Roy Hill Iron Ore Pty Ltd

TSF Decant Water Disposal Risk Assessment

January 2019

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1. Introduction

Roy Hill Iron Ore Pty Ltd (RHIO) appointed GHD to undertake a desktop review and risk assessment of the proposed use of tailing storage facility (TSF) decant water for dust suppression (DS) and disposal via managed aquifer recharge (MAR).

This report documents the findings of the desktop review and risk assessment. The report is structured as follows:

- **Project Description** - This section summarises the tailings management operations, TSF, decant water quality and volume, and the mine site operational equipment for water for dust suppression.

- **Environmental Setting** - This section summarises the environmental setting within the mining lease and adjacent land. This section draws from the findings from past studies.

- **Dust suppression conceptual model and risk assessment** - This section identifies the source, pathway, receptor linkages with regard to potential contaminants within the TSF decant water, and developing a mass balance and assessing the potential risk to receptors.

- **Managed aquifer recharge conceptual model and risk assessment** - This section summarises source, pathway, receptor linkages with regard to potential contaminants within the TSF decant water, models potential scenarios and provides an assessment of risks.

- **Conclusions and management options** - This section summarises the findings of the study and provide management options to mitigate potential risks.

1.1 Project background

RHIO operates an above ground TSF. Supernatant recovered from the TSF is returned to the process plant (return process water), however the quantities of water that can be returned to the process plant will become restricted in the near future (ie. due to chloride concentration), therefore it will be necessary to discharge supernatant (non-return process water) to alternate mine site use and or disposal.

Future tailings disposal into in-pit TSFs are proposed which will require quantities of decant water, up to 20 ML/day, to be removed and disposed. RHIO is currently assessing disposal of decant water via dust suppression and MAR.

Dust suppression - RHIO requested advice from the Department of Water and Environmental Regulation (DWER) regarding the proposed use of TSF decent water for dust suppression. DWER recommended in their response that the TSF decant water is not used on a long-term basis for dust suppression on mine roads. This study reviews the potential risk of negative impact to the environment associated with the use of TSF decant water for dust suppression during the RHIO life of mine.

MAR - A Section 45C application for the 24-month RHIO MAR Strategy was approved by the Environmental Protection Authority (EPA) for Ministerial Statements (MS) 824 and 829 on 11 May 2018. Amendment Notice # 6 of the RHIO Mine Operating Licence was issued on the 5 October 2018 for the implementation of the 24-month MAR strategy. RHIO is proposing to construct up to 50 reinjection bores and 7 recharge basins within the Mine tenement. In the context of this amendment to the RHIO Mine Operating Licence MAR strategy, this study reviews the potential risks or benefits of potential changes to the environment associated with the use of TSF decant water for MAR.

1.2 Study objectives

Based on the quality and quantity of TSF decant water, RHIO requires an assessment of the potential environmental impacts from disposal of 20 ML/day of TSF decant water via road dust suppression (up to 20 ML/day) and/or MAR (up to 20 ML/day). A combination of dust suppression and MAR is proposed to be used at any time, with the total disposal not exceeding 20 ML/day.

1.3 Scope

The scope of the study included:

1. Review and define environmental setting, including reviewing the following information provided by RHIO:

- Astron 2015, RHIO Desktop Study and Risk assessment, Management of Saline Water Used for Dust Suppression, unpublished report for RHIO

- RHIO Saline Water for Dust Suppression, Management Plan, internal RHIO procedure

- TSF decant water quality results 2018 provided by RHIO

- Existing soil quality results provided by RHIO

- Soil Water Consultants 2010, 'Roy Hill soil and waste characterisation', unpublished report for Hancock Prospecting Pty Ltd

- SRK Consulting (Australasia) Pty Ltd, August 2017, Geochemical Characterisation of Iron Ore Tailings, unpublished report for RHIO, Document Number - EP-REP-0113

- RHIO-001-LET-5988 Letter to OEPA - Saline Water Use June 2015

GHD is currently assisting RHIO with life of mine groundwater impact assessment and with detailed design of Zulu 5 in-pit TSF, the outcome of which are also used to inform this assessment, particularly for MAR assessment.

2. Review and define the process of reuse of TSF decant water for dust suppression in WA and the disposal of TSF decant water via MAR to define the operational process and consider best management approach.

3. Conduct an initial screening assessment (Tier 1 risk assessment) by comparing TSF water quality data with existing assessment criteria, including:

- ANZECC 2000 Australian and New Zealand Environment Conservation Council (ANZECC) Australian and New Zealand Guidelines for Fresh and Marine Water Quality

- ASC NEPM National Environmental Protection Council (NEPC) National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1)

- DWER WA Contaminated Sites Act 2003 and Contaminated Sites Regulations 2006, and associated Contaminated Site Management Series Guideline.

4. Development of a conceptual model for source, pathway and receptor (fate and transport) for contaminants of concern (those contaminants exceeding the initial screening assessment criteria).

5. Complete a semi-quantitative risk assessment for contaminants of concern. The risk assessment included calculation of mass balances for contaminants of concern, and assessing concentrating and diluting processes, and draw on available published eco-toxicological limits for local flora and fauna.

6. Review engineering options where unacceptable risks are identified.

7. Provide an environmental impact assessment report detailing the results of the assessment.

1.4 Regulatory context

1.4.1 Licences and approvals

RHIO is required to protect remnant vegetation and to maintain surface and groundwater quality within the project area as outlined in approvals and licences issued under State legislation for the Project. The Project has been assessed by the EPA under Part IV of the Environmental Protection Act 1986 and approved by the Minister for the Environment, with conditions outlined in Ministerial Statements (MS) 824 and 979 for Stage 1 of the Project and MS 829 and 980 for Stage 2.

Ministerial Conditions have placed limits on the extent of native vegetation clearing at the Mine. A total of 11,993 hectares of vegetation has been approved for clearing as specified in MS 824 (7,200 ha) and MS 829 (4,793 ha).

Condition 6 of both MS 824 and MS 829 pertains to monitoring and managing the health of riparian and groundwater dependent vegetation in the context of groundwater abstraction, and Condition 7 of MS 979 and Condition 9 of MS 980 pertain to monitoring and managing the health of mulga vegetation in the context of surface water diversions. Condition 8 of MS 824 and Condition 10 of MS829 pertain to the protection and management of surface water and groundwater quality in the context of run-off and seepage from waste facilities, evaporation ponds and locations where salt is encapsulated.

RHIO submitted an application for a Section 45C to the EPA to amend the dewater volumes and allow the use of saline mine dewater for dust suppression. Approval of the proposed amendment was received on 11 February 2016 with the revision of the Mine Key Characteristics Table. This allows RHIO to use saline dewater for dust suppression up to 3.7GL/ a with a TDS less than 40,000mg/L. The approval of use of saline dewater for dust suppression is pertinent to this study, as the saline dewater has a significantly higher TDS concentration than the TSF decant water. Thus, the salinity (TDS) of the TSF decant water is not expected to pose a risk of harm to the environment based on approval for water with up to 40,000mg/L TDS already in place.

Section 45C application for the 24-month RHIO MAR Strategy was approved by the EPA for MS 824 and 829 on 11 May 2018. Amendment Notice #6 for the RHIO Mine Operating Licence was issued on the 5 October 2018.

1.4.2 Guideline framework

The relevant legislation and guidelines that outline the appropriate framework for the baseline contamination assessment include:

- NEPC (1999) National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1).
- ANZECC (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality.
- Contaminated Sites Act 2003 and Contaminated Sites Regulations 2006.
- DER Contaminated Sites Management Series guidelines.
- DER (2014) Assessment and management of contaminated sites guideline.

1.5 Limitations

This report: has been prepared by GHD for Roy Hill Iron Ore Pty Ltd and may only be used and relied on by Roy Hill Iron Ore Pty Ltd for the purpose agreed between GHD and the Roy Hill Iron Ore Pty Ltd.

GHD otherwise disclaims responsibility to any person other than Roy Hill Iron Ore Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Roy Hill Iron Ore Pty Ltd and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

2. Project description

The purpose of this section is to provide background context on the project, source of tailings and the TSF decant water quality.

The Roy Hill Iron Ore Project is an iron ore mining, rail and port project developed in the Eastern Pilbara region of WA. The project area is located at the eastern edge of the Chichester range, approximately 115 km north of Newman (Figure 2-1), on Roy Hill Pastoral Station which is used for low intensity cattle grazing.

The main ore body extends along the lower to mid slopes of the Chichester Range (up to 70 km long) and underlying the adjacent plain for a distance of 1 km to 2 km across the strike. The mine comprises numerous open pits, a mine processing plant and associated infrastructure for transport, utilities and accommodation.

The construction of mining and processing facilities was completed in 2015, with the first iron ore railed to the Roy Hill Port Facility in October 2015. Haul roads have been constructed with dust suppression being regularly applied across the road network.

2.1 Tailing storage facility operations

Tailings are generated during ore processing comprising cyclones, up-current classifiers and spirals (GHD, 2013 a-c). The processing plant consists of a series of individual scrubbing, screening and de-sanding circuits, as shown in Figure 2-2.

The wet scrubbing units are used to break down the sticky clays attached to the ore, into a fine suspended clay fraction suitable for subsequent wet beneficiation. Beneficiation is the process of separating the valuable material from the waste material.

After passing through the wet scrubber units the ore is fed into the screening circuit. The screening circuit sorts the ore into Lump and Fines products. Lump ore produced from the processing plant will range in size from 8 mm to 40 mm, while Fines ore will be less than 8 mm in size.

This top deck of the screen separates oversize material (>40 mm) which is then tertiary crushed for further size reduction. The lower deck separates material into Lump product (>8 mm to <40 mm) which is delivered via conveyors straight to the lump product stockyard.

Sub 8 mm ore is transferred to a single deck wet banana screen, which separates the ore into Fines product (<8 mm to >1 mm) with the undersize material (<1 mm) pumped to the de-sanding circuit for gangue (impurities) removal.
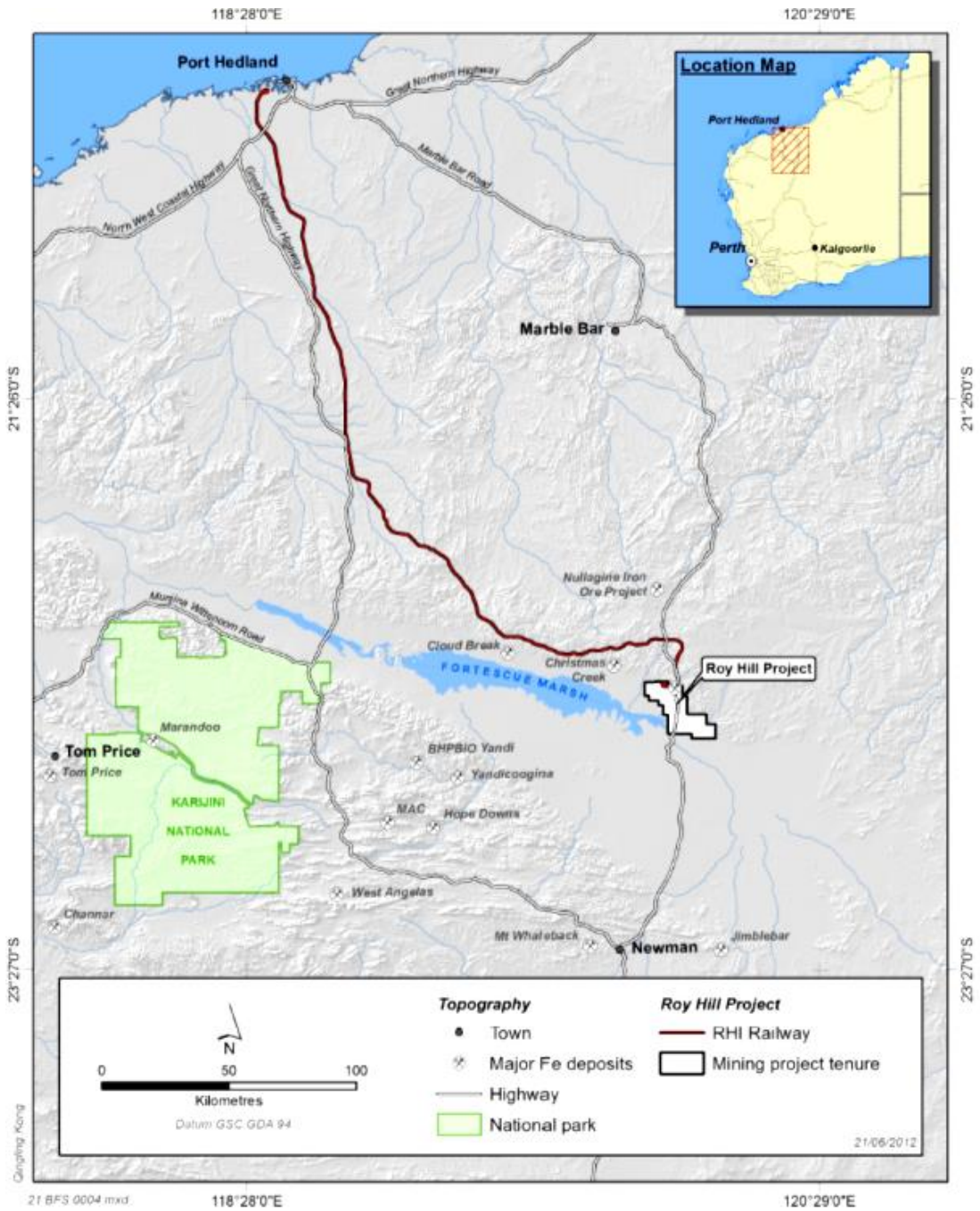
Figure 2-1: Roy Hill project location
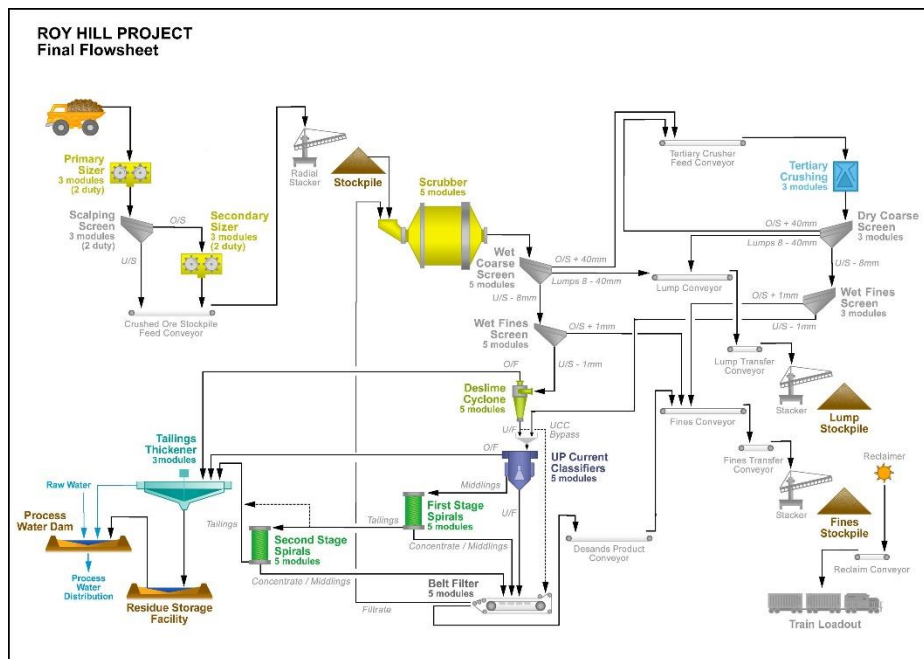
Figure 2-2: Ore processing plant flowsheet *(source: RHIO 2018)*

Five de-sand modules operate in parallel in this circuit with each module consisting of cyclone classification, up current classification and spiral concentration units which use water and gravity movement to filter and remove gangue material.

Each module contains both rougher and scavenger spirals. Rougher spirals produce three products; concentrate, middlings and tailings, with concentrate directed to vacuum filter belts for de-watering and middlings and tailings material sent to the scavenger spirals.

Scavenger spirals recover any iron minerals that is contained in the middlings and tailings material. Concentrate from the scavenger spirals is sent to the vacuum filter belts for de-watering and tailings are pumped to the residue thickener for disposal to the tailings storage facility.

De-watered ultra-fines product is then recombined with coarse Fines on the Fines transfer conveyor and delivered to the mine stockyard.

Tailings streams are mixed in a conventional thickener to increase the solids content of the slurry to a maximum of 55% w/w before being pumped to the tailings storage facility (TSF). No hazardous chemicals are known to be added to the tailings are part of this process. Annual tailings production rates are as follows:

- 2016: 8.7 million tonnes;

- 2017: 12.2 million tonnes; and

- 2018 (onwards): 13.3 million tonnes.

The Roy Hill mine site currently operates a conventional above ground TSF (AG TSF). The AG TSF has the capacity for around 79 million m^3 (or 126 million tonnes of tailings) at full capacity. The AG TSF is divided into two cells, with areas of approximately 194 ha (Cell 1) and 185 ha (Cell 2).

In-pit disposal has been identified as the preferred method for the long-term management of tailings. Future tailings disposal into in-pit TSFs (ITPTSF) are proposed requiring quantities of decant water, up to 20 ML/day, to be removed and disposed.

2.2   AG TSF decant water quality

AG TSF decant water quality data was provided by RHIO, based on water quality monitoring completed by RHIO on a weekly basis between April and September 2018. The water samples were submitted to SGS Laboratory for analysis of a broad range of parameters.

Prior to analysis of inorganic parameters, samples where laboratory filtered with a 0.2 µm filter.

The results of AG TSF decant water analysis are provided in Appendix A, and key findings are summarised below:

- Total dissolved solids (TDS) concentrations ranged from 2,700 to 5,200 mg/L. These concentrations are considered to be low to moderate salinity levels. RHIO has approval to use saline water up to 40,000 mg/L TDS from dewatering for dust suppression.

- The values of pH range from 7.6 to 8.0. The TSF decant water is near-neutral / slightly alkaline.

- Nutrients represented by total nitrogen ranged up to 81 mg/L with a mean of 42.5 mg/L, higher than the background concentrations in the receiving groundwater. Compared to ANZECC (2000) fresh water guidelines 95% ecosystem protection, total nitrogen concentrations in the TSF water are higher than the 'regional default low-risk trigger value' of 0.5 mg/L.

- Inorganic (including dissolved metals) concentrations were determined for the following: As, Ba, Be, B, Cd, Ca, Cl, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, P, K, Se, S, Ag, Na, Sr, S, Tl, Sn, Ti, V, and Zn. The results are shown in Appendix A. As further discussed in Section 5, the maximum concentrations for each metal have been compared to ANZECC (2000) fresh water guidelines 95% ecosystem protection. Where guideline values are available, all concentrations were below the trigger levels with the exception of **boron, chromium (total), selenium, and zinc**. Table 2-1 shows summary statistics for concentrations of boron, chromium, selenium and zinc measured in AG TSF decant water.

Table 2-1: Summary statistics for concentrations of boron, chromium, selenium and zinc measured in AG TSF decant water

Analyte	Boron	Chromium	Selenium	Zinc
Units	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Count	38	38	38	38
Minimum	0.15	0.04	0.01	0.01
Maximum	1.2	0.14	0.041	0.021
Average	0.53	0.07	0.023	0.006
ANZECC 95% trigger level	0.37	0.0004	0.011	0.008

2.3   Dust suppression water requirements at RHIO

RHIO received approval to reuse saline water from mine dewatering by way of dust suppression in 2015.

Based on the current road usage, it is expected that an average of 9 ML/d of water will be required for dust suppression, with peaks to 14 ML/d (low of around 5 ML/d). As the mine operating footprint expands the requirement for water for dust suppression will increase. To allow for expected expansion, this study has considered a maximum future dust suppression water requirement of 20 ML/d.

3. Environmental setting

The purpose of this section is to describe the sensitive environmental receptors at the site. These receptors have been considered in the conceptual model development in subsequent sections.

The following section on environmental setting has been largely sourced from Astron (2018) who completed an extensive summary as part of their risk assessment for use of saline water for dust suppression at the site.

3.1   Climate

The project area experiences an arid sub-tropical climate with two distinct seasons: a hot, wet summer extending from December through to April, and a mild dry winter from May to November.

Rainfall in the region is highly variable and associated with tropical lows, cyclones and local thunderstorms and mostly falls during the summer months. Annual rainfall in the region is typically between 250 mm to 400 mm. Average annual rainfall from a rainfall gauge located at the Roy Hill Pastoral Station from 1900 to 1998 was approximately 260 mm (Environ 2009).

Average annual rainfall at Noreena Downs, 39 km north east of Roy Hill, is 325 mm (Bureau of Meteorology (BoM) station number 4026) (BoM 2014). The monthly distribution of rainfall for Noreena Downs is presented in Table 1.

Evaporation rates in the region are very high, ranging between 3,200 mm and 3,600 mm per year (Van Vreeswyk et al. 2004), which exceeds average annual rainfall by an order of magnitude. Daily rainfall data is currently being collected from three rainfall gauges within the project area; Rain1, Rain3 and RainLog2 (see RHIO (2014) for details).

Table 3-1 Long term average monthly rainfall for Noreena Downs. (Bureau of Meteorology station number 4026)

1911-2014	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
Rainfall [mm]	66.9	74.3	53.2	22.7	20.3	18.7	10.1	6.8	1.6	5.1	9.5	36.2	326

3.2   Hydrological setting

Regionally, the project area lies in between the Chichester Range and the Hamersley Range on the eastern end of an extensive surface water and groundwater system that drains into the Fortescue Marsh. There are several main drainage lines which traverse the mining area and drain towards the Marsh, including Kulbee Creek and Kulkinbah Creek (Figure 3-1).
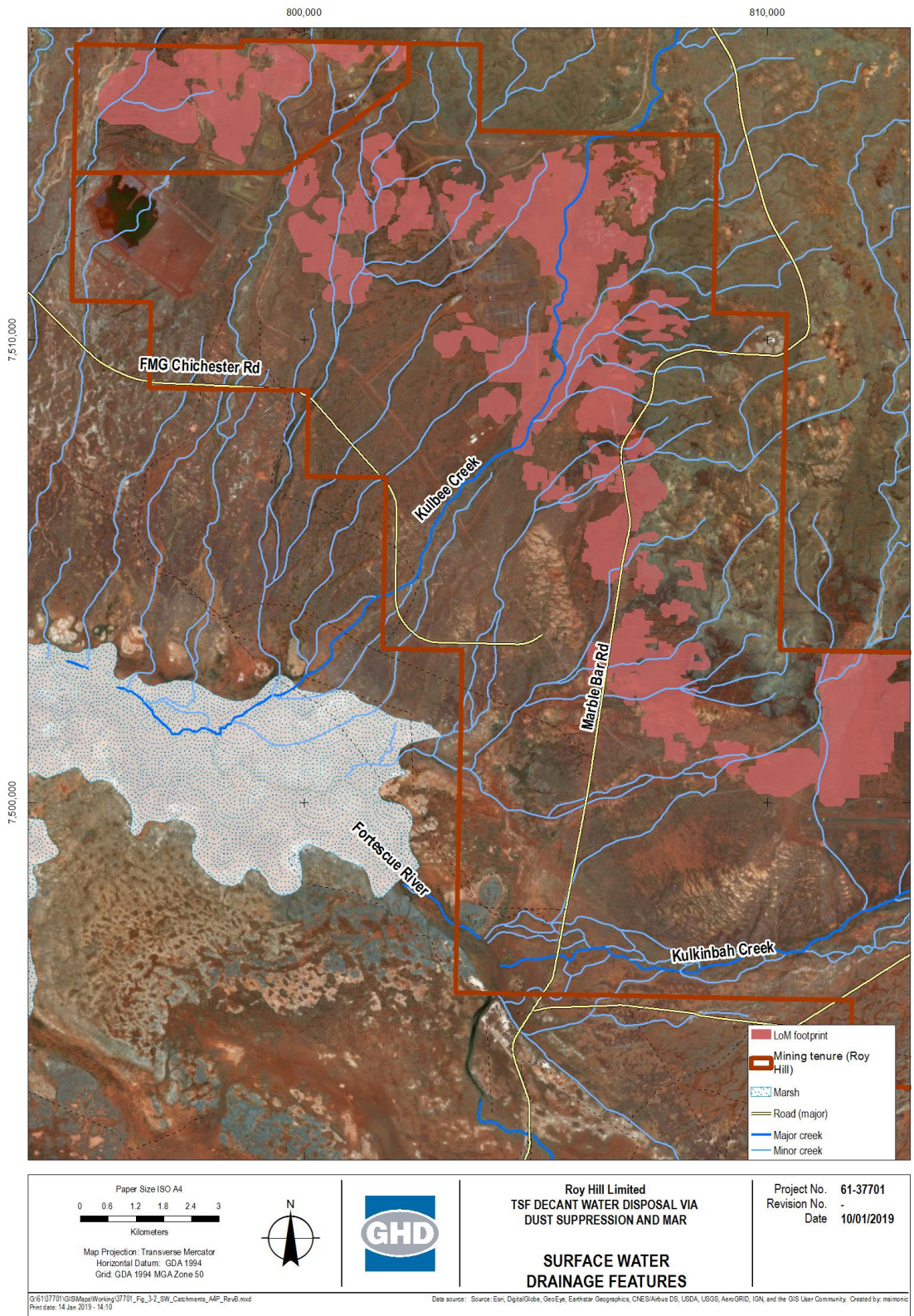
Figure 3-1: Creeks and drainages within project area prior to mine development

The mining area is located in the southern foothills and adjacent plains of the Chichester Range which gently slopes to the southwest, with slopes typically around 1° to 2°. The slopes of the Chichester Range are gently undulating in nature and there is a defined break-of-slope delineating the Range from the plain which extend to the edge of the Fortescue Marsh. The

plain varies in width from 8 km to 15 km and becomes essentially flat approaching the Marsh, with a slope of only 0.2° to 0.3° (Soil Water Consultants 2010).

The southern slopes of the Chichester Range are drained by relatively well-defined creeks and other un-named smaller water courses. As slopes become gentler, these creeks and water courses become less defined, braided or completely dispersed in the flat plains. These water courses are ephemeral and can experience long periods of no flow during drought. Flow typically occurs following large rainfall events, and major flow events can be very intense, as evidenced by considerable dissection of the land surface along creek lines, and the accumulation of large weathered rocks and coarse debris in creek beds.

The water quality in creeks during flow events is generally good (low salinity), although turbidity can be high. There are no permanent creeks, surface water pools or wetlands within the mining area.

Across flatter portions of the landscape, surface flows can occur as what is known as 'sheet flow'. Sheet flows can be 1 cm to 10 cm deep and extend downslope for many hundreds of metres as a result of incident rainfall and overtopping of creeks and drainage lines during major flow events. Sheet flow is recognised as being an ecologically important phenomenon in Mulga environments, driving the distribution and storage of soil moisture (Heyting 2011).

With respect to unsealed roads, significant rainfall events have the potential to generate large volumes of runoff which in turn has the potential to mobilise and redistribute salt that has accumulated on roads following dust suppression using saline water.

3.3   Soils

In general, the soils in the region can be described as red-brown sandy clay soils with a predominantly loamy texture (Figure 3-2). They have been deposited by alluvial, fluvial and colluvial processes or formed in situ by weathering of detrital parent rocks and minerals.

There is a marked topographic sequence from the Chichester Range to the Fortescue Marsh with regard to varying soil depth, texture and gravel or stone content. Briefly, surface soils of hills and ridges of the lower slopes of the Chichester Range consist of red shallow loams with high stone or gravel contents overlying fresh or partially weathered rocks or other cemented layers, whereas soils beyond the slopes of the range are typically red loamy earths that become deeper and finer textured with increasing distance downslope towards the Marsh (Soil Water Consultants 2010). These soils tend to be well-structured and friable and often with complex layering of coarse gravels or stones.

Table 3-2: Soil mapping units within the Roy Hill Iron Ore project area

Characteristic	SMU 1	SMU 2 and SMU 3
Basic description	Skeleton soils on ironstone	SMU 2: Shallow gravelly loams SMU 3: Deep gravelly loams
Spatial distribution	Restricted to outcropping and upper slopes of the Chichester Range along the north eastern portion of the project area	SMU 2: Restricted to broad open valleys between mesas and mid to lower slopes of the Chichester Range SMU 3: Along footslopes of the Chichester Range and within the adjacent flat plain Together, SMU 2 and 3 cover the majority of the project area
Depth of surface soils	Very shallow, typically < 30 cm depth	SMU 2: 1m to 2 m SMU 3: > 2 m

Characteristic	SMU 1	SMU 2 and SMU 3
Texture	Gravelly Sandy Loams	Gravelly Loams, with defined alternating layers of coarse angular gravel and well-structured, red-brown silty loam There is a greater prevalence of loamy soil material, particularly in surface soils, on the western side of the project area
pH	Neutral (pH 6 to 7)	SMU 2: Moderately acidic to neutral (pH 5 to 7) SMU 3: Neutral to slightly alkaline (pH 7 to 8)
Salinity	Non-saline (EC1:5 < 0.1 dS/m)	Non-saline (EC1:5 < 0.2 dS/m)
Sodicity	Non-sodic (ESP < 6%) but potentially dispersive due to low salinity	Non-sodic (ESP < 2%), but potentially dispersive due to low salinity
Plant available nutrients	Low	Gravelly soil material: low Loamy soil material: low to moderate
Organic carbon	Low, reflective of relatively low vegetation cover	Moderate, due to higher vegetation cover and abundance of roots in friable materials
Permeability	High capacity for leaching of salt and nutrients	Moderate to high capacity for leaching of salt and nutrients
Plant Available Water (PAW)	Generally low due to high gravel content	Gravelly soil material: generally low, PAW around 8% Loamy soil material: generally high, PAW around 14%
Hard setting potential	Low, due to high gravel content	Gravelly soil material: low Loamy soil material: high
Associated Vegetation	Dominated by hummock grassland, principally Triodia spp., with isolated trees and shrubs	Varies from isolated low trees and sparse mixed height shrubs with some larger trees in drainage lines (SMU 2) to moderately dense to open tall Acacia aneura woodland with midstorey of tall shrubs (SMU 3)

Source: Soil Water Consultants (2010)

Following a detailed soil survey (Soil Water Consultants 2010), three distinct soil mapping units (SMU) have been defined within the project area:

• SMU1 – skeleton soils over ironstone

• SMU 2 – shallow gravelly loam

• SMU 3 – deep gravelly loam.

SMU 2 and SMU 3 are essentially similar, with the only difference being the depth of surface soils overlying the base ironstone or laterite material. Relevant physical and chemical characteristic of these units are summarised in Table 2; refer to Soil Water Consultants (2010) for detailed descriptions and spatial distribution across the project area.
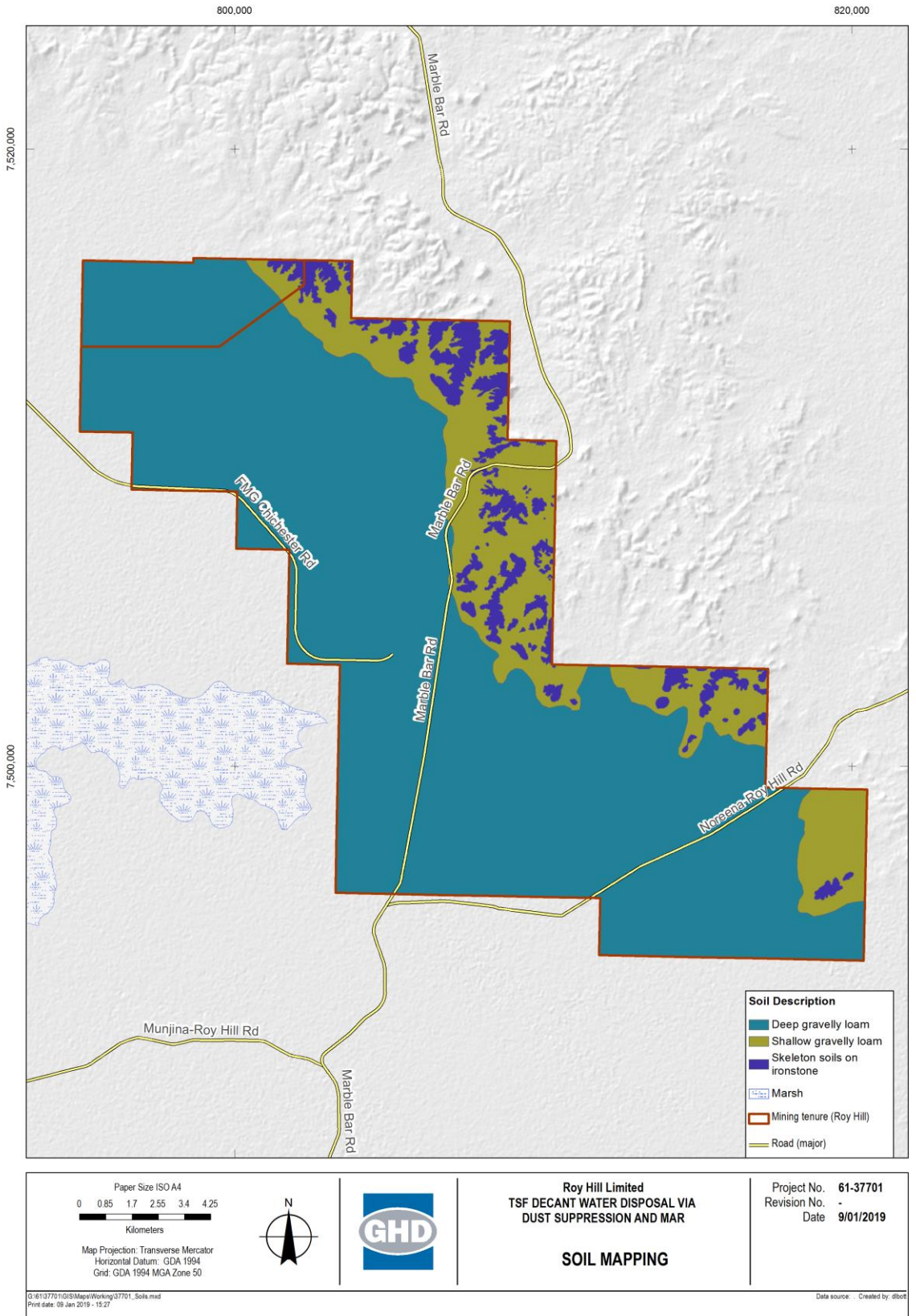
Figure 3-2: Soil mapping

3.4　Background soil chemistry

A baseline soil quality survey was undertaken by RHIO in August 2016. Twenty-four soil samples were collected and analysed for pH, EC and metals concentrations. The analytical reports are provided in **Appendix A**.

3.5　Vegetation

Comprehensive flora and vegetation surveys of the mining area have been carried out to characterise the specific vegetation assemblages, condition and presence of significant vegetation communities (Ecologia 2009).

Overall, approximately 60% of the mining tenement consists of mulga plains habitat with pockets of moderately dense Acacia aneura (mulga) over scattered low shrubs and tracts of bare gravel plain (Figure 3-4). The majority of mulga occurs within the vicinity of drainage lines in the north-western portion of the mining area. Other common features of mulga vegetation associations include variable canopy density of A. aneura and variable ground cover of tussock grasses and herbs including the introduced buffel grass (*Cenchrus ciliaris).

There is a wide variation in the levels of shrub and grass cover and level of maturity of A. aneura, reflective of the mosaic of landscape fire history. The mulga low woodlands vegetation associations in the Fortescue Plains sub-region have significant environmental value as they occur near the northern most extent of mulga in the Pilbara Bioregion.

The mining tenement also contains pockets of riparian and potentially groundwater dependent (phreatophytic) vegetation in the vicinity of creeks, floodplains and drainage lines, including species such as Eucalyptus victrix (coolibah), E. camaldulensis (river red gum) and Melaleuca glomerata.

Figure 3-3: Upper reaches of the Kulbee Creek, typical of riparian vegetation in the vicinity of creeks in the area (source: Gilberts and Associates, 2009)

Riparian and groundwater dependent vegetation associations are regarded as having significant environmental value that often requires them to be protected from the effects of groundwater abstraction.

Flora assessments have demonstrated the presence of 547 species, 53 families and 170 genera in the mining area (Ecologia 2009; Vital Options Consulting 2010). No declared rare flora listed under the Wildlife Conservation Act, 1950 and no flora listed under the Environment Protection and Biodiversity Conservation Act, 1999 has been recorded within the mining area

(Ecologia 2009), however six flora species of conservation significance (priority taxa) have been recorded, as outlined in Ecologia (2009).

One weed with declared weed status in the East Pilbara, *Parkinsonia aculeate (parkinsonia), has been recorded. This species, which has been found to occur at a small number of sites along creek banks and floodplains within the mining area, is categorised as a weed of national significance.

Based on the Ecologia (2009) assessment and subsequent amendments by Vital Options Consulting (2010), four specific vegetation associations and 21 subtypes have been identified and mapped within the mining area, as described below:

1. Triodia sp. hummock grassland:

    i)   Isolated to open low trees and shrubs over *Triodia brizoides* hummock grasslands on slopes and crests.

    ii) Isolated to open low trees and mixed height shrubs over *Triodia sp.* Shovelanna Hill hummock grasslands on slopes and plains.

    iii) Isolated low trees and isolated to sparse mixed height shrubs over *Triodia longiceps* hummock grasslands on colluvial deposits.

    iv) Isolated low trees over sparse to open mid to low shrubland over *Triodia basedowii* hummock grasslands.

    v)   Isolated low trees over sparse to open mid to low shrubland over *Triodia epactia* hummock grasslands.

    vi) Isolated low trees over sparse to open mid to low shrubland over *Triodia wiseana* hummock grasslands.

    vii) Isolated low trees over sparse to open mid to low shrubland over *Triodia lanigera* hummock grasslands.

2. Riparian associations:

    i)   Low forest to woodland *of Eucalyptus victrix/Corymbia hamersleyana* over open high *Atalaya hemiglauca/Acacia pyrifolia* over open low shrubs over dense *Cenchrus ciliaris* (buffel grass)

    ii) Scattered *Eucalyptus victrix* over a low woodland of *Acacia aneura/A. coriacea subsp. pendens/Atalaya hemiglauca* over open shrubs over dense *Cenchrus ciliaris* grassland.

    iii) Open woodland of *Acacia pruinocarpa, A. citrinoviridis* over dense midstratum of *Petalostylis labicheoides* over sparse low shrubs over sparse tussock grasses and *Triodia epactia*.

    iv) Floodplains adjacent to major creeklines: Open forest to woodland of Eucalyptus victrix over open mid-height shrubland dominated by *Acacia tetragonophylla*, *A. sclerosperma*, *Vachellia farnesiana* over sparse mixed tussock grasses and herbs.

    v)   Floodplains: Isolated trees to open woodland of *Eucalyptus victrix* over open *Acacia synchronicia* over mixed low shrubs to low shrubs over open to closed mixed tussock grasses.

    vi) Open woodland of *Acacia pruinocarpa*, *A. aneura var. intermedia* over dense midstratum of *Petalostylis labicheoides* over sparse low shrubs over sparse tussock grasses and *Triodia epactia*.

3. *Acacia aneura* low woodlands and tall shrublands:

i) *Acacia aneura*, *A. rhodophloia* open forest and woodlands over sparse low shrubs and closed tussock grassland and herbland ± *Triodia longiceps*.

ii) Open woodland of *Acacia pruinocarpa*, *A. aneura* over open mixed shrubland over open grasses.

iii) Moderately dense to open tall *Acacia aneura* shrubland over sparse to open *A. tetragonophylla*, *Senna artemisioides* subsp. *helmsii* shrubs over moderately dense to open grassland dominated by *Aristida contorta*.

iv) Groves of *Acacia aneura*, *Acacia rhodophloia* woodland over sparse shrubland of *Eremophila forrestii* subsp. *forrestii*, *Senