TECHNICAL MEMO

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Date: 24 November 2020
To: Sarah Blake – Manager Environment and Approvals, Roy Hill
From: Ron Colman – Technical Director Water Management
Pages: 13 inc. this page
Regarding: **Remote MAR North – Subterranean Fauna and Hydrogeology**

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1 BACKGROUND

In preparation for managing increased surplus dewatering water at the Roy Hill iron ore mine (RHIO), and to avoid mining schedule delays due to a limited ability to dispose of the excess water, RHIO have commenced investigations into the Remote Managed Aquifer Recharge – North (**RMAR-N**) borefield area. From earlier work, the RMAR-N area is considered to have the potential for management of significant volumes of high salinity water via reinjection. The area is inferred to feature a confined aquifer in the karstic Wittenoom Formation that is saline to hypersaline, and possibly highly permeable.

The development of the RMAR-N borefield represents a key aspect of water management at Roy Hill. At present most of the surplus water from dewatering operations at RHIO's mining operations are injected into the Southwest Injection Borefield (SWIB) adjacent to the mining operations. The SWIB modelled injection capacity is estimated at 80 ML/d. However, as mining progresses more ore is being sourced from below the water table resulting in the volume of groundwater being abstracted from active pits increasing significantly with a commensurate increase in surplus water. The SWIB borefield is expected to reach capacity by mid-2022. Thus, a plan to develop the RMAR-N borefield was envisaged to support the increased dewatering activity via an additional disposal area.

The RMAR-N borefield investigations were aimed at demonstrating that the aquifer can accommodate the excess water, and that the impact of water injection is limited to the deeper aquifer. The investigation drilling programme was aimed at characterising the local geology, hydrogeology and groundwater conditions in order to improve the hydrogeological conceptualisation and to assess the potential of the RMAR-N to support the disposal of up to 20ML/d of saline water.

The exploration drilling programme completed under the current phase of works, supervised and reported on by RPS, comprised the construction and testing pumping of four (4) injection bores, the construction of thirteen (13) deep monitoring bores, eighteen (18) shallow monitoring bores, and twenty (20) environmental bores.

It is understood that environmental approval for the RMAR-N scheme needs to consider the potential impact on any subterranean fauna. This consideration needs to be based on the spatial geological knowledge of the proposed MAR area obtained from the current drilling and test pumping program. The main inference to be addressed is the degree of habitat connectivity between any potentially impacted areas of the proposed MAR scheme and adjacent non-impacted areas.

This technical memo is provided as a summary of the inferred geology and hydrogeology from the recent drilling and testing program, undertaken in 2020, with conclusions drawn from an interpretation of the observed data.

2 GEOLOGY

The RMAR-N area lies at the northern end of a large, north sloping, alluvial fan in the Fortescue Valley (Figure 1). The valley is orientated roughly east-west and lies between the Hamersley Range to the south and the Chichester Range to the north. The Fortescue River runs through the Hamersley Range, running typically northwards, before following the valley westward and reaching the Fortescue Marshes, a RAMSAR wetland that contains saline water.

