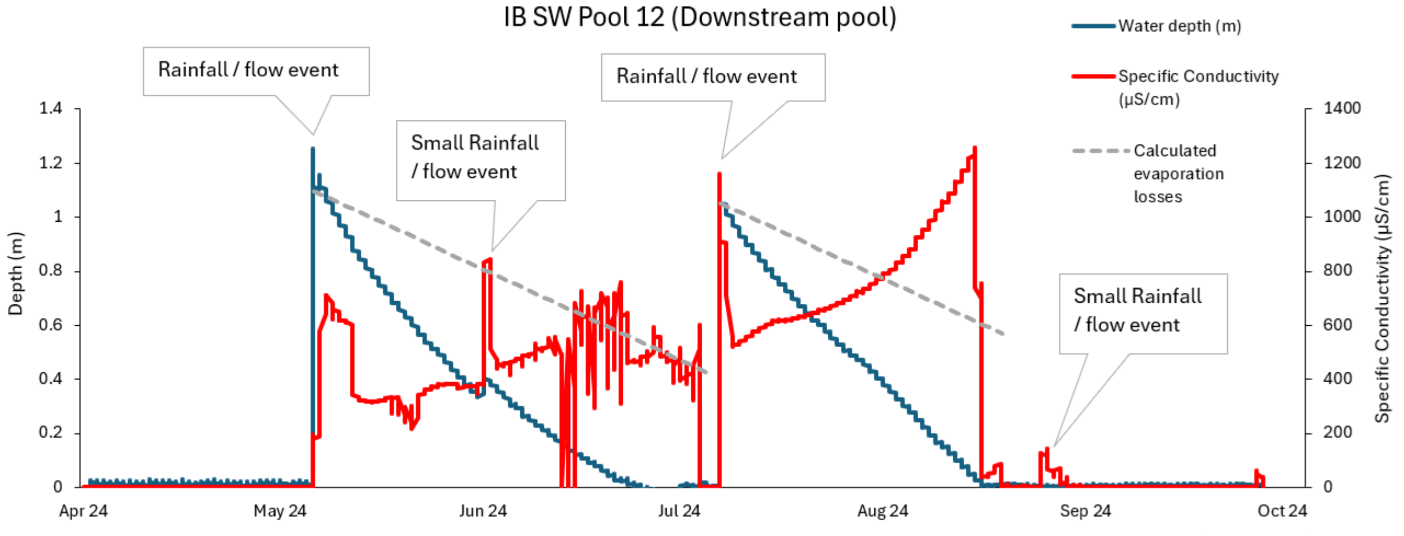


Figure 3-34 Water level and specific conductivity plot for Site 12 pool – April to Oct 2024

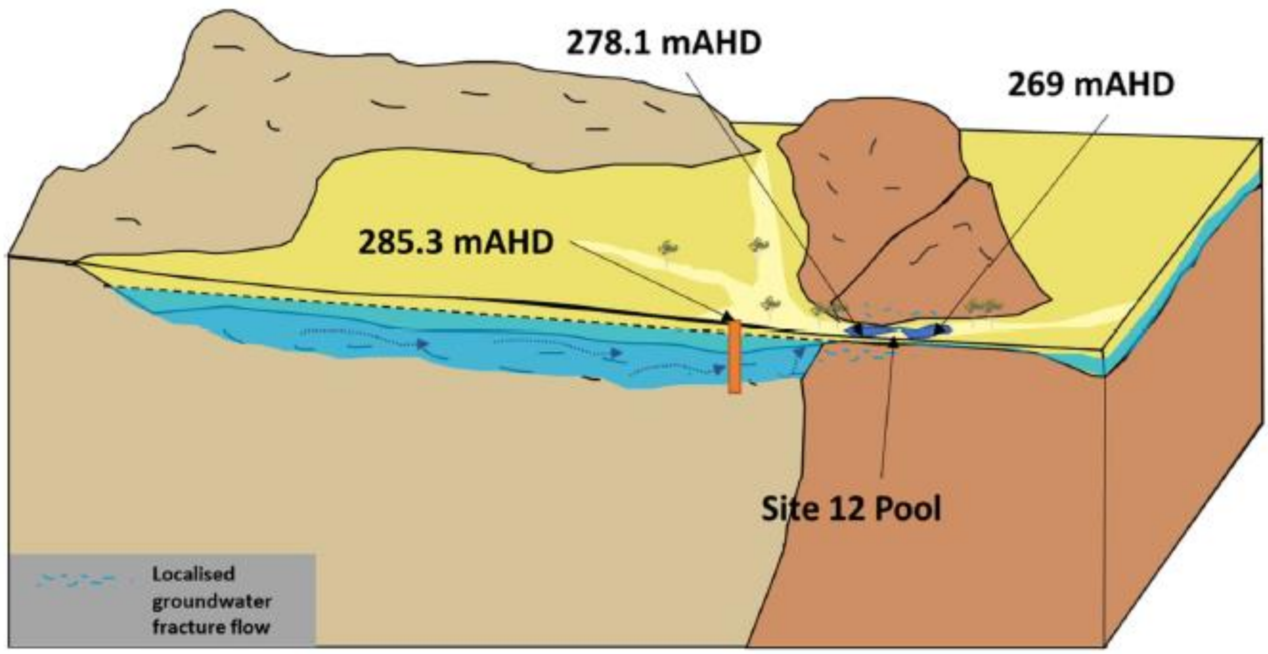


Figure 3-35 Conceptual schematic of Site 12 Pool, showing relative water levels in upstream catchment and pool system (adapted from Bourke et al., [2023]) (Fortescue, 2023).

4. CONCLUSIONS

The application of the Bourke et. al (2023) method for deriving a conceptual hydraulic model for pools within the NSE study area has provided a useful framework to understand potential impact mechanisms for each pool. The method has been adapted to the conceptual models relevant to the pools of this specific study area and, additional water persistence information added to the methodology.

The Bourke et. al (2023) approach has been combined with the ANAE classification system to provide a more comprehensive framework including hydrologic (water persistence) considerations.

We have systematically identified pools across the study area and provided an important pre-cursor step to the impact assessment process.

A total of 102 pools were identified within the Study Area, that have the potential to be impacted by the NSE development. The majority of the identified pools (69%) were periodic or ephemeral with respect to water permanence with 11% being seasonally inundated, 14% commonly wet and 7% permanent.

For the purposes of impact assessment, individual pools were grouped into local "reaches" along connecting sections of drainage lines, resulting in a total of 82 reaches. Of the 82 pools, 41% were type 1A (Alluvium - perched throughflow), 11% were Type 1b (Alluvium/bedrock - perched surface water throughflow), 26% were Type 2a (Bedrock - perched surface water), 11% were Type 2b (Bedrock - fracture flow groundwater source), 9% were Type 2a/2b (Potentially either 2a or 2b) and 2% were Type 3 (Bedrock aquiclude - groundwater discharge). No reaches of Type 4 were identified (Topographically controlled groundwater outflow).

