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Memo

To	Briony Sinclair, Neil Dixon	**Company**	Mardie Minerals Pty Ltd
From	Bruce Harvey & Duncan Storey	**Job No.**	293F
Date	2/06/2021	**Doc No.**	019a
Subject	Mardie Project – Groundwater Risk Assessment – Optimised Project		

1. INTRODUCTION

Mardie Minerals' Mardie Project is located on the Pilbara coastline of Western Australia, approximately 100km south-west of Karratha (Figure 1). The project includes the construction of extensive evaporation ponds and crystallisers for the extraction of salt products from sea water.

An initial Groundwater Risk Assessment was provided to Mardie Minerals by AQ2 in 2020 (AQ2 document 293C_009b - Mardie Project – Desktop Groundwater Risk Assessment). That document focused on impacts the project may have on groundwater in the vicinity of Mardie Pool and coastal habitats. Given recent proposed changes to the location and size of evaporation and crystalliser ponds (the Optimised Project), Mardie Minerals requires that a further Groundwater Risk Assessment be conducted. The areas of focus for this supplementary study are:

- Impacts due to the revised location of crystallisers, which are now proposed to extend north by a greater distance across the Fortescue River alluvial valley.
- The effects of ongoing dewatering at Citic Pacific's Sino Iron Project.
- Assessment of potential impacts at Mt Salt.
- Other potential groundwater risks which become apparent during this investigation.

The environmental impact assessment for the Mardie Project previously identified that the understanding of the risks posed to vegetation, local groundwater and sensitive environmental receptors as a result of saline seepage from the Project's proposed concentration and crystallisation ponds should be improved. With the recent adoption of the Optimised Project layout the potential effects on the ecohydrological system are to be reassessed for the northern section of the development area.

The purpose of this memo report is to advise BCI on the significance of any knowledge gaps, critical assumptions, and inadequately described risks to the surrounding environment associated with changes to the project layout.

This report builds on the findings of AQ2 (2020), and its contents should be considered as supplementary to the observations, findings and recommendations of AQ2 (2020).

2. OPTIMISED PROJECT LAYOUT

Optimisation of the later stages of the crystallising process has resulted in changes to the proposed pond layout (Figure 1). Key changes from the previous layout include:

- Increased area for evaporation ponds near the end of the evaporation train (ponds 7-9), extending 5km further north-east and with east-west width increasing from approximately 1.5km to 3km.

- Relocation and expansion of the Primary Crystalliser ponds, which are now proposed to be approximately 7.5km (north-south) by 2.5km (east-west) in size. The south-west corner of this pond will be about 1km ENE from Mardie Pool.
- Relocation of the Secondary and KTMS Crystallisers, which are now placed between the expanded evaporation ponds and the Primary Crystalliser.

3. CONCEPTUAL ECOHYDROLOGICAL SYSTEM

The conceptual ecohydrological system for the area covered by the original layout is described in AQ2 (2020). With the extension of the Optimised Layout further onto the Fortescue River, the hydrogeological regime of the Fortescue River alluvial valley is of increased significance.

The Fortescue River alluvial aquifer forms a delta which begins approximately 30km inland at its narrowest point near North West Coastal Highway, fanning out to the north west to be almost 25km wide near the coast (Figure 2). The main channel of the Fortescue River meanders along the eastern boundary of the alluvial fan, incised into the valley sediments to a depth of 4-6m.

General groundwater levels and flow direction within the project area (Figure 2) have been estimated from historical and recent groundwater level measurements as no full concurrent set of levels has been located. Historical hydrographs sourced from DWER indicate significant long term and seasonal changes in groundwater level at most recorded bores within the range +/- 1mAHD.

The alluvial aquifer consists of interbedded clay, gravel and calcrete overlying relatively impermeable limestone, sandstone and shale units. Basement rocks consist of Proterozoic chert and banded iron formation which crop out along Mardie Road and to the east of the Fortescue River. The permeable units have a saturated thickness of up to 15m (Commander, 1989) within a maximum sequence thickness of 30m. Figure 3 displays a representative cross-section developed from extensive drilling in the Lower Fortescue River (Haig 2009).

The estimated average annual recharge to the alluvial aquifer is 11GL. This recharge occurs directly from the Fortescue River to the alluvial gravels by periodic streamflow (median flow 121GL/a). The gravel deposits carry a fresh water lobe (< 1000mg/L) toward the coast. This fresh water lobe grades into saline water at the seawater interface and towards the margins of the alluvial fan (Figure 4).

4. ECOLOGICAL STRESSORS

Ecological stressors for the original project layout have been described previously (AQ2,2020). These stressors remain valid in the context of the Optimised Layout, and are now also relevant for a greater length of coastline including the south-west region of the Fortescue River alluvial aquifer.

Downward seepage of hypersaline water from evaporation ponds and crystallisers is seen as the main area of concern for sustainability of the groundwater system at the Mardie Project. In particular, Mardie Pool and coastal ecological communities were investigated as potential receptors.

Soilwater Group (2019) carried out modelling of the potential for seepage to impact on groundwater receptors using the infrastructure design as existed in November 2019. Since that time the proposed location of Secondary and KTMS crystalliser ponds has been revised under the Optimised layout, and the area covered by the Primary Crystalliser has been extended north by several kilometres. The proposed buffer between the Primary Crystalliser and the down-gradient Mardie Pool and Creek remains at approximately 1000m.

AQ2(2020) noted that the conceptual groundwater model used to estimate seepage and flow beneath the evaporation ponds possibly used an incorrect static water level based on the assumption of lenses of “perched” water being present. Literature and data review indicates that water beneath the ponds and supratidal flats is hypersaline, and likely presents a density-driven barrier to the flow of fresher groundwater towards the coast. It was inferred that hydraulic pressure of water in the evaporation ponds may cause mounding which could interfere with the balanced density-flow system which possibly supports algal mat communities on the flats, and may contribute to the groundwater system in the vicinity of mangrove stands. Further investigation was recommended including seepage and density flow modelling, taking into account the variable salinity of water in the evaporation ponds which is expected to increase from south to north.

Potential for seepage of hypersaline water into the gravel units of the Fortescue River alluvium has not been investigated. Previous modelling focussed on a calcarenite layer at depth as being the critical high-permeability conduit for transport of hypersaline seepage towards Mardie Pool from the previous crystalliser location. The hydrogeological characteristics of the aquifer beneath the Primary Crystalliser of the Optimised Layout is well understood through historical drilling and testing (Commander 1989). Given the recognised greater hydraulic gradients and transmissivity within the alluvial valley (Figure 2), brine reaching the water table in this area may be diluted and carried toward the coast at a greater rate. It is noted that the area from the Primary Crystalliser to near the coast would be almost completely covered by constructed ponds, and that no surficial ecological receptors would remain.