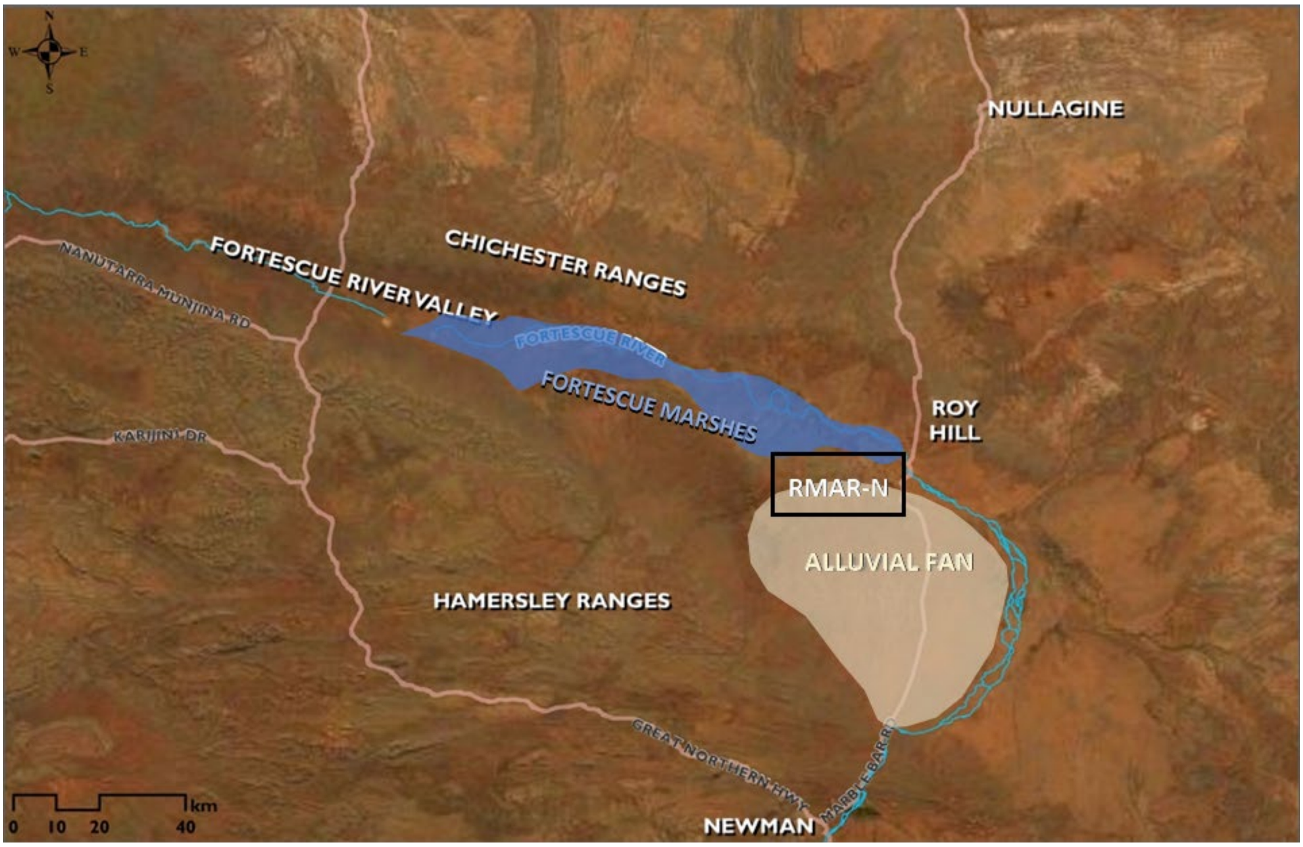

Figure 1 Regional localities around the RMAR-N

2.1 Stratigraphy

Drilling programs in 2009 and 2015 were used to create a regional stratigraphy for the RMAR-N area as detailed in MWH (2009) and Managed Recharge (2018). Drilling results from the current investigation have provided more detail and led to a re-assessment of the local Cenozoic Stratigraphy as summarised in Table 1 below.

A brief geological description of each formation, in ascending order, is also provided.

Table 1: Regional Stratigraphy

Age	Roy Hill Stratigraphy	This Study Stratigraphy
Cenozoic	Alluvium	Alluvium
	Calcrete/Silcrete	Marl
		Clay
	Detritals	Karstic infill
Archaean	Wittenoom Formation	Wittenoom Formation
	Marra Mamba Iron Formation	Marra Mamba Iron Formation
	Jeerinah Formation	Jeerinah Formation

1. Marra Mamba Iron Formation and Jeerinah Formation

The Marra Mamba Iron Formation, comprising banded iron formation, shale, and carbonate beds overlies the Jeerinah Formation a sequence of volcaniclastic rocks, shale, dolomite, sandstone, and chert. Neither of these units were encountered during the investigation programme.

2. Wittenoom Formation

The drilling in this program shows that in the RAMR-N area the basement geology comprises dolomite of the Wittenoom Formation (likely Paraburdoo Member, given the monotonous dolomite encountered) with a complete in-situ weathering profile above. The Wittenoom Formation varies from white to green to bright pink, very hard crystalline dolomite that is frequently fractured, with limonite staining on fracture surfaces. The in-situ weathering profile shows the saprock – saprolite – duricrust sequence typical of deeply weathered rocks in Western Australia. However, following exposure and formation of the duricrust, the sequence was buried and weathered in-situ through interaction with groundwater, and the former calcrete/silcrete duricrust is now either a white to pale yellow-green clay-rich layer or a white very fine silica sand layer depending on the earlier cementing material. This former duricrust layer is also often enriched with pyrolusite (manganese oxide) that forms a black ‘greasy’ clay in hand specimen.

The depth of weathering in the Wittenoom Formation (including the areas of karstic infill) is typically around 50m thick, but varies from 102 to 22m, The weathering also varies greatly over short distances, with holes drilled on the same drilling pad (within 50m of each other) showing up to 20m difference in weathering thickness..

Laboratory analysis of bulk samples from the Wittenoom Formation show that the Wittenoom Formation is characterized by elevated Cao, and MgO, and a corresponding decrease in SiO_2 content.

The Wittenoom Formation also appears to have formed large karstic cavities and voids that appear to have collapsed and filled with detritus as described below (karstic infill).

3. Karstic Infill

Previously described as detritals, this appears to be more accurately described as karstic infill. This material comprises mixed gravel, sand, silt, and clay from above that has filled collapsed karstic voids in the Wittenoom Dolomite. The gravel often features BIF and chert fragments, indicating the material may have been transported from the south during flood events.

Karstic infill is characterized by elevated proportions of FeO and SiO_2, lower proportion of CaO and MgO, as well as a very small increase in proportion of K_2O in laboratory analysis of bulk samples from the drilling returns

4. Clay

A dark reddish brown, soft to firm clay layer overlies the weathered dolomite, and likely represents an early alluvial or fluvial phase in the area. The clay often contains some sand or gravel and is typically not lithified. The clay unit was encountered throughout the drilling program, varying from 8 to 24m thick with an average thickness in the order of 16m.

This unit is distinct in bulk sample analysis (characterised by elevated Al_2O_3), and in the gamma response in downhole geophysics; the weathered dolomite below and marl above are both significantly subdued in comparison. Both characteristics confirm the material has a much higher proportion of clay-rich minerals and is a separate geological layer.

5. Marl

Although previously described as a calcrete (MWH, 2009; Managed Recharge, 2019) the lithified clay rich unit above the Clay is more appropriately described as a marl. The rock does not feature vugs or cavities and appears to be composed of clay bound up by carbonate minerals. This contrasts with the typically porous and karstic calcrete that is encountered elsewhere in the Pilbara and Yilgarn.

The marl features elevated CaO and MgO, diminished SiO_2 and Fe compared to adjacent units in bulk sample analysis and has a more subdued gamma response than the other adjacent Cenozoic units.

Across the RMAR-N area the Marl is in the order of 7m thick, varying from 14m to 2m thick in exploration drilling.

6. Alluvium

Surface material in the RMAR-N area comprises alluvial clay, sand and gravel associated with Fortescue River flood events, with material grading finer towards the Fortescue Marsh. This surface material is part of a large Cenozoic alluvial fan, formed by the outflow of the Fortescue River as it leaves the Hamersley Ranges and enters the Fortescue Valley. At present the Fortescue River channel follows the extreme eastern side of the alluvial fan, but through its history has probably meandered across the alluvial fan. The local thickness of the alluvium varies from about 24m to 2m, with an average of 9m.

The alluvium features elevated Al_2O_3 and SiO_2 in the bulk sample analysis as well as a strong gamma response in downhole geophysics, similar to the clay beneath the marl.

3 HYDROGEOLOGY

Earlier drilling and hydrogeological analysis of the RMAR-N area by MWH (2009, 2015), Managed Recharge (2018) and GHD (2019) has defined two aquifer systems in the RMAR-N study area: an upper alluvial and calcrete (now defined as marl) (**Shallow**) aquifer, and a lower dolomite (**Deep**) aquifer separated by an aquiclude (Figure 2).

Drilling for this programme has enabled better definition of the aquifers, as outlined below.

3.1.1 Shallow Aquifer

The shallow aquifer comprises Cenozoic alluvial and fluvial deposits lying above locally calcretised and silcretised clay-rich sediments; now defined as ‘marl’. It is largely composed of clay, with some gravel (as fragments of BIF, chert, and shale) and sand. The aquifer does not typically yield more than a few L/s and water quality ranges from brackish to saline according to the proximity to the Fortescue Marsh and Fortescue River; salinity generally increasing away from the river and towards the marsh. The shallow aquifer is typically between 10 and 40m thick.

Exploration drilling in the current program provided more detail on the nature of this aquifer. The saturated thickness of the aquifer in this programme was typically around 5m thick, varying from 9m at RHPZ0441S to being absent at RHPZ0438S. Flows from the aquifer during drilling are typically very low to absent, with only one bore recording a yield during drilling (RHPZ0432S; 1.3L/s). Electrical conductivity of the water in the monitoring bores varied from 4,200 to 49,000 µS/cm (2,600mg/L to 36,000 mg/L). The salinity of the groundwater is highly dependent on the proximity to the Fortescue Marsh, with bores closer to the Marsh featuring much higher salinity.

The water quality in the Shallow Aquifer contrasts with the Deep Aquifer, featuring much lower salinity, and much higher Total alkalinity than the later. The shallow aquifer is also enriched in dissolved Si (about 50 mg/L higher) and nutrients (NO_3 and NO_2 around 5mg/L higher) and depleted in Mn, Sr, and Boron (around 5–7 mg/L lower).

3.1.2 Aquiclude

Although not clearly defined in earlier studies, previous test pumping indicated there was a confining layer of likely alluvial (and possibly lacustrine) clays and clay from the weathered Wittenoom Formation overlying the deep aquifer (MWH, 2009).

Drilling undertaken for this study encountered a red-brown clay bed, that varied in consistency from soft to firm (and rarely weakly lithified) and was typically plastic. This clay-rich layer lies immediately above the weathered dolomite, and during drilling there was typically no flow or greatly diminished flow through this section. The clay was encountered in all bores, varying in thickness from 8 m to 24m with an average of 16m.

The available information offers good evidence that the clay material forms an aquiclude dividing the shallow and deep aquifers across the RMAR-N area.

3.1.3 Deep Aquifer

The deep aquifer is formed in the weathered, karstic, and fractured dolomite of the Wittenoom Formation, and may be up to 60m thick. The yield from the aquifer is much higher than the shallow aquifer, with karstic features and fracture zones yielding over 30L/s (MWH, 2009) from well-constructed abstraction bores.

The current drilling program shows that the aquifer appears to have formed at the base of the paleo-weathering profile in the Wittenoom Formation, from the lower saprolite to the fractured fresh rock below.

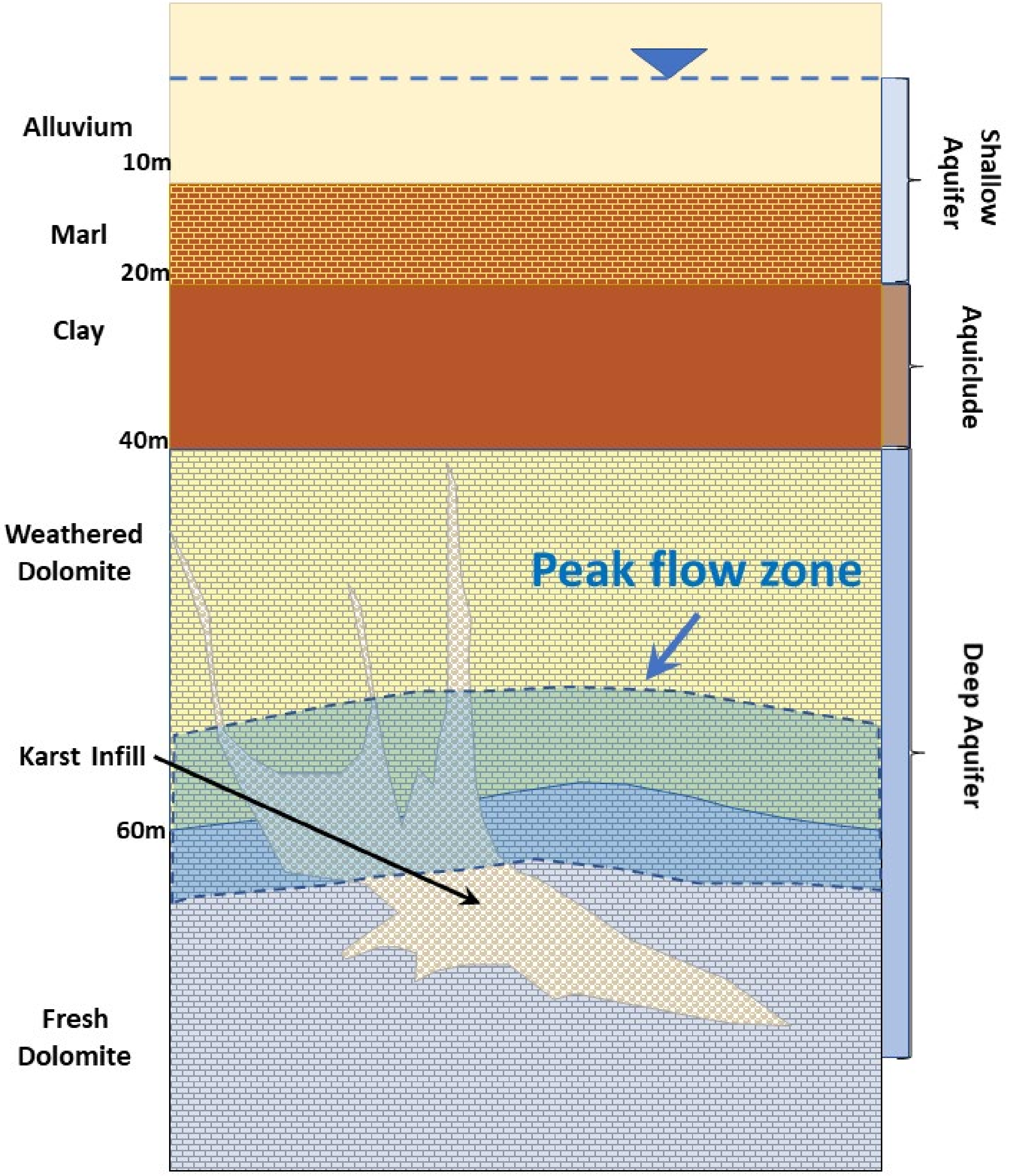

Figure 2 Conceptual arrangement of aquifers in the RMAR-N area (not to scale)

Yields ranged up to over 60L/s in some deep aquifer bores, and during drilling tended to peak within about 10 metres of encountering dolomite rock.

The current drilling program also noted that salinity in the deep aquifer was largely driven by the proximity to the Fortescue Marsh; however, this is complicated by what may be density driven variations, these variations in salinity were also observed in the aquifer water level.

This aquifer is the key target for the RMAR-N Program injection.

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4 SUMMARY

The results of the current investigation program can be summarised in the following figures.

Figure 3 shows the geographical spread of the investigation bores drilled during the current program along with indicative locations of proposed additional investigation bores.

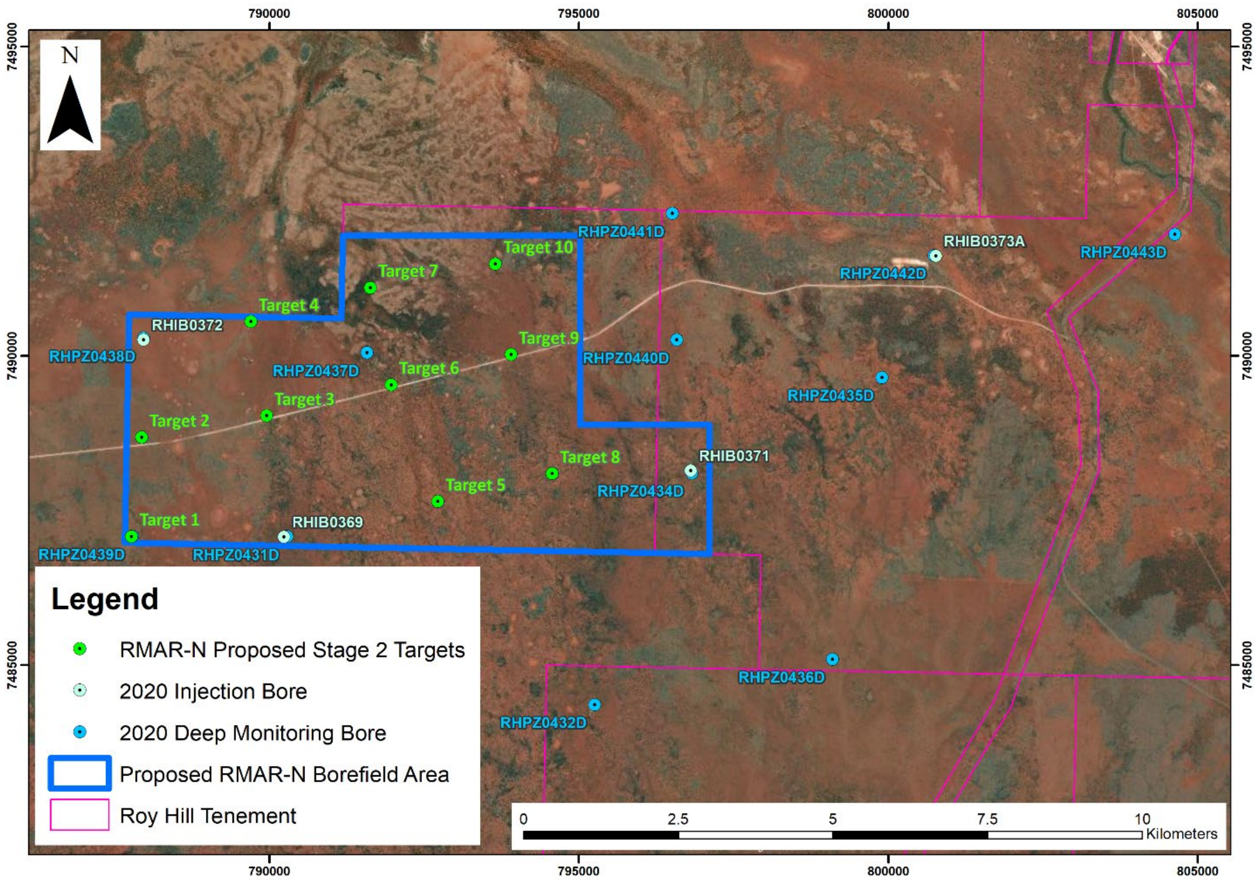

Figure 3 Investigation bores of current program and proposed additional bores

Figure 4 shows the surface geology for the proposed RMAR-N scheme within a regional context. The formations present within the proposed borefield area are considered to be contiguous with areas outside the proposed scheme area.

Two cross sections (labelled A-A' and B-B') are indicated on Figure 4 and presented as Figures 5 and 6. The cross sections present the interpreted geology from the investigation drilling program.

Salinities encountered in the completed bores are presented in Figure 7 for the shallow aquifer and in Figure 8 for the deeper aquifer.

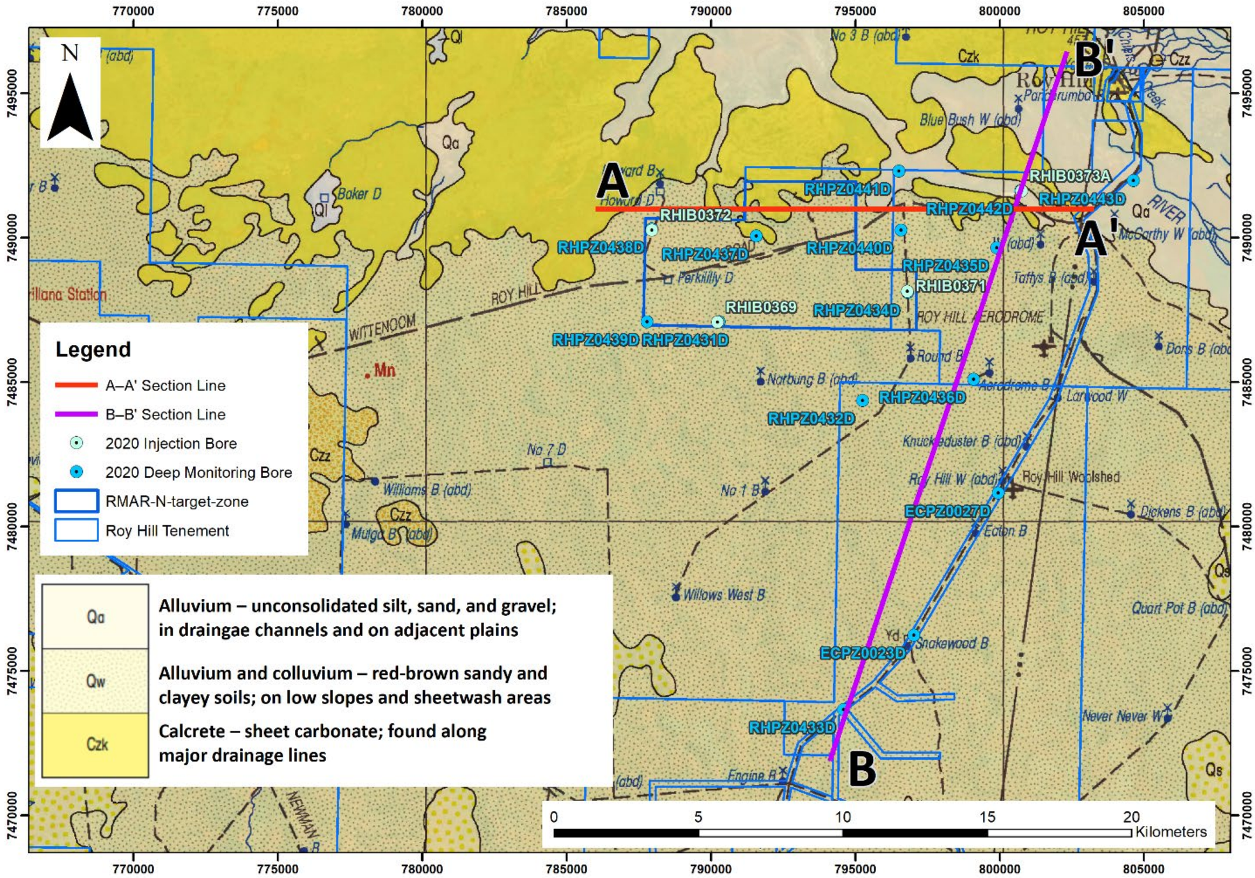

Figure 4 Regional surface geology (from Roy Hill 1:250,000 geological sheet)

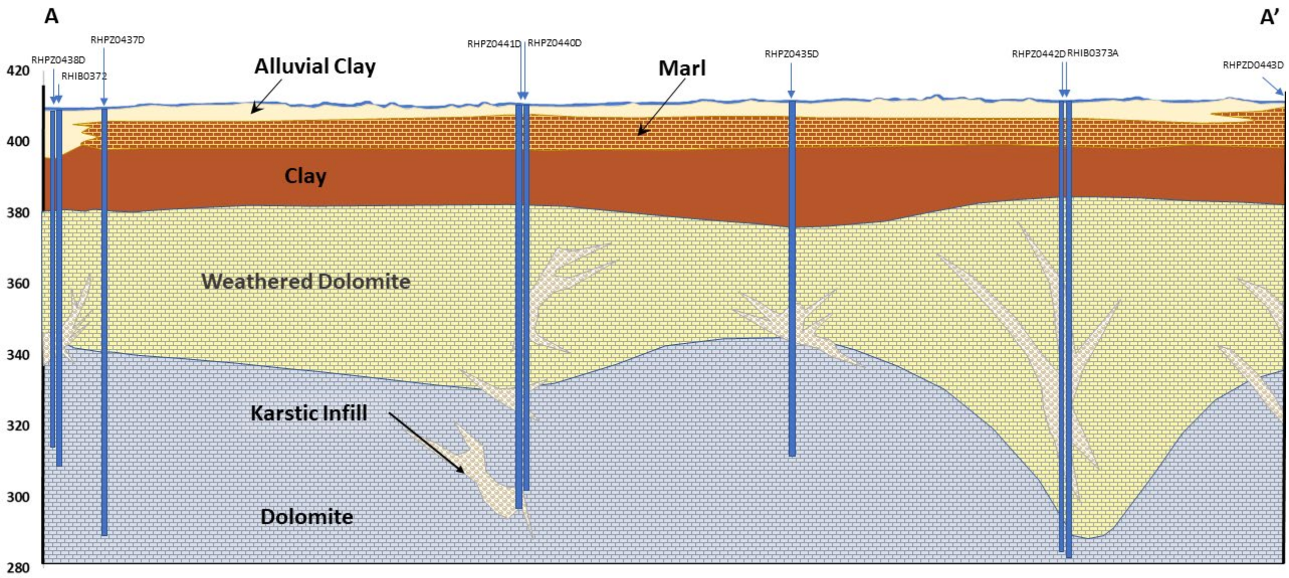

Figure 5 Section A-A' located west to east.

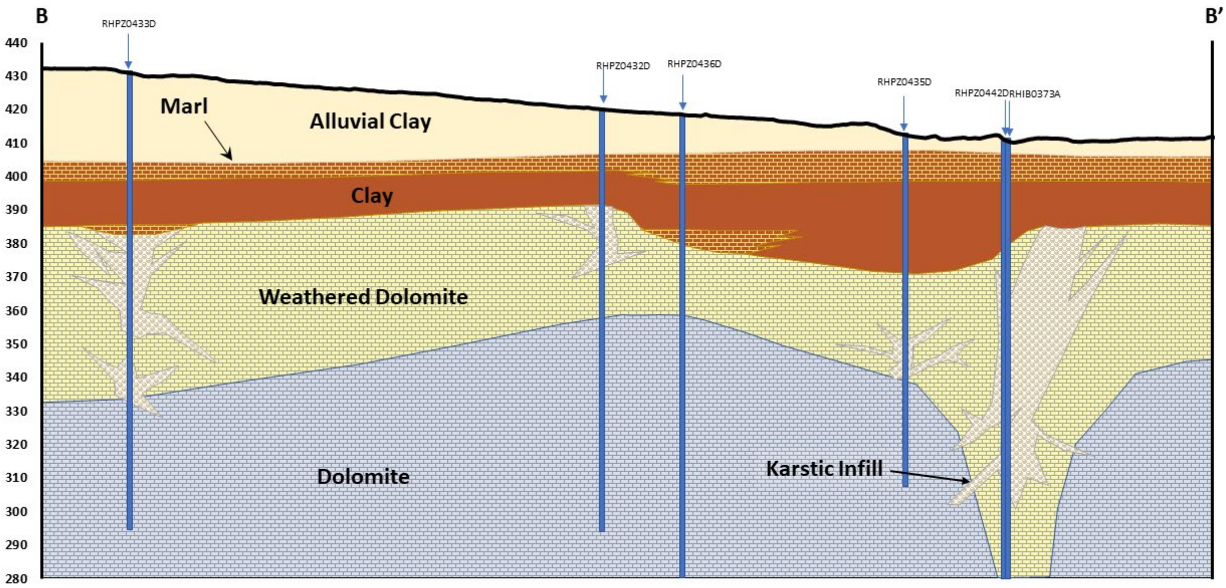

Figure 6 Section B-B’ located south to north

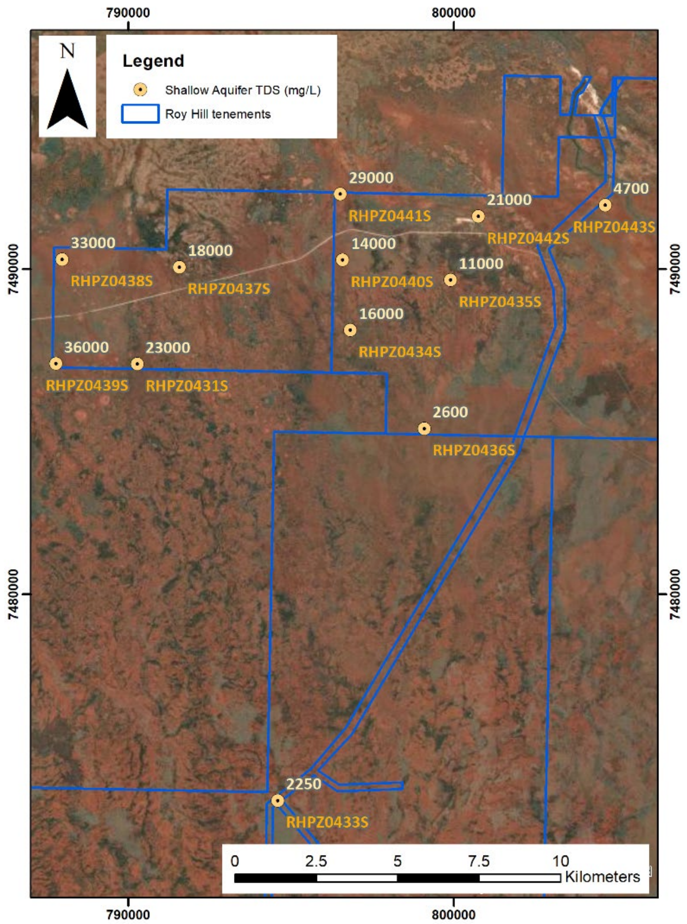

Figure 7 Shallow aquifer salinities

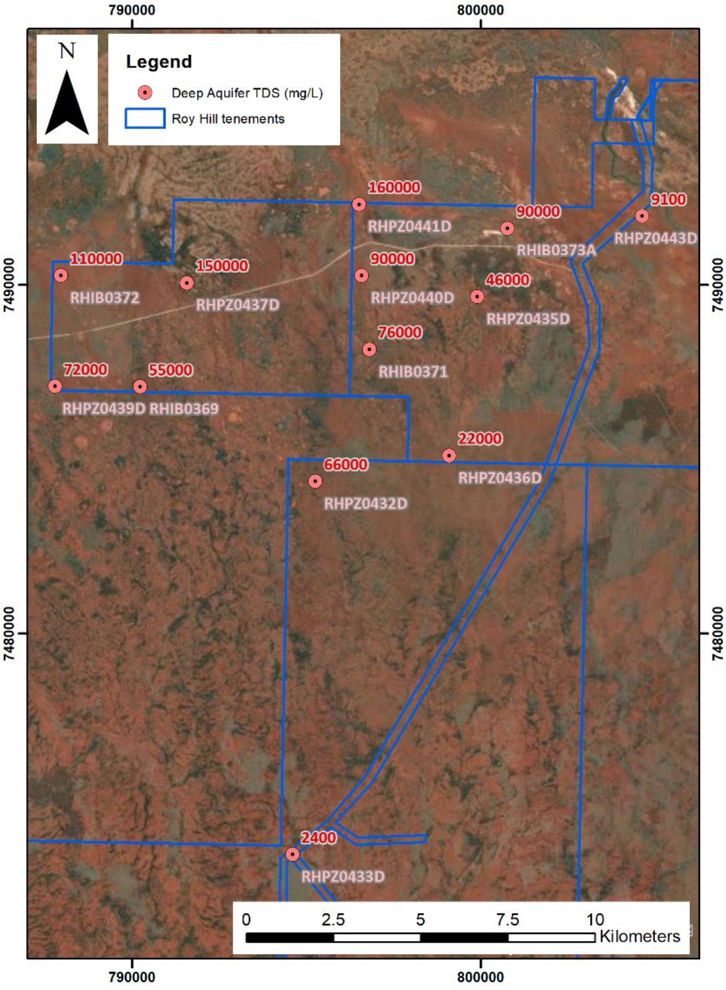

Figure 8 Deep aquifer salinities

5 CONCLUSIONS

It is considered that the observed geological and water quality data from the current exploration drilling programme supports the pre-existing hydrogeological conceptual model of a shallow unconfined aquifer separated from a deep confined aquifer by a thick and continuous clay aquiclude.

The following pertinent conclusions can be made:

- There are two separate aquifers present in the proposed RMAR-N area
- There is a laterally continuous clay layer separating the two aquifers
- Water quality data indicate that the two aquifers are not hydraulically connected in the RMAR-N area.
- Water level data indicate that the two aquifers are not hydraulically connected in the RMAR-N area.
- It is considered that the shallow aquifer is laterally continuous over the proposed RMAR-N area and likely to extend outside the RMAR-N area

Based on regional geology and observed hydrostratigraphy, it is highly likely that connectivity of the formations extends well beyond the RMAR-N area in both the shallow and deep aquifers, including the clay layer separating the two aquifers. Consequently, with respect to the potential for impact on subterranean fauna, the following conclusion can be made:

- The injection of surplus water into the deeper more saline aquifer is considered to have minimal potential for impact on the brackish shallow aquifer.

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