5. REFERENCES

Aquatic Ecosystems Task Group (2012). Aquatic Ecosystems Toolkit. Module 2. Interim Australian National Aquatic Ecosystem Classification Framework. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Bourke, S. A., Shanafield, M., Hedley, P., Chapman, S., & Dogramaci, S. (2023). A hydrological framework for persistent pools along non-perennial rivers. Hydrology and Earth System Sciences, 27(3), 809–836. https://doi.org/10.5194/hess-27-809-2023

Fortescue (2023). Iron Bridge Mine Area Hydrogeological Assessment. Strategic Planning. 10/03/2023. IB-5700-RP-WM-0002 Rev 0.

Fortescue. (2025). Site 12 Pool Catchment Waterways Assessment – North Star Extension.

NASA (2024). EARTHDATA: Shuttle Radar Topography Mission (SRTM) dataset (30m grid). https://www.earthdata.nasa.gov/data/instruments/srtm

APPENDIX A. IMAGE LIST

File Name	Month	Year
FMG_North_Star_2011_Aug.ecw	Aug	2011
FMG_North_Star_2012_Feb_40cm.ecw	Feb	2012
FMG_North_Star_2012_Dec_15cm.ecw	Dec	2012
FMG_North_Star_2013_Sept_15cm.ecw	Sept	2013
FMG_North_Star_2014_Jan.ecw	Jan	2014
FMG_North_Star_Area1_2014_Feb_15cm.ecw	Feb	2014
FMG_North_Star_Area3_2014_Feb_15cm.ecw	Feb	2014
FMG_North_Star_Area2_2014_Feb_15cm.ecw	Feb	2014
FMG_North_Star_2014_March_15cm.ecw	March	2014
FMG_North_Star_2014_June_15cm.ecw	June	2014
FMG_North_Star_Mine_2014_Sept_15cm.ecw	Sept	2014
FMG_North_Star_2014_Nov_15cm.ecw	Nov	2014
FMG_North_Star_2015_April_15cm.ecw	April	2015
FMG_North_Star_2015_June_15cm.ecw	June	2015
FMG_North_Star_2015_Sept_15cm.ecw	Sept	2015
FMG_North_Star_Mine_2015_Nov_15cm.ecw	Nov	2015
FMG_North_Star_2016_Apr_15cm.ecw	April	2016
FMG_North_Star_2016_June_15cm.ecw	June	2016
FMG_North_Star_2016_Sept_15cm.ecw	Sept	2016
FMG_North_Star_2016_Dec_15cm.ecw	Dec	2016
FMG_North_Star_2017_April_15cm.ecw	April	2017
FMG_North_Star_2017_June_15cm.ecw	June	2017
FMG_North_Star_2017_Sept_15cm.ecw	Sept	2017
FMG_North_Star_2017_Nov_15cm.ecw	Nov	2017
FMG_North_Star_2018_June_15cm.ecw	June	2018
FMG_Iron_Bridge_2019_July_15cm.ecw	July	2019
FMG_Iron_Bridge_2019_Oct_15cm.ecw	Oct	2019
FMG_Iron_Bridge_2020_April_15cm.ecw	April	2020

File Name	Month	Year
FMG_Iron_Bridge_2020_June_15cm.ecw	June	2020
FMG_Iron_Bridge_2020_Sept_15cm.ecw	Sept	2020
FMG_Iron_Bridge_2021_Jan_15cm.ecw	Jan	2021
FMG_Iron_Bridge_South_2021_Jan_15cm.ecw	Jan	2021
FMG_Iron_Bridge_Extra_2021_Jan_15cm.ecw	Jan	2021
FMG_Iron_Bridge_North_2021_Jan_15cm.ecw	Jan	2021
FMG_Iron_Bridge_South_2021_Nov_15cm.ecw	Nov	2021
FMG_Iron_Bridge_North_2021_Nov_15cm.ecw	Nov	2021
FMG_Iron_Bridge_2022_Jul_15cm.ecw	July	2022
FMG_Iron_Bridge_2022_Aug_15cm.ecw	Aug	2022
FMG_Iron_Bridge_Decarb_2023_Mar_15cm.ecw	March	2023
FMG_Iron_Bridge_2023_Mar_15cm.ecw	March	2023
FMG_Iron_Bridge_2023_June_15cm.ecw	June	2023
FMG_Iron_Bridge_2023_Nov_15cm.ecw	Nov	2023

APPENDIX B.
POOL IDENTIFICATION DATA

Site_Name	Easting	Northing	# Images Assessed	# Images showing water present	Water Pres_ by Count %	Water_Pres_by Count_Class ANAE_1_0.7_0.5	Average fullness score	Bourke (2023) Concept. #	Substrate - Air Photo Interpretation	Elevation mAHD (from Elvis)	Elevation mAHD (from LiDAR)	Fortescue Groundwater Level (mAHD)	Reach Name
1-IB_SW_Pool12	716214	7649319	23	13	0.57	Seasonal Inundation	1.57	3	Alluvium	299	271	N/A	Site 12 Pool
2-S12string	716180	7649353	17	8	0.47	Periodic Inund./Ephemeral	1.12	3	Alluvium	299	272	N/A	Site 12 Pool
3-S12string	716120	7649369	32	17	0.53	Seasonal Inundation	1.66	3	Bed/Alluv	288	273	N/A	Site 12 Pool
4-S12string	716011	7649323	32	10	0.31	Periodic Inund./Ephemeral	0.50	3	Bed/Alluv	284	277	N/A	Site 12 Pool
5-S12string	715992	7649310	32	15	0.47	Periodic Inund./Ephemeral	1.25	3	Bed/Alluv	288	277	N/A	Site 12 Pool
6-S12string	715961	7649297	31	22	0.71	Commonly Wet	2.10	3	Bedrock	290	277	N/A	Site 12 Pool
7-S12string	715889	7649272	29	24	0.83	Commonly Wet	2.59	3	Bedrock	302	278	N/A	Site 12 Pool
8 - IB_SW_Pool12_01	715759	7649293	31	26	0.84	Commonly Wet	2.10	3	Bedrock	295	279	242	Site 12 Pool
9	715493	7649165	39	14	0.36	Periodic Inund./Ephemeral	0.97	1a	Alluvium	291	285	265	Pool 9
11	715579	7650019	31	8	0.26	Periodic Inund./Ephemeral	0.87	2a	Bedrock	319	301	272	Pool 11
15	716422	7650055	28	5	0.18	Periodic Inund./Ephemeral	0.25	1b	Bed/Alluv	317	308	N/A	15
36 - IB_SW_TSF_02	708623	7655816	36	10	0.28	Periodic Inund./Ephemeral	0.50	1a	Alluvium	244	229	N/A	36 - IB_SW_TSF_02
37	708560	7655276	36	8	0.22	Periodic Inund./Ephemeral	0.36	1a	Alluvium	242	234	229	37
38	709063	7655126	36	7	0.19	Periodic Inund./Ephemeral	0.28	1a	Alluvium	239	234	224	38
39 - IB_SW_TSF_03	709342	7654472	36	8	0.22	Periodic Inund./Ephemeral	0.50	1a	Alluvium	245	240	221	39 - IB_SW_TSF_03
40	709078	7653220	36	3	0.08	Periodic Inund./Ephemeral	0.11	1a	Alluvium	258	251	N/A	40
41	709098	7653376	33	7	0.21	Periodic Inund./Ephemeral	0.55	1a	Alluvium	260	248	N/A	41
42	708956	7652223	37	37	1.00	Permanent	2.70	2b	Bedrock	302	273	N/A	42
43	709016	7652062	34	19	0.56	Seasonal Inundation	0.97	2a/2b	Bedrock	311	307	N/A	43
44	708259	7652648	33	33	1.00	Permanent	2.97	2b	Bedrock	304	280	N/A	93
45	708135	7649959	41	15	0.37	Periodic Inund./Ephemeral	1.02	2a	Bedrock	282	273	226	45
46	708122	7650085	39	4	0.10	Periodic Inund./Ephemeral	0.10	1a	Alluvium	285	276	224	46
47	708232	7649402	41	7	0.17	Periodic Inund./Ephemeral	0.59	1a	Bed/Alluv	270	262	237	47
48	709157	7649833	39	0	0.00	Periodic Inund./Ephemeral	0.00	2a	Bedrock	316	295	213	48
49	716592	7649930	28	3	0.11	Periodic Inund./Ephemeral	0.18	1b	Bedrock	305	291	N/A	49
50	715631	7645705	29	1	0.03	Periodic Inund./Ephemeral	0.03	1a	Alluvium	301	289	N/A	Pool 50
51 - GV_SW_WRD _01	714379	7645915	35	1	0.03	Periodic Inund./Ephemeral	0.03	1b	Bed/Alluv	329	315	306	Pool 51
52	715393	7644317	32	18	0.56	Seasonal Inundation	1.25	2a/2b	Bedrock	306	297	N/A	NJA19-002
GV_SW_Pool_ Mundagoora_SS	712553	7645679	32	32	1.00	Permanent	3.69	3	Bedrock	310	289	294	Mundagoora Pool
55 - GV_SW_Pool_SW	712578	7643390	33	5	0.15	Periodic Inund./Ephemeral	0.27	1a	Alluvium	305	293	N/A	Pool-SW
56 - GV_SW_Pool_SWGV_DS	712479	7643316	36	8	0.22	Periodic Inund./Ephemeral	0.44	1a	Alluvium	295	290	N/A	Pool-SW
57	713259	7645204	29	0	0.00	Periodic Inund./Ephemeral	0.00	2a	Bedrock	384	380	323	Pool 57
59	712964	7644815	20	1	0.05	Periodic Inund./Ephemeral	0.05	2a	Bedrock	344	313	295	Pool 59
60 - IB_SW_Pool_ Central Ck	704355	7646334	37	9	0.24	Periodic Inund./Ephemeral	0.35	1a	Alluvium	231	223	205	60 - IB_SW_Pool_Central Ck
61 - GV_SW_Pool_ NJA19-002	715410	7644325	32	17	0.53	Seasonal Inundation	1.19	2a/2b	Bedrock	303	293	N/A	NJA19-002
62	713280	7644655	28	1	0.04	Periodic Inund./Ephemeral	0.04	2a	Bedrock	375	366	331	Pool 62
63	713276	7645204	35	0	0.00	Periodic Inund./Ephemeral	0.00	2a	Bedrock	392	386	326	Pool 57
64	713239	7645214	24	2	0.08	Periodic Inund./Ephemeral	0.08	2a	Bedrock	385	372	320	Pool 67
65	713289	7644654	27	0	0.00	Periodic Inund./Ephemeral	0.00	2a	Bedrock	375	370	335	Pool 62
78 - GV_SW_Pool _GR	713224	7644657	27	5	0.19	Periodic Inund./Ephemeral	0.19	2a	Bedrock	367	354	324	Pool 62
79	704231	7646892	37	12	0.32	Periodic Inund./Ephemeral	0.65	1a	Alluvium	229	222	206	79
80	704031	7647099	37	9	0.24	Periodic Inund./Ephemeral	0.62	1a	Alluvium	227	221	215	80
81	702817	7648380	36	11	0.31	Periodic Inund./Ephemeral	0.89	1a	Alluvium	224	217	209	81
82	702453	7648540	30	8	0.27	Periodic Inund./Ephemeral	0.80	1a	Alluvium	221	216	208	82

Site_Name	Easting	Northing	# Images Assessed	# Images showing water present	Water Pres_ by Count %	Water_Pres_by Count_Class ANAE_1_0.7_0.5	Average fullness score	Bourke (2023) Concept. #	Substrate - Air Photo Interpretation	Elevation mAHD (from Elvis)	Elevation mAHD (from LiDAR)	Fortescue Groundwater Level (mAHD)	Reach Name
83	702015	7648422	35	13	0.37	Periodic Inund./Ephemeral	0.97	1a	Alluvium	222	214	209	83
84	706803	7643258	33	8	0.24	Periodic Inund./Ephemeral	0.45	1a	Alluvium	249	238	N/A	84
85	706705	7643341	33	4	0.12	Periodic Inund./Ephemeral	0.12	1a	Alluvium	246	237	N/A	85
86	706410	7643591	20	9	0.45	Periodic Inund./Ephemeral	0.85	1b	Bed/Alluv	239	236	N/A	86
87	704935	7646015	34	6	0.18	Periodic Inund./Ephemeral	0.26	1a	Alluvium	231	225	219	87
88	713647	7642067	17	0	0.00	Periodic Inund./Ephemeral	0.00	2a	Bedrock	367	353	N/A	88
93	708280	7652681	26	26	1.00	Permanent	3.19	2b	Bedrock	292	274	N/A	93
94	705344	7648904	23	18	0.78	Commonly Wet	1.96	2a/2b	Bedrock	336	322	241	97 - Zanes Gorge Pool
95	705323	7648785	26	6	0.23	Periodic Inund./Ephemeral	0.35	2a	Bedrock	332	314	249	97 - Zanes Gorge Pool
96	705307	7648735	25	10	0.40	Periodic Inund./Ephemeral	0.52	2a	Bedrock	325	312	255	97 - Zanes Gorge Pool
97 - Zanes Gorge Pool	705244	7648705	15	11	0.73	Commonly Wet	1.60	2a/2b	Bedrock	319	304	249	97 - Zanes Gorge Pool
98 - Dingo Lair Pool	704831	7648782	0	0	0.75	Commonly Wet	N/A	2a	Bedrock	296	266	204	98 - Dingo Lair Pool
99	704008	7649076	2	0	0.00	Periodic Inund./Ephemeral	0.00	2a	Bedrock	275	244	186	99
100	703940	7649597	5	4	0.80	Commonly Wet	1.80	2a	Bedrock	318	308	206	100
101	703061	7650110	4	2	0.50	Seasonal Inundation	1.00	2a	Bedrock	306	288	186	101
102	702778	7649877	9	3	0.33	Periodic Inund./Ephemeral	0.89	1b	Bed/Alluv	282	272	196	102
103	702725	7649772	9	3	0.33	Periodic Inund./Ephemeral	0.78	2a	Bedrock	277	269	198	104 - Craigs Pool upper
104 - Craigs Pool upper	702686	7649667	6	1	0.17	Periodic Inund./Ephemeral	0.17	2a	Bedrock	277	268	208	104 - Craigs Pool upper
105	708476	7650583	38	34	0.89	Commonly Wet	2.26	2a/2b	Bedrock	301	289	N/A	105
106	708797	7650684	33	2	0.06	Periodic Inund./Ephemeral	0.15	2a	Bedrock	337	332	N/A	106
107	708817	7651728	37	16	0.43	Periodic Inund./Ephemeral	0.68	2a	Bedrock	346	335	N/A	107
108	705354	7651357	37	3	0.08	Periodic Inund./Ephemeral	0.08	1a	Alluvium	333	327	N/A	108
109	705329	7651564	39	2	0.05	Periodic Inund./Ephemeral	0.05	1a	Alluvium	332	325	N/A	109
110	705199	7652242	28	1	0.04	Periodic Inund./Ephemeral	0.04	1a	Alluvium	321	315	N/A	110
111	705033	7652270	28	11	0.39	Periodic Inund./Ephemeral	1.21	1a	Alluvium	320	312	N/A	112
112	705034	7652395	29	6	0.21	Periodic Inund./Ephemeral	0.59	1a	Alluvium	319	312	N/A	112
113	705172	7652684	28	7	0.25	Periodic Inund./Ephemeral	0.46	1a	Alluvium	317	308	N/A	115
114	705129	7652745	28	5	0.18	Periodic Inund./Ephemeral	0.46	2a	Bedrock	316	307	N/A	115
115	705049	7652807	28	8	0.29	Periodic Inund./Ephemeral	0.71	1b	Bed/Alluv	318	305	N/A	115
116	704676	7652900	26	5	0.19	Periodic Inund./Ephemeral	0.50	1a	Alluvium	308	301	N/A	116
117	704418	7652877	26	3	0.12	Periodic Inund./Ephemeral	0.38	1a	Alluvium	308	299	N/A	117
118	704234	7652831	26	6	0.23	Periodic Inund./Ephemeral	0.54	2a	Bedrock	303	291	N/A	119
119	704201	7652897	24	18	0.75	Commonly Wet	1.63	2a/2b	Bedrock	301	287	N/A	119
120	704065	7653289	25	8	0.32	Periodic Inund./Ephemeral	0.92	2a	Bedrock	293	275	N/A	120
121	703938	7653549	21	13	0.62	Seasonal Inundation	2.14	2a/2b	Bedrock	271	258	N/A	121
122	703904	7653670	13	2	0.15	Periodic Inund./Ephemeral	0.54	1b	Bed/Alluv	262	256	N/A	122
124	703665	7653928	13	5	0.38	Periodic Inund./Ephemeral	0.92	1b	Bed/Alluv	260	241	N/A	124
125	703463	7653911	13	5	0.38	Periodic Inund./Ephemeral	1.23	1a	Bedrock	251	235	N/A	125
IB_SW_Pool_Fig	711667	7650621	42	42	1.00	Permanent	2.86	2b	Bedrock	310	303	266	IB_SW_Pool_Fig
IB_SW_Pool_ Cow Spring	711101	7648578	42	42	1.00	Permanent	2.95	2b	Bedrock	312	297	264	IB_SW_Pool_Cow Spring
GV_SW_Pool_NJA21-006-US	718007	7645416	20	5	0.25	Periodic Inund./Ephemeral	0.65	2a	Bedrock	267	260	N/A	Pool NJA21-006-US
GV_SW_Pool_NJA19-004	715896	7646284	32	17	0.53	Seasonal Inundation	0.53	2a/2b	Bedrock	299	285	N/A	GV_SW_Pool_NJA19-004
GV_SW_Pool_NJA21-006-DS	720057	7644905	20	1	0.05	Periodic Inund./Ephemeral	5.55	1a	Alluvium	243	240	N/A	Pool NJA21-006-DS
IB_SW_DryReject_ DS_02	709338	7643632	45	1	0.02	Periodic Inund./Ephemeral	0.02	1a	Alluvium	267	252	231	Pool IB-SW-Dry-Reject-DS-002
GE_1	698078	7652675	6	1	0.17	Periodic Inund./Ephemeral	0.50	2a	Bedrock	275	258	N/A	GE_1

Site_Name	Easting	Northing	# Images Assessed	# Images showing water present	Water Pres_ by Count %	Water_Pres_by Count_Class ANAE_1_0.7_0.5	Average fullness score	Bourke (2023) Concept. #	Substrate - Air Photo Interpretation	Elevation mAHD (from Elvis)	Elevation mAHD (from LiDAR)	Fortescue Groundwater Level (mAHD)	Reach Name
GE_2	700658	7652474	9	5	0.56	Seasonal Inundation	1.00	2a	Bedrock	308	279	N/A	GE_2
GE_3	703325	7653085	23	9	0.39	Periodic Inund./Ephemeral	0.74	1a	Alluvium	241	236	N/A	GE_3
GE_4	702821	7652593	10	10	1.00	Permanent	2.50	2b	Bedrock	280	247	N/A	GE_4
GE_5	704264	7651720	27	23	0.85	Commonly Wet	2.81	2b	Bedrock	289	262	N/A	GE_5
GE_6	701353	7652700	6	5	0.83	Commonly Wet	1.17	2a	Bedrock	300	286	N/A	GE_6
GE_7	704124	7639903	10	6	0.60	Seasonal Inundation	1.10	1a	Alluvium	248	N/A	N/A	GE_7
GE_8	705054	7639832	11	2	0.18	Periodic Inund./Ephemeral	0.27	1a	Alluvium	270	N/A	N/A	GE_8
GE_9	710488	7639953	10	3	0.30	Periodic Inund./Ephemeral	0.50	1b	Bedrock	284	273	N/A	GE_9
GE_10	714871	7642125	24	19	0.79	Commonly Wet	1.96	2a	Bedrock	311	297	N/A	GE 10
GE_11	696605	7650254	25	7	0.28	Periodic Inund./Ephemeral	0.80	1a	Alluvium	201	196	N/A	GE_11
GE_12	696149	7650428	26	13	0.50	Seasonal Inundation	1.31	1a	Alluvium	199	N/A	N/A	GE_12
126 - Craigs Pool lower	702605	7649573	1	1	1.00	Commonly Wet	3.00	2b	Bedrock	248	N/A	N/A	126 - Craigs Pool lower
127 - Astrid Bee Cave	700186	7650960	N/A	N/A	N/A	Commonly Wet	N/A	2b	Bedrock	246	N/A	N/A	127 - Astrid Bee Cave

APPENDIX C. EVIDENCE MATRIX BY POOL FOR HYDROLOGIC CONCEPTUALISATION

Site Name	Bourke (2023) Conceptualisation #	Water Permanence	EM based source	EM - Water Presence	EM - Fullness Score	EM - Substrate	EM - Location	EM - Elevation	EM - Depth to regional GW	EM - Catchment Size	EM - Flow Regime	EM - Vegetation	EM – Hydro-chemistry	Potentially Sensitive to Surface Water Changes	Potentially Sensitive to Local Groundwater Changes	Potentially Sensitive to Regional Groundwater Changes
1-IB_SW_Pool12	3	Seasonal Inundation	SW/GW	SW	SW	nc	GW	GW	GW-R	nc	SW	GW	SW	No	Yes	Yes
2-S12string	3	Periodic Inund./Ephemeral	SW/GW	SW	SW	nc	GW	GW	GW-R	nc	na	GW	na	No	Yes	Yes
3-S12string	3	Seasonal Inundation	SW/GW	SW	SW	nc	GW	GW	GW-R	nc	na	GW	na	No	Yes	Yes
4-S12string	3	Periodic Inund./Ephemeral	SW/GW	SW	SW	nc	GW	GW	GW-R	nc	na	GW	na	No	Yes	Yes
5-S12string	3	Periodic Inund./Ephemeral	SW/GW	SW	SW	nc	GW	GW	GW-R	nc	na	GW	na	No	Yes	Yes
6-S12string	3	Commonly Wet	GW	GW	GW	GW	GW	GW	GW-R	GW	GW	GW	GW	No	Yes	Yes
7-S12string	3	Commonly Wet	GW	GW	GW	GW	GW	GW	GW-R	GW	GW	GW	GW	No	Yes	Yes
8 - IB_SW_Pool12_01	3	Commonly Wet	GW	GW	GW	GW	GW	GW	GW-R	GW	GW	GW	GW	No	Yes	Yes
9	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	nc	SW	nc	SW	SW	SW	Yes	No	No
11	2a	Periodic Inund./Ephemeral	SW	SW	SW	GW	GW	nc	nc	nc	na	SW	na	Yes	No	No
15	1b	Periodic Inund./Ephemeral	SW	SW	SW	nc	SW	SW	SW	SW	na	SW	na	Yes	No	No
36 - IB_SW_TSF_02	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
37	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
38	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
39 - IB_SW_TSF_03	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
40	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
41	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
42	2b	Permanent	GW	GW	GW	nc	nc	GW	GW-L	GW	na	SW	na	No	Yes	No
43	2a/2b	Seasonal Inundation	SW	SW	SW	nc	nc	GW	GW-L	nc	na	SW	na	Yes	Yes	No
44	2b	Permanent	GW	GW	GW	nc	nc	GW	GW-L	GW	na	SW	na	No	Yes	No
45	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
46	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
47	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
48	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	nc	na	SW	na	Yes	No	No
49	1b	Periodic Inund./Ephemeral	SW	SW	SW	nc	SW	SW	nc	nc	na	SW	na	Yes	No	No
50	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
51 - GV_SW_WRD_01	1b	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	nc	SW	SW	SW	na	Yes	No	No
52	2a/2b	Seasonal Inundation	SW	SW	SW	nc	GW	GW	nc	GW	na	SW	na	Yes	Yes	No
GV_SW_Pool_Mundagoora_SS	3	Permanent	GW	GW	GW	nc	GW	GW	GW-R	nc	GW	GW	GW	No	Yes	Yes
55 - GV_SW_Pool_SW	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	nc	nc	nc	SW	SW	SW	Yes	No	No
56 - GV_SW_Pool_SWGV_DS	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	nc	nc	nc	SW	SW	SW	Yes	No	No
57	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
59	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
60 - IB_SW_Pool_Central Ck	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	SW	SW	SW	Yes	No	No
61 - GV_SW_Pool_NJA19-002	2a/2b	Seasonal Inundation	SW/GW	SW/GW	SW/GW	SW	SW	SW	GW-L	GW	GW	SW	na	Yes	Yes	No
62	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
63	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
64	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
65	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
78 - GV_SW_Pool_GR	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	SW	Yes	No	No
79	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No

Site Name	Bourke (2023) Conceptualisation #	Water Permanence	EM based source	EM - Water Presence	EM - Fullness Score	EM - Substrate	EM - Location	EM - Elevation	EM - Depth to regional GW	EM - Catchment Size	EM - Flow Regime	EM - Vegetation	EM – Hydro-chemistry	Potentially Sensitive to Surface Water Changes	Potentially Sensitive to Local Groundwater Changes	Potentially Sensitive to Regional Groundwater Changes
80	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
81	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
82	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
83	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
84	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
85	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
86	1b	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
87	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
88	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
93	2b	Permanent	GW	GW	GW	nc	nc	GW	GW-L	GW	na	SW	na	No	Yes	No
94	2a/2b	Commonly Wet	GW	GW	GW	nc	nc	nc	GW-L	nc	na	SW	na	Yes	Yes	No
95	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	nc	nc	na	SW	na	Yes	No	No
96	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	nc	nc	na	SW	na	Yes	No	No
97 - Zanes Gorge Pool	2a/2b	Commonly Wet	GW	GW	GW	nc	nc	nc	GW-L	nc	na	nc	na	Yes	Yes	No
98 - Dingo Lair Pool	2a	Commonly Wet	GW	GW	GW	nc	nc	nc	GW-L	nc	na	nc	na	Yes	No	No
99	2a	Periodic Inund./Ephemeral	GW	GW	GW	nc	nc	nc	GW-L	nc	na	nc	na	Yes	No	No
100	2a	Commonly Wet	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
101	2a	Seasonal Inundation	GW	GW	GW	nc	nc	nc	GW-L	nc	na	nc	na	Yes	No	No
102	1b	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
103	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
104 - Craigs Pool upper	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	nc	SW	nc	na	SW	na	Yes	No	No
105	2a/2b	Commonly Wet	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	Yes	No
106	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
107	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	GW	SW	nc	na	SW	na	Yes	No	No
108	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
109	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
110	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
111	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
112	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
113	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
114	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
115	1b	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
116	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
117	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
118	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
119	2a/2b	Commonly Wet	GW	GW	GW	nc	GW	GW	GW-L	nc	na	SW	na	Yes	Yes	No
120	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
121	2a/2b	Seasonal Inundation	GW	GW	GW	nc	GW	GW	GW-L	nc	na	SW	na	Yes	Yes	No
122	1b	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
124	1b	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
125	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No