5. ISSUES RAISED BY LAYOUT CHANGES FOR THE OPTIMISED PROJECT

5.1 Mt Salt Mound Spring

Mt Salt is located approximately 1400m directly north from the new location of the SOP Plant and the northern boundary of the evaporation ponds under the Optimised Project layout (Figure 2). Commander (1989) describes Mt Salt as a bare, rounded hill formed by a mound spring which rises several metres above the surrounding plain.

Mound springs are formed when water under artesian pressure continuously discharges at surface A typical structure for a mound spring is displayed in Figure 5. Over time accumulation of precipitates at the discharge point results in the development of a raised mound of tufa (a variety of limestone).

Williams (1968) implies that the water source for the Mt Salt mound spring is Cretaceous sediments which are thought to outcrop in the lower reaches of the Fortescue River (the recharge location). The Cretaceous sediments are resumed to dip gently west beneath the alluvial valley sediments.

Water discharging beneath the summit at Mt Salt was described by Commander (1989) as saline, with TDS measurement of 27,800mg/L (equivalent EC approx. 40,000uS/cm). The higher salinity and artesian nature of the discharge above the alluvial plain (and significantly elevated above the estimated static water level of 1-2mAHD) implies a confined source which is isolated from the unconfined alluvial aquifer. Recent aerial photography (via GSWA's Geoview website) shows that very little vegetation is present on Mt Salt, presumably due to unfavourable groundwater salinity. A review of ecological values of the Lower Fortescue River area by Dept of Water (Loomes 2010) does not mention Mt Salt.

The flow diagram approximated from historical and recent groundwater level data for the alluvial unconfined aquifer (Figure 2) indicates that groundwater passing beneath the SOP Plant (the closest potential source of contamination) most likely continues in a north-westerly direction, remaining greater than 1000m from Mt Salt. This observation, and evidence of the confined nature of the spring water source, indicate it is likely that the mound spring of Mt Salt would not be affected by potential groundwater regime changes due to seepage from the crystallisers.

5.2 Dewatering at Sino Iron Project

The Sino Iron Project of Citic Pacific Mining Ltd lies 15km to the north-east of the Primary Crystalliser ponds on the opposite side of the Fortescue River alluvial valley. The western pit at Sino Iron cuts into the Fortescue River alluvial aquifer at its western side (or will as mining progresses). Excess dewatering effluent at Sino Iron is currently discharged to the Fortescue River mouth, generally on the high tide due to the need to dilute the hypersaline water.

An EPA report into Sino Iron Mine Continuation (EPA 2017) recommended Citic's abstraction allocation be increased to 8GL/a (from the previous 2GL/a). Strategen (2017) discusses the indicative cumulative drawdown within the Fortescue River alluvial aquifer due to dewatering at Sino Iron over the life of the mine and post-closure. The 0.5m and 1.0m cumulative drawdown contours are displayed in Figure 6. The contours are representative of the maximum expected extent of drawdown to these levels. The full radius of influence (contour of 0m drawdown) is not represented in these documents.

The 0.5m dewatering drawdown contour extends to within 3.5km of the Primary Crystallisers, and by extrapolation dewatering at Sino Iron may reduce the water level beneath the crystallisers by 0 to 0.3m. Given the estimated existing long-term water levels in the Fortescue Alluvium, the hydraulic gradient toward the coast may be reduced slightly over the life of the Sino Iron Mine and in the post closure period. The groundwater flow direction may also be diverted marginally to the north in the area of the crystallisers.

5.3 Groundwater Dependent Ecosystems

AQ2 (2020) discusses vegetation species and associated salinity tolerance in the vicinity of Mardie Pool. Inferences of that investigation are valid in the context of the Optimised Layout due to the similar location proposed for the Primary Crystalliser.

Loomes (2010) carried out an investigation into the ecological values and issues of the Lower Fortescue River. Named river pools and areas of riparian vegetation were mapped across the alluvial plain (Figure 7). While vegetation at Mardie Pool was not identified in that study, vegetation species identified along pools and channels across the alluvial plain were the same as those identified at Mardie Pool. All of these areas of riparian vegetation (other than Mardie Pool) are located up hydraulic gradient from Mardie Project infrastructure by at least 3km. Therefore it is unlikely that hypersaline seepage from crystallisers could potentially impact riparian vegetation other than at Mardie Pool.

Evaporation Ponds 8 and 9 of the Optimised Project layout are now proposed to extend further north along the coast, near to a greater number of tidal creeks and mangrove stands. In the southern part of the project (ponds 1 to 7) it is thought that hypersaline water beneath the supratidal flats creates a barrier to flow of fresher groundwater towards the coast. It is postulated that fresh water over-rides the dense hypersaline water, leading to density circulation and upwelling of minerals which supports the development of algal mat communities.

Figure 8 displays electrical conductivity values for water in test pits across the northern evaporation ponds. The EC values indicate that salinity of groundwater decreases to the north towards the centre of the alluvial valley. Imagery also shows that tidal creeks (and possibly mangrove stands) do not exist north of Pond 9, presumably due to lower groundwater salinity from discharge of the alluvial valley aquifer and intermittent flood sheet wash preventing development of creeks.

Risks and recommendations regarding coastal ecological systems outlined in AQ2(2020) are valid in the context of the Optimised Layout, with a greater length of coastline potentially impacted should changes to the groundwater regime occur.

6. RISKS

The Environmental Review Document lists several potential impacts to groundwater at the Mardie Project. These are re-stated from AQ2 (2020):

- Potential mounding and surface expression of groundwater inland of the ponds;
- Seepage from ponds resulting in elevated salinity in underlying groundwater; and
- Changes in groundwater salinity regimes due to mounding.

Additional or associated risks evident from the AQ2 (2020) review were:

- Transport of hypersaline water towards groundwater dependent ecosystems;
- Increased salinity of surface water in Mardie Pool;
- Disruption of the freshwater/saltwater interface at Mardie Pool and in the upstream creek valley;
- Morbidity of vegetation which is fully or partly dependent on fresh groundwater; and
- Possible disruption of fresh groundwater flow towards coastal ecosystems (mangrove habitat adjacent to tidal creeks, and algal mat communities on supratidal flats) due to mounding of groundwater beneath evaporation ponds.

Further associated risks evident from review of the Optimised Project layout are:

- Greater area of supratidal flats covered by evaporation ponds extending further north. Possible disruption of hypersaline density balance beneath Ponds 8 and 9 due to groundwater mounding, leading to changes to groundwater regime near mangrove habitat.
- Potential for seepage of hypersaline water into the Fortescue River alluvial gravels. Possible density flow within higher permeability units.

7. DATA GAPS AND UNCERTAINTIES

Data gaps and uncertainties identified in AQ2 (2020) are also relevant for the Optimised Project, hence are reproduced here with updates and additions as necessary.

All permeability testing has occurred as part of geotechnical investigations, so is therefore focussed on physical characteristics of surface and near-surface formations. No long or short-term hydrogeological testing has been carried out on bores constructed within the clay/calcrete layers. CPT investigations have been employed in the vicinity of the secondary crystallisers and Mardie Pool. Infiltration and groundwater flow assumptions made for seepage modelling are therefore based on geotechnical assessments and falling head tests at distant sites rather than in-situ local measurements.

The groundwater monitoring network currently employed by Mardie Minerals is based on station bores which are generally open hole or of unknown construction and are irregularly pumped (at low rates). These bores are sparsely and randomly located in relation to the proposed project infrastructure and groundwater receptors. Estimations of SWL and groundwater flow paths in the vicinity of Mardie Pool and the crystallisers are necessarily based on limited information (spatially and temporally). A large number of DWER bores are present across the alluvial plain, however those closer to the Mardie Project infrastructure appear to not be regularly monitored.

Knowledge of the salinity distribution and groundwater gradients around Mardie Pool and the crystallisers is rudimentary due to limited historical sampling and the present location of monitoring points. The nearest station bores are 350m and 3000m from Mardie Pool.

The modelling of seepage from the originally-located secondary crystalliser pond was undertaken using a 2D unsaturated zone model which showed the potential for saline seepage to reach the pool for 2 seepage scenarios. The modelling approach did not allow quantification of the volume of seepage or the consequences for changes in the relative groundwater heads between the fresh and saline water bodies in the aquifer and the associated water quality in the pool. Specifically, regardless of seepage volume, changes in pressure head may result in a change in the saline water interface.

Seepage modelling has not been undertaken using a hydrogeological model equivalent to the interbedded gravels and clays of the Fortescue River alluvial fan. Potential seepage and flow characteristics of the ground underlying the northern end of the Primary, Secondary and KTMS crystallisers has not been defined.

Modelling of seepage from evaporation ponds towards coastal receptors (including mangrove and algal mat ecosystems) appears to be based on an incorrect assumption of the groundwater level beneath the ponds. SWL was specified by Soilwater Group (2019) at 8mbgl whereas data indicates that actual groundwater level is possibly less than 1mbgl. The model does not take into account the possibility of a hypersaline plume beneath the supratidal flats which may create a barrier to fresh water flow towards the coast.

Literature review has shown that much research has been carried out into the dependence of coastal ecosystems on fresh groundwater inflow and upwelling for supply of nutrients and dilution of salt, however it is unclear whether the coastal groundwater regime at Mardie is similar to those examples (although this seems possible). Vertical distribution of salinity beneath the flats, and the location of the seawater interface are also undefined across much of the development envelope.

8. RECOMMENDATIONS

Recommendations made in AQ2 (2020) are relevant for the Optimised Project layout. They are reproduced here with additions and changes where necessary.

AQ2 recommends that further studies are required to characterise the groundwater quality and flow system around Mardie Pool, the proposed new locations for the crystalliser ponds and the evaporation ponds. Knowledge of the groundwater regime is limited due to the number, location and construction of sampling points.

Further work to characterise the groundwater regime relevant to Mardie Pool could include the following:

- Detailed investigation into the true groundwater dependence of the various vegetation species surrounding Mardie Pool. The presence of M.argentea is suggestive of a groundwater dependent system. However, it would be beneficial to gain some indication of quality of groundwater being used by the trees and their salt-tolerance which will contribute to the development of triggers and thresholds in a groundwater management plan.
- Expansion of the monitoring network - Installation of monitoring/testing bores into the calcrete/gravel layer between the proposed crystallisation ponds and Mardie Pool. This would include locating bores within and outside the theoretical fresh water lens along Mardie Pool.
- Installation of monitoring equipment for both water level and water quality in Mardie Pool; this monitoring should be undertaken using a remote data logger.
- Using the expanded monitoring network, long-term pre-construction monitoring of groundwater levels and salinity should be undertaken to determine baseline water quality and gradients.
- Test pumping program to determine in-situ permeability of calcrete and potential for hypersaline seepage to be transported to Mardie Pool.
- Investigation of the salinity distribution around Mardie Pool and the crystalliser ponds, possibly through non-invasive geophysical profiling (in combination with sampling from bores drilled while expanding the monitoring network).
- The drilling and testing programme should include testing in the area between the ponds and Mardie pool where, if required, a seepage recovery system may need to be developed. The objective would be to confirm the design parameters and feasibility of saline seepage recovery.
- Completion of 3D density-dependent flow modelling to:
    - Estimate the volume of seepage that may reach the pools, and changes in the relative groundwater heads that will influence the saline interface and water quality in the pools.
    - Confirm the efficacy of a saline seepage recovery or management system that may have to be developed (depending on triggers and thresholds to be developed in a groundwater management plan).

Further work to characterise the groundwater regime relevant to the evaporation/crystalliser ponds (including the Optimised Project changes), Fortescue River alluvial aquifer and coastal ecosystems could include the following:

- Re-evaluation of seepage modelling for the evaporation ponds based on a shallower SWL (<1mbgl) beneath the supratidal flats.
- Detailed investigation into the groundwater dependence of the mangrove species existing in tidal areas to the west of the proposed ponds.
- Installation of bores to enable monitoring of the vertical distribution of salinity near mangrove stands to determine water quality and the existence (or not) of fresh groundwater flow through the root zone. This may also assist in locating the seawater interface.
- Hydraulic testing programme to determine in-situ permeability of gravelly clay layers and potential for transportation of hypersaline seepage from the evaporation ponds to the mangrove communities.

- Investigation into the dependence of algal mat communities on upwelling groundwater for moisture and nutrient supply. This may take the form of nested bore installations to quantify vertical hydraulic gradients (pressure and salinity) in areas where algal mats are present.
- Consideration of the effects of brine salinity on modelling (density-coupled modelling) of seepage and groundwater flow.
- Collection of new groundwater level data from bores across the western part of the Fortescue River alluvial plain, station bores and recently installed monitoring bores to establish the current groundwater flow regime.
- Review of Fortescue River alluvial aquifer permeability data, and implementation of a hydraulic testing program using existing or newly installed bores if historical data is not suitable.
- Seepage modelling using parameters reflecting the characteristics of the Fortescue River alluvial plain and the differing brine concentrations which will be held within the crystallisers.

Development of a Groundwater Management Plan is likely to be necessary for the site in line with DWER recommendations. The Groundwater Management Plan should include the following:

- Commitments for ongoing data collection, review and updates to the plan based on new data.
- The development of triggers and thresholds with respect to water quality or level. The modelling exercise will help determine what the appropriate triggers are.
- Adaptive management response when triggers and thresholds are crossed such as increased monitoring or saline seepage recovery.
- Confirmation of the feasibility of proposed management measures (i.e. that modelling shows the monitored trigger is appropriate and that proposed management options are feasible).

We trust this memo report meets your requirements. Please contact us if you have any queries.