Site Name	Bourke (2023) Conceptualisation #	Water Permanence	EM based source	EM - Water Presence	EM - Fullness Score	EM - Substrate	EM - Location	EM - Elevation	EM - Depth to regional GW	EM - Catchment Size	EM - Flow Regime	EM - Vegetation	EM – Hydro-chemistry	Potentially Sensitive to Surface Water Changes	Potentially Sensitive to Local Groundwater Changes	Potentially Sensitive to Regional Groundwater Changes
IB_SW_Pool_Fig	2b	Permanent	GW	GW	GW	GW	GW	GW	GW-L	GW	GW	GW	GW	No	Yes	No
IB_SW_Pool_Cow Spring	2b	Permanent	GW	GW	GW	GW	GW	GW	GW-L	GW	GW	GW	GW	No	Yes	No
GV_SW_Pool_NJA21-006-US	2a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	SW	SW	SW	Yes	No	No
GV_SW_Pool_NJA19-004	2a/2b	Seasonal Inundation	SW	SW	SW	nc	SW	SW	nc	SW	SW	SW	SW	Yes	Yes	No
GV_SW_Pool_NJA21-006-DS	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	SW	SW	SW	Yes	No	No
IB_SW_DryReject_DS_02	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	SW	SW	SW	Yes	No	No
GE_1	2a	Periodic Inund./Ephemeral	SW	SW	SW	nc	nc	SW	nc	nc	na	SW	na	Yes	No	No
GE_2	2a	Seasonal Inundation	SW	SW	SW	nc	nc	nc	nc	nc	na	SW	na	Yes	No	No
GE_3	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
GE_4	2b	Permanent	GW	GW	GW	nc	GW	SW/GW-L	nc	GW	na	GW	na	No	Yes	No
GE_5	2b	Commonly Wet	GW	GW	GW	nc	GW	nc	GW-L	nc	na	SW	na	No	Yes	No
GE_6	2a	Commonly Wet	SW	SW	SW	nc	nc	nc	nc	nc	na	SW	na	Yes	No	No
GE_7	1a	Seasonal Inundation	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
GE_8	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	nc	SW	na	SW	na	Yes	No	No
GE_9	1b	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	nc	nc	SW	na	SW	na	Yes	No	No
GE_10	2a	Commonly Wet	GW	GW	GW	nc	nc	nc	GW-L	nc	na	SW	na	Yes	No	No
GE_11	1a	Periodic Inund./Ephemeral	SW	SW	SW	SW	SW	SW	SW	SW	na	SW	na	Yes	No	No
GE_12	1a	Seasonal Inundation	SW	SW	SW	SW	SW	SW	SW	SW	na	SW	na	Yes	No	No
126 - Craigs Pool lower	2b	Commonly Wet	GW	GW	GW	nc	nc	nc	GW-L	nc	na	nc	na	No	Yes	No
127 - Astrid Bee Cave	2b	Commonly Wet	GW	GW	GW	nc	nc	nc	GW-L	nc	na	nc	na	No	Yes	No

Notes:

GW = Groundwater

GW-L = Groundwater from a local aquifer

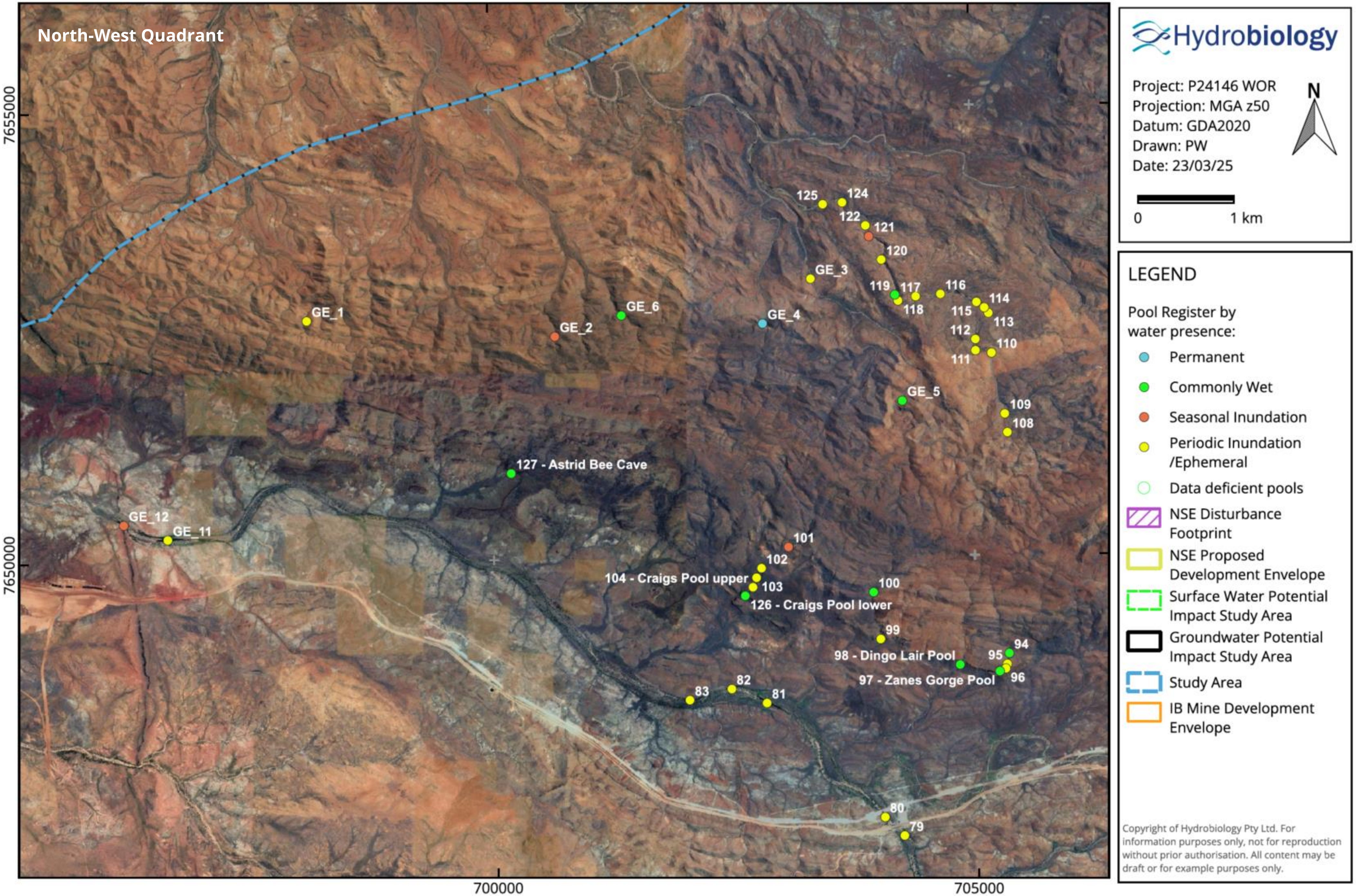
GW-R = Groundwater from the regional aquifer

SW = Surface Water (including alluvial throughflow)

nc = not conclusive (or no reasonable conclusion could be reached from this line of evidence)

na = not available. There was not sufficient data or evidence to support a conclusion

APPENDIX D. POOL DETAIL MAPS


North-West Quadrant
7655000
7650000
700000
705000
GE_1
GE_2
GE_3
GE_4
GE_5
GE_6
GE_11
GE_12
125
124
122
121
120
119
117
118
116
115
114
113
112
111
110
109
108
127 - Astrid Bee Cave
101
102
104 - Craigs Pool upper
103
126 - Craigs Pool lower
100
99
98 - Dingo Lair Pool
97 - Zanes Gorge Pool
94
95
96
83
82
81
80
79
Hydrobiology
Project: P24146 WOR
Projection: MGA z50
Datum: GDA2020
Drawn: PW
Date: 23/03/25
N
0
1 km
LEGEND
Pool Register by water presence:
Permanent
Commonly Wet
Seasonal Inundation
Periodic Inundation /Ephemeral
Data deficient pools
NSE Disturbance Footprint
NSE Proposed Development Envelope
Surface Water Potential Impact Study Area
Groundwater Potential Impact Study Area
Study Area
IB Mine Development Envelope
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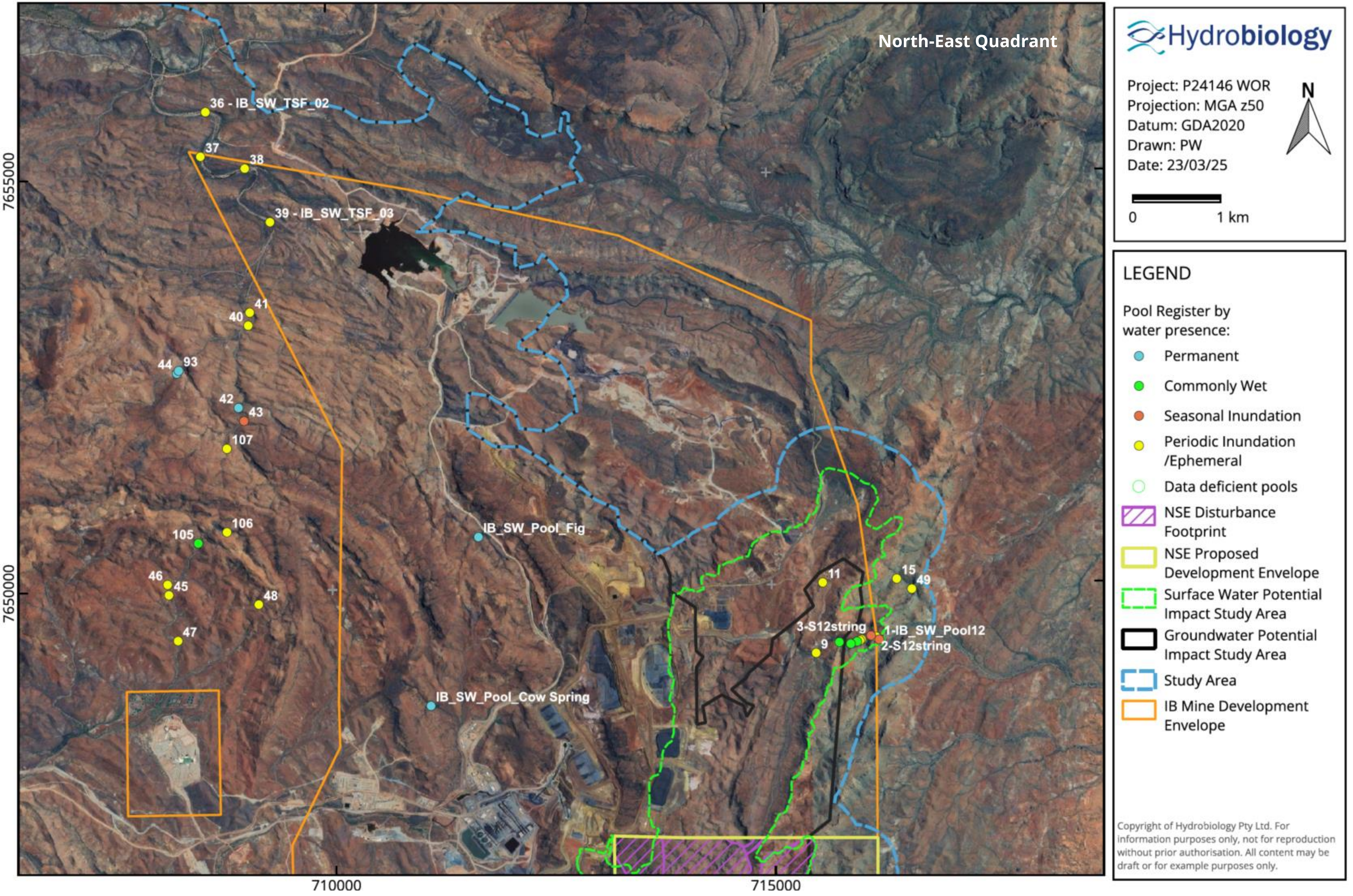
North-East Quadrant
36 - IB_SW_TSF_02
37
38
39 - IB_SW_TSF_03
41
40
44
93
42
43
107
106
105
IB_SW_Pool_Fig
46
45
48
47
IB_SW_Pool_Cow Spring
11
15
49
3-S12string
1-IB_SW_Pool12
9
2-S12string
7655000
7650000
710000
715000
Hydrobiology
Project: P24146 WOR
Projection: MGA z50
Datum: GDA2020
Drawn: PW
Date: 23/03/25
N
0
1 km
LEGEND
Pool Register by water presence:
Permanent
Commonly Wet
Seasonal Inundation
Periodic Inundation /Ephemeral
Data deficient pools
NSE Disturbance Footprint
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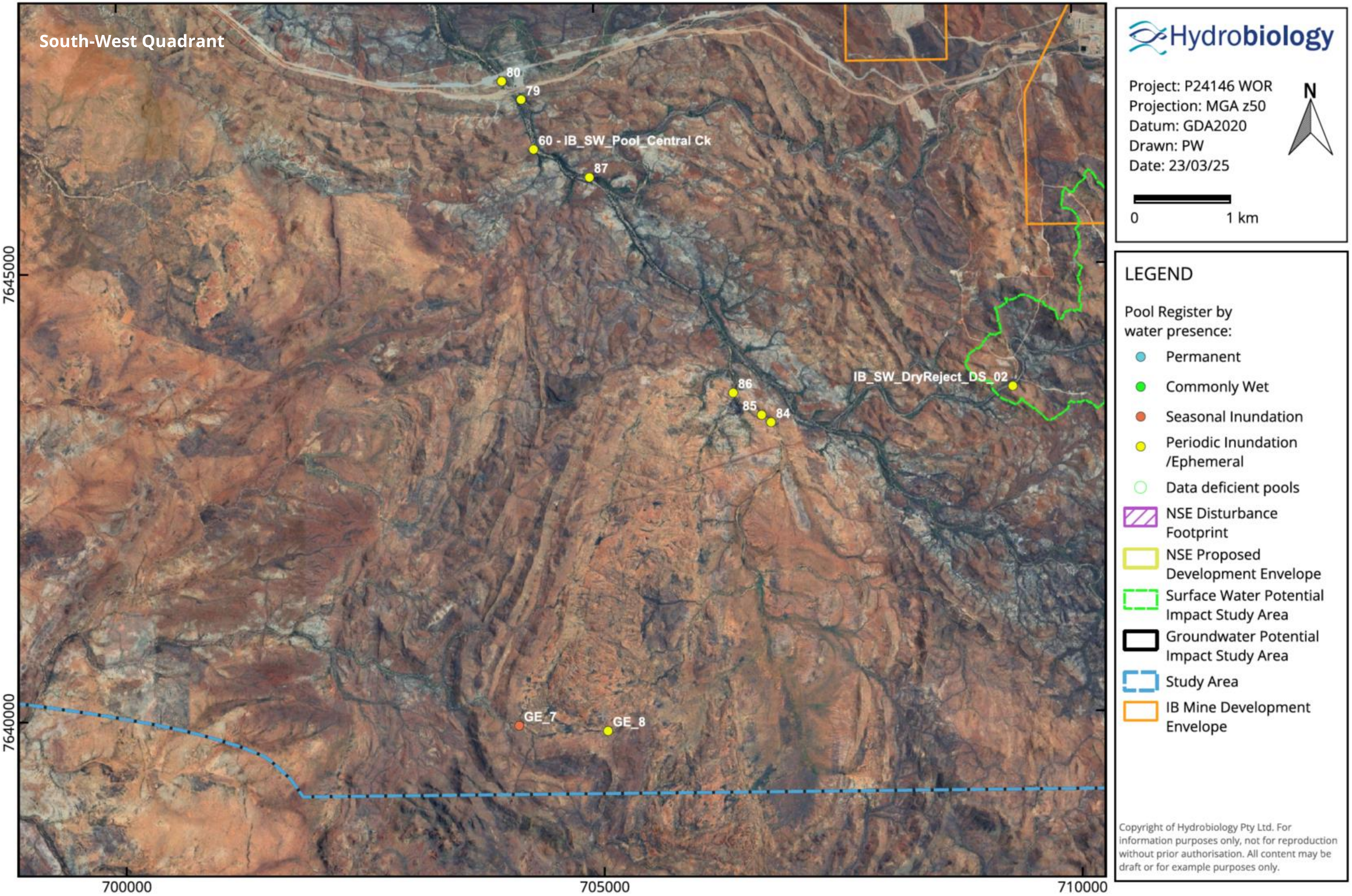
South-West Quadrant
80
79
60 - IB_SW_Pool_Central Ck
87
86
85
84
IB_SW_DryReject_DS_02
GE_7
GE_8
7645000
7640000
700000
705000
710000
Hydrobiology
Project: P24146 WOR
Projection: MGA z50
Datum: GDA2020
Drawn: PW
Date: 23/03/25
N
0
1 km
LEGEND
Pool Register by water presence:
Permanent
Commonly Wet
Seasonal Inundation
Periodic Inundation /Ephemeral
Data deficient pools
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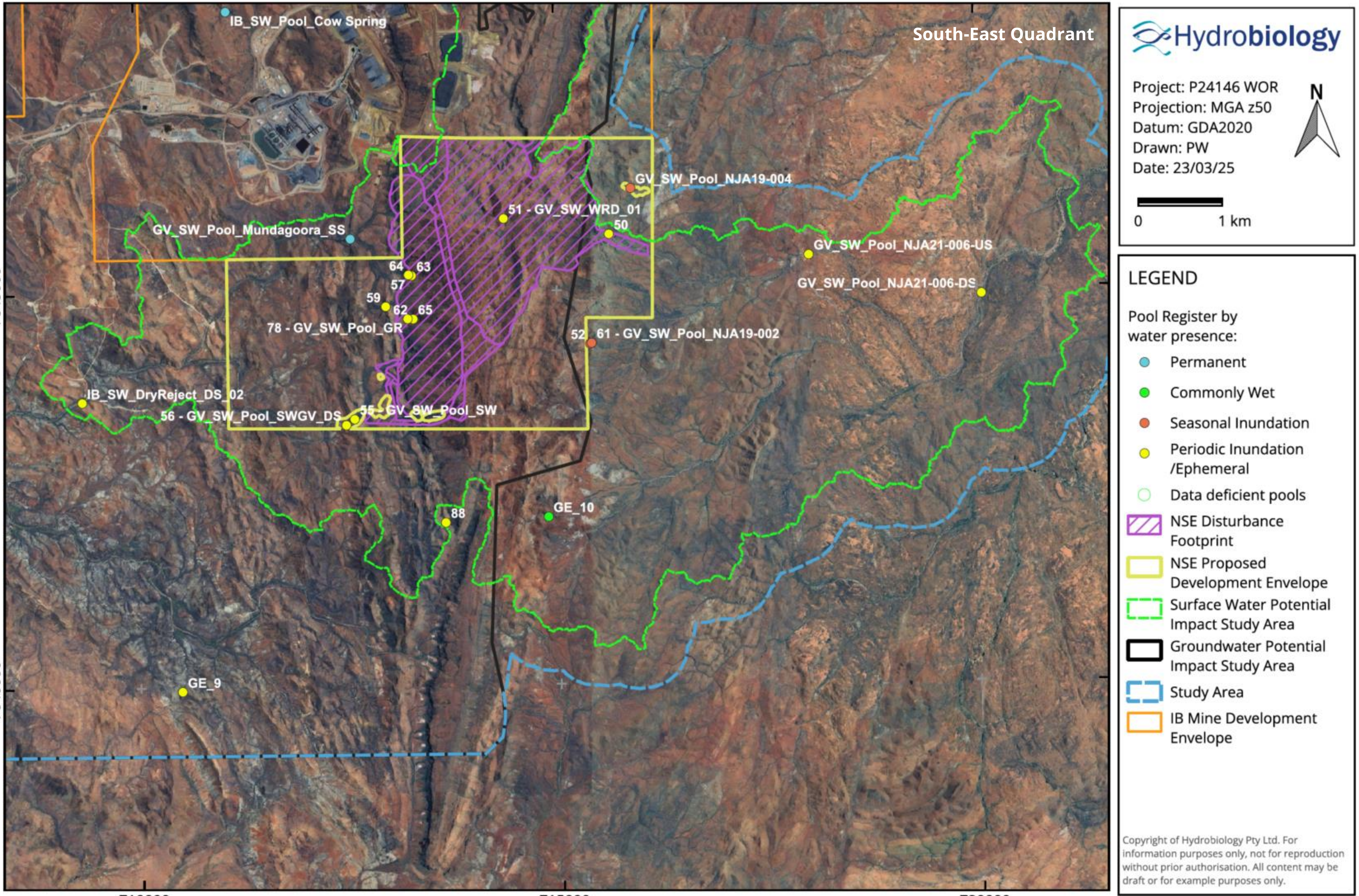
South-East Quadrant
IB_SW_Pool_Cow Spring
GV_SW_Pool_NJA19-004
51 - GV_SW_WRD_01
50
GV_SW_Pool_Mundagoora_SS
GV_SW_Pool_NJA21-006-US
GV_SW_Pool_NJA21-006-DS
64
63
57
59
62
65
78 - GV_SW_Pool_GR
52
61 - GV_SW_Pool_NJA19-002
IB_SW_DryReject_DS_02
56 - GV_SW_Pool_SWGV_DS
55 - GV_SW_Pool_SW
88
GE_10
GE_9
7645000
7640000
710000
715000
720000
Hydrobiology
Project: P24146 WOR
Projection: MGA z50
Datum: GDA2020
Drawn: PW
Date: 23/03/25
N
0
1 km
LEGEND
Pool Register by water presence:
Permanent
Commonly Wet
Seasonal Inundation
Periodic Inundation /Ephemeral
Data deficient pools
NSE Disturbance Footprint
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