Regards,

Bruce

Hydrogeologist

Duncan

Director / Consulting Hydrogeologist

Author: BPH,DGS (2/06/21)
Checked: DGS (3/06/21)
Reviewed: DGS (3/06/21)

Attached:

Figure 1: Mardie Project Location and Site Layout
Figure 2: Mardie Project Estimated Groundwater Levels and Flow
Figure 3: Cross Section - Fortescue River alluvial valley (from Haig 2009)
Figure 4: Fortescue River Alluvial Valley GW Salinity and levels (Haig 2009)
Figure 5: Typical structure of a mound spring (Mudd 1998).
Figure 6: Mardie Project – Sino Iron Project Cumulative Drawdown
Figure 7: Fortescue River Valley Riparian Vegetation
Figure 8: Mardie Project Test Pit and Bore Groundwater Salinity 2019

References

AQ2, 2019. *Mardie Salt Project – Results of Water Supply Drilling*. Memo Report prepared for BCI Minerals Ltd. December 2019.

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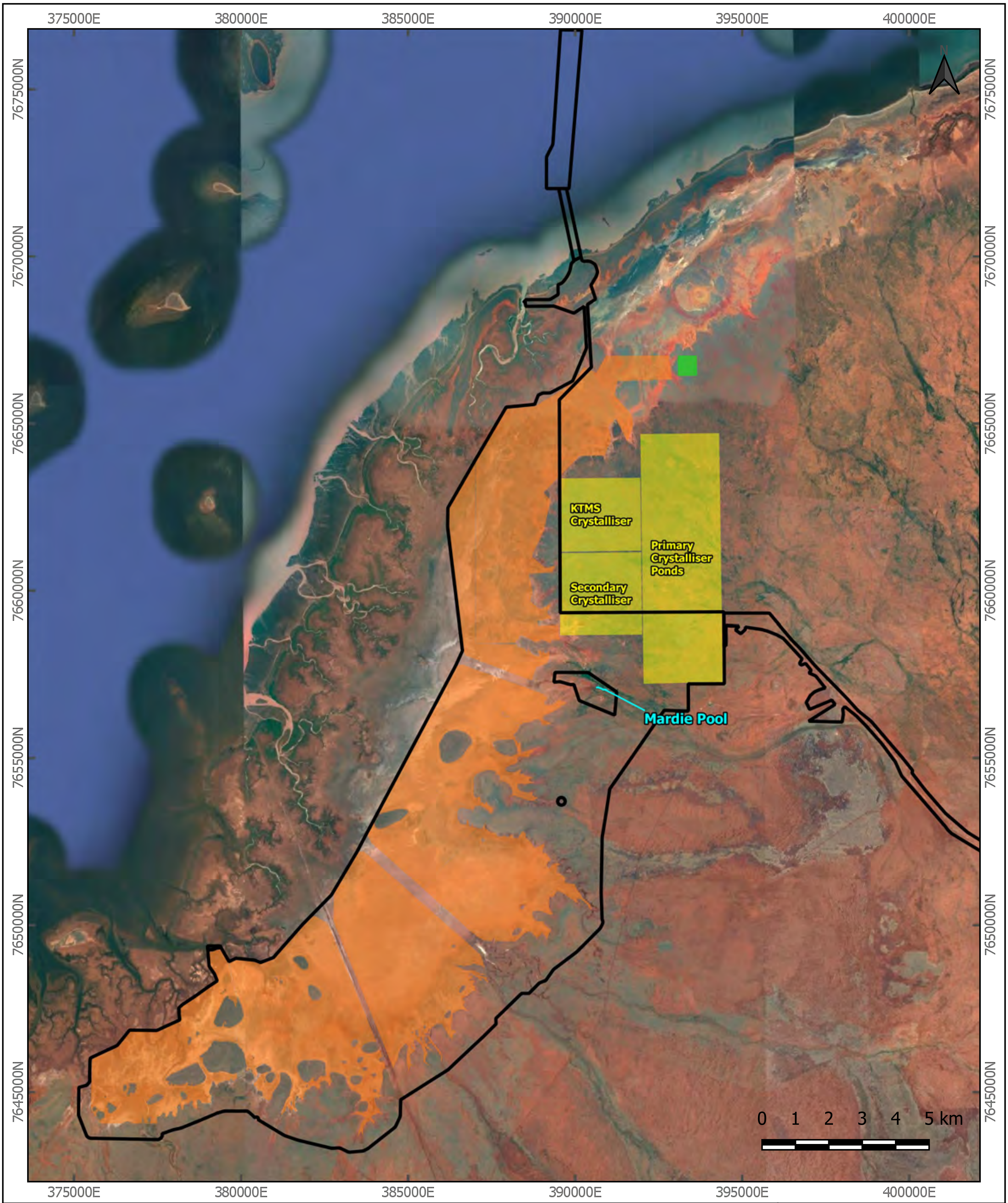
FIGURES



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Legend

- Development Envelope
- SOP Plant
- Mardie Pool
- Crystallisers
- Evaporation Ponds

AUTHOR: BPH
DRAWN: BPH
DATE: 24/05/2021

REPORT NO: 019a
JOB No: 293F
Coordinates: MGA Zone 50

Notes and Data Sources:
Background Image (C) Google
Project Infrastructure data supplied by BCI Minerals

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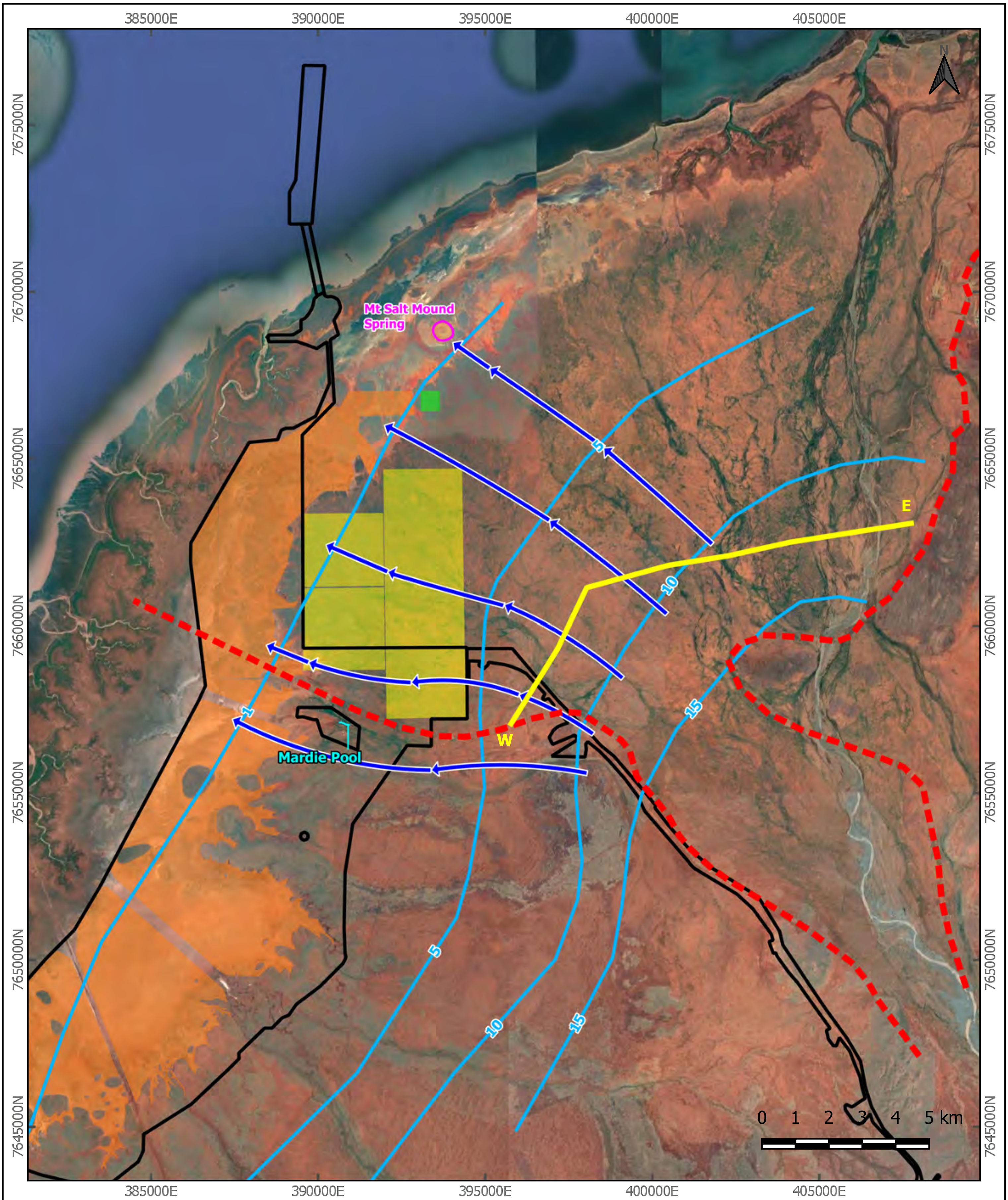
Figure 1

Mardie Project Location and Site Layout



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Legend

- Development Envelope
- Fortescue River Valley Cross Section
- SOP Plant
- Mardie Pool
- Crystallisers
- Evaporation Ponds
- Fortescue Alluvials Boundary
- Estimated Water Level mRL
- Groundwater Flow Direction

AUTHOR: BPH
DRAWN: BPH
DATE: 25/05/2021

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JOB No: 293F
Coordinates: MGA Zone 50

Notes and Data Sources:
Background Image (C) Google
Project Infrastructure data supplied by BCI Minerals

Figure 2

Mardie Project Estimated Groundwater Levels and Flow

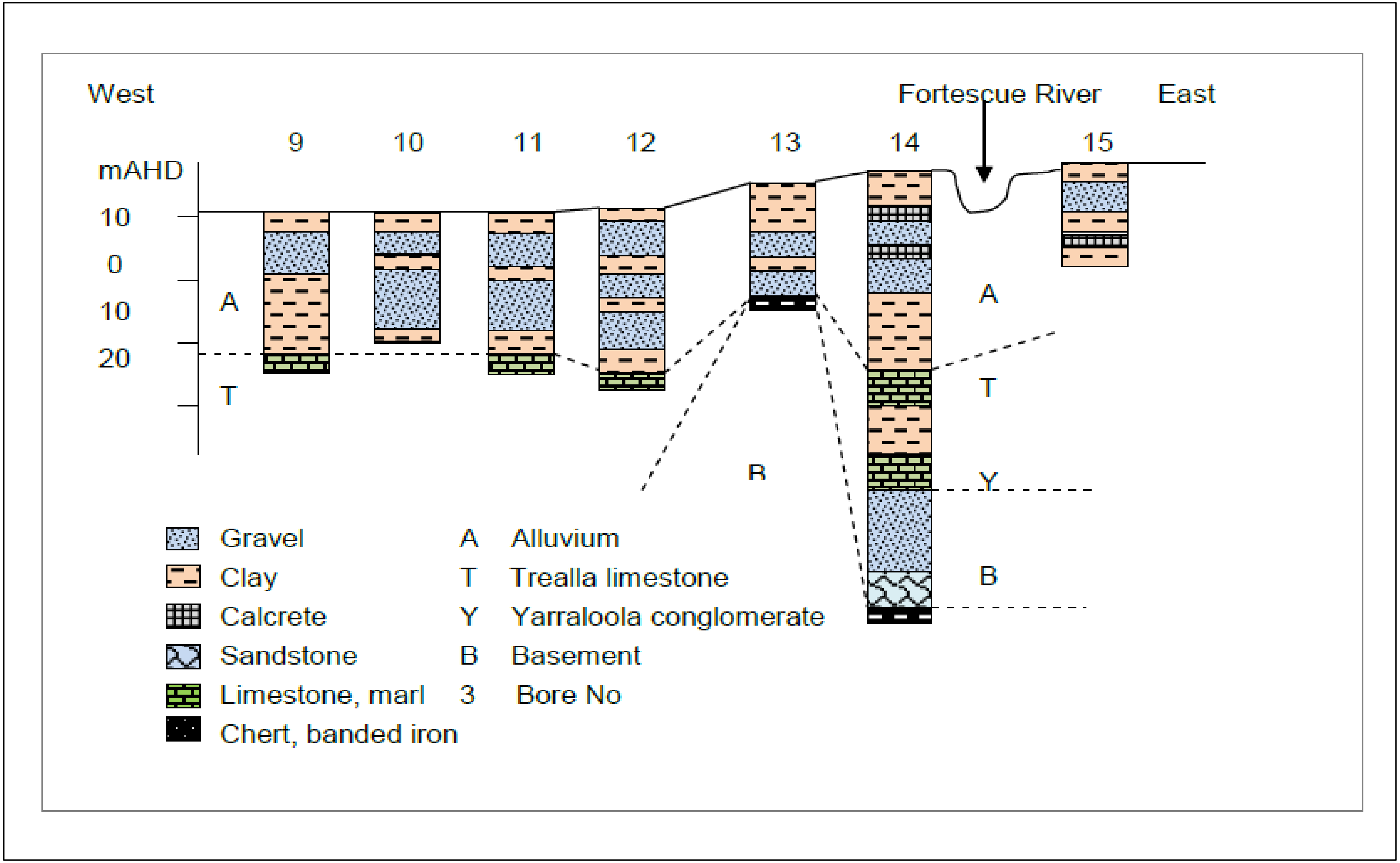

Figure 3 – Cross Section – Fortescue River Alluvial Valley (from Haig 2009)

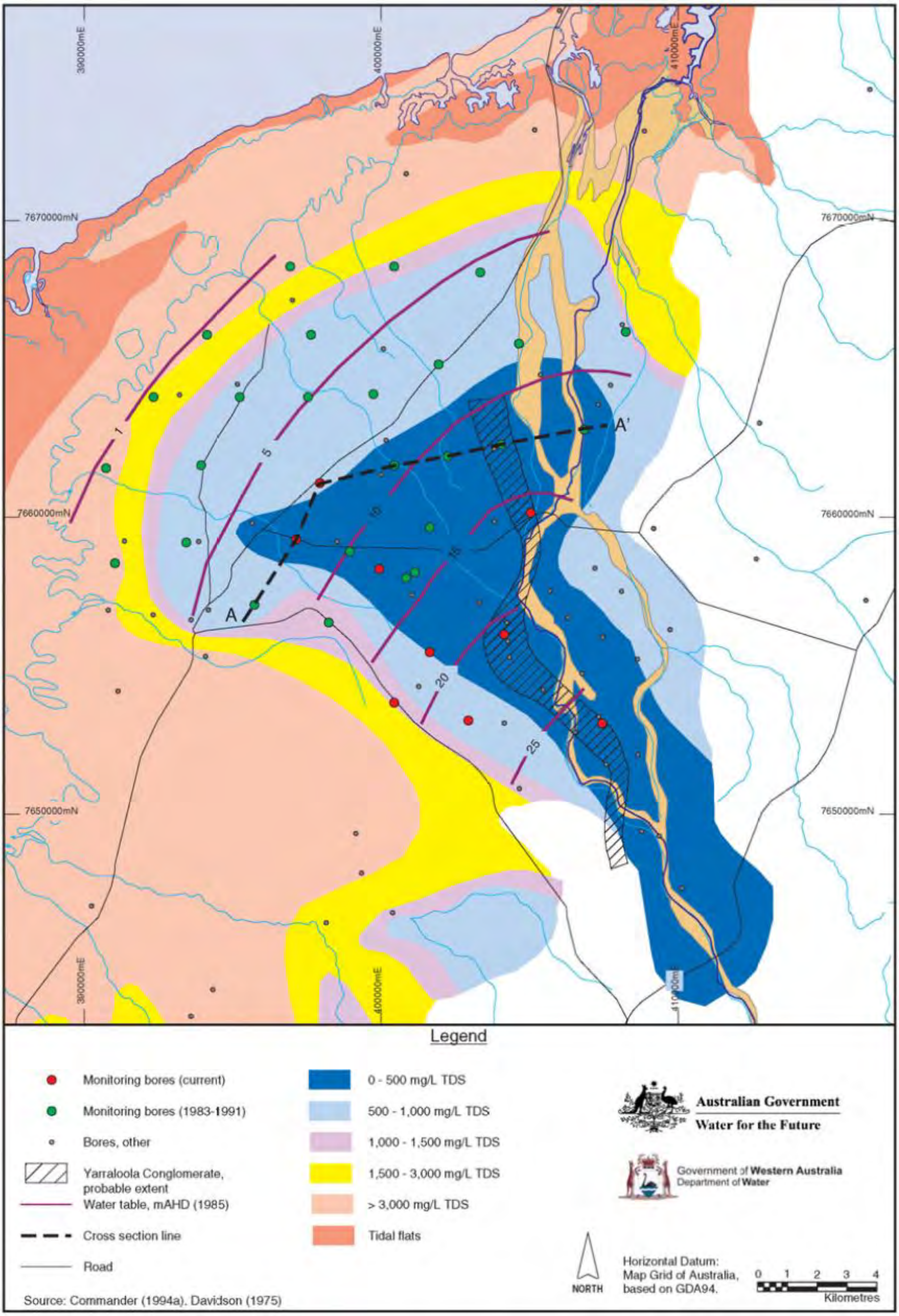

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Figure 4 – Fortescue River Alluvial Valley GW Salinity and Levels (from Haig 2009)

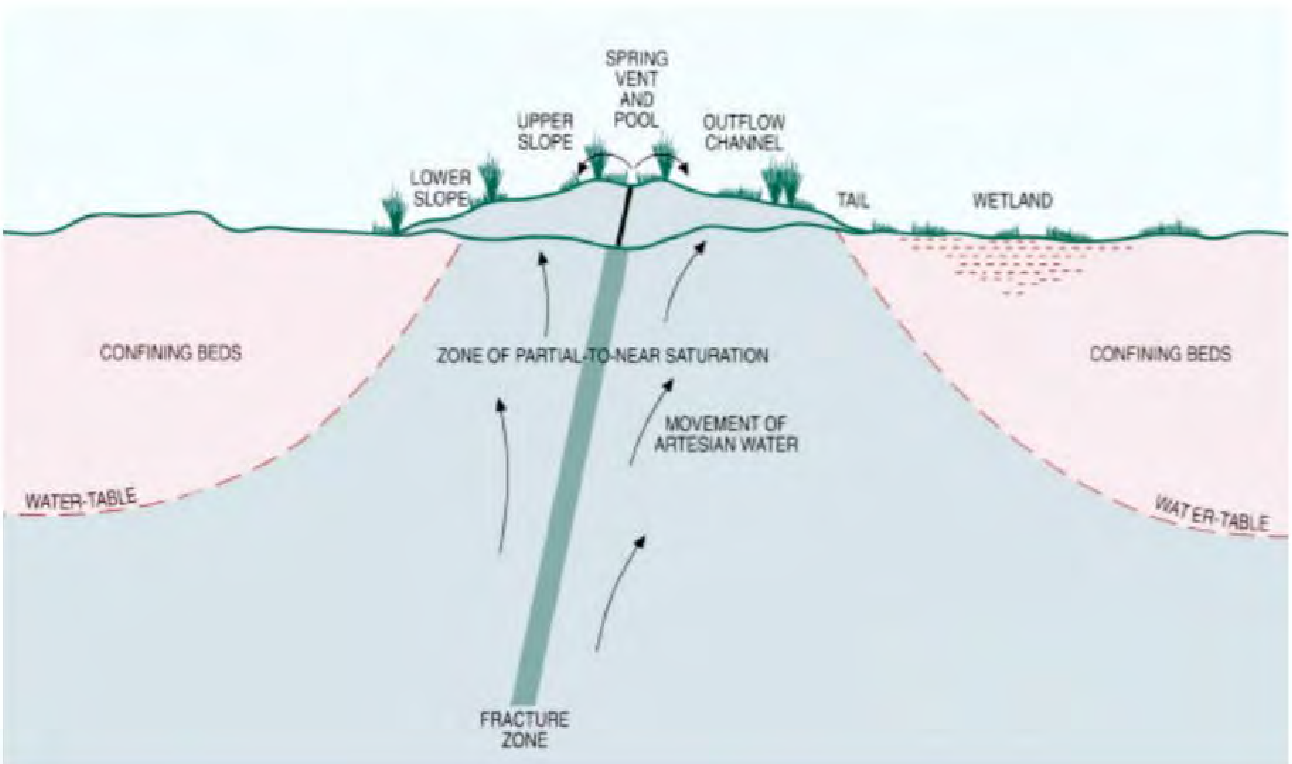

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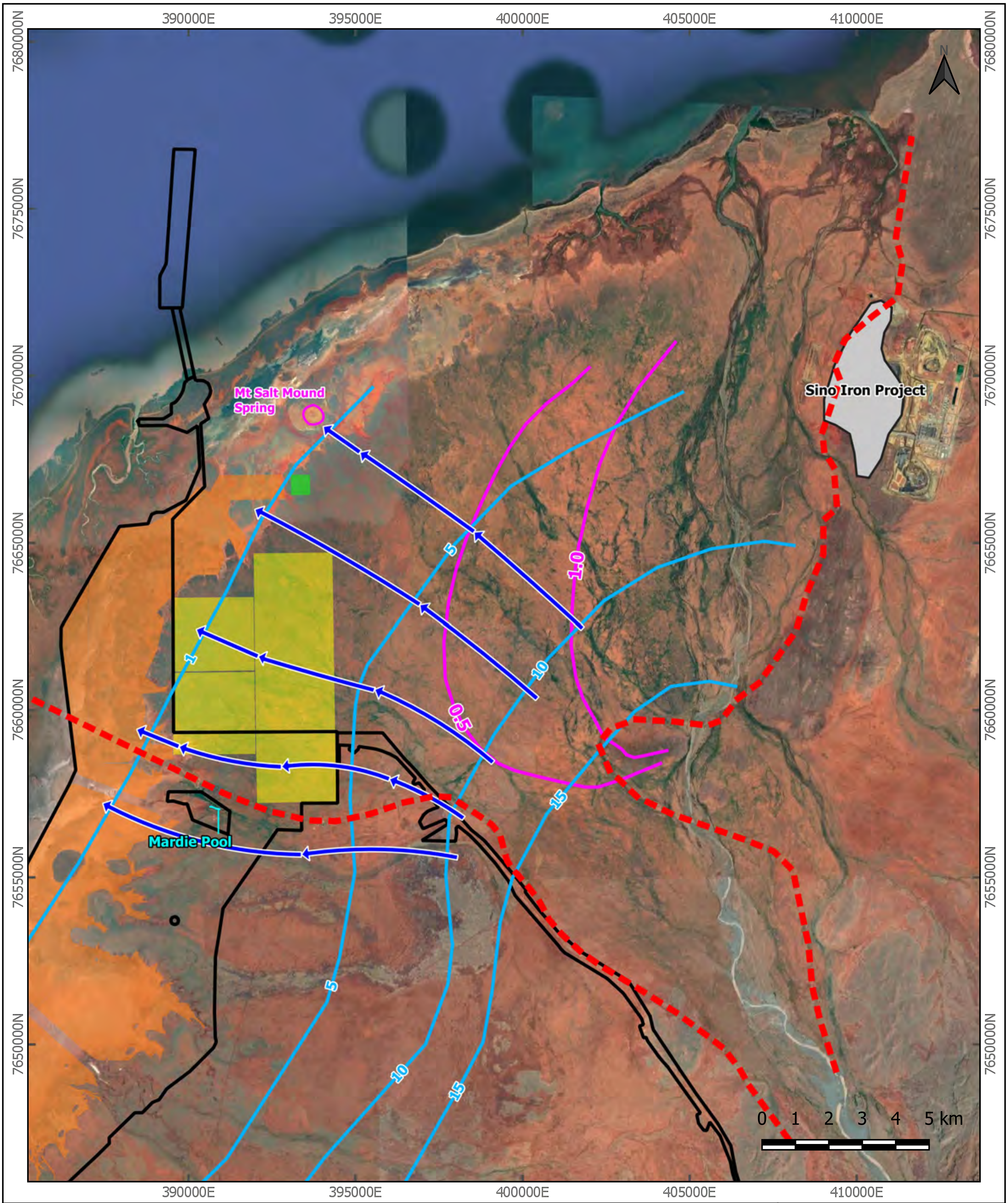
Figure 5 – Typical structure of a mound spring (Mudd 1998)



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Legend

- Mt Salt Mound Spring
- Fortescue Alluvials Boundary
- Groundwater Flow Direction
- Estimated Water Level mRL
- Sino Iron Cumulative Drawdown (m)
- Mardie Pool
- Development Envelope
- SOP Plant
- Crystallisers
- Evaporation Ponds

AUTHOR: BPH
DRAWN: BPH
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Notes and Data Sources:
Background Image (C) Google
Project Infrastructure data supplied by BCI Minerals
Water Levels based on historical data.

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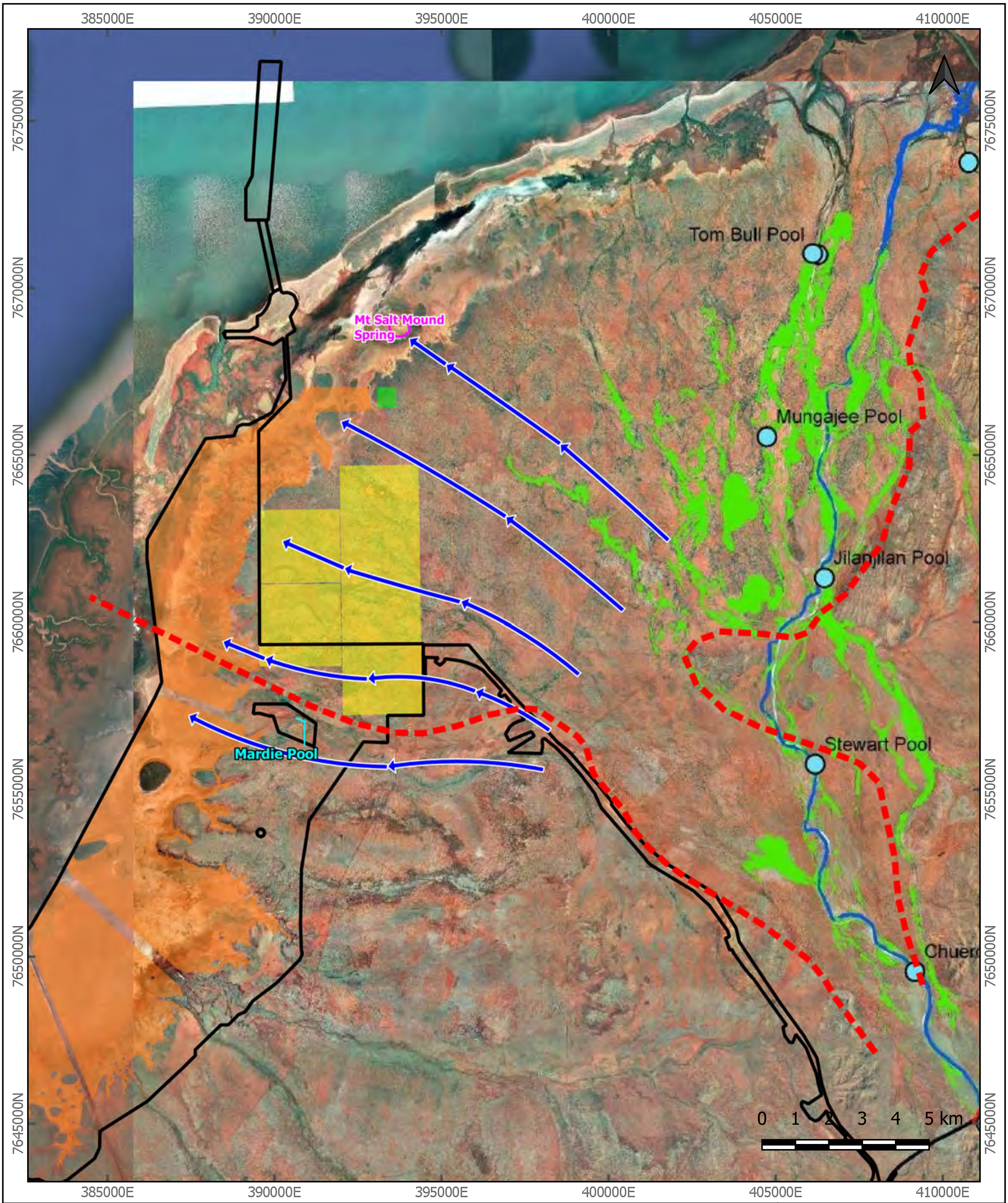
Figure 6

Mardie Project
Sino Iron Project
Cumulative
Drawdown



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Legend

- Mt Salt Mound Spring
- Fortescue Alluvials Boundary
- Groundwater Flow Direction
- Development Envelope
- SOP Plant
- Crystallisers
- Evaporation Ponds
- Mardie Pool

Green shaded areas - Riparian Vegetation after Loomes (2010)

AUTHOR: BPH	REPORT NO: 019a	Notes and Data Sources:
DRAWN: BPH	JOB No: 293F	Background Image (C) Google Project Infrastructure data supplied by BCI Minerals Water Levels based on historical data.
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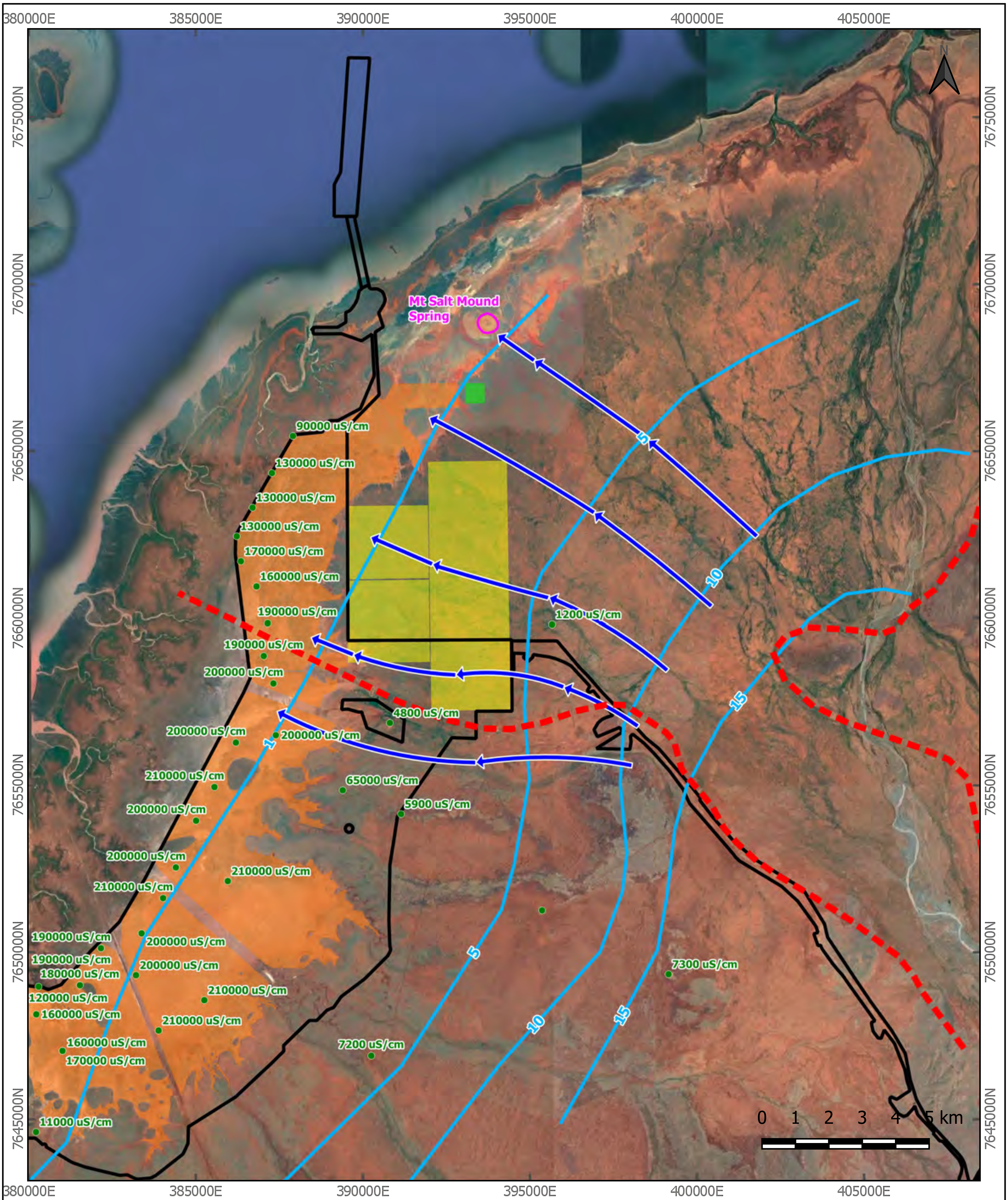
Figure 7

Mardie Project
Fortescue River Valley
Riparian Vegetation



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Legend

- Mt Salt Mound Spring
- Test Pit and Bore GW Salinity
- Fortescue Alluvials Boundary
- Groundwater Flow Direction
- Estimated Water Level mRL
- Development Envelope
- SOP Plant
- Crystallisers
- Evaporation Ponds

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Figure 8

Mardie Project Test Pit and Bore Groundwater Salinity - 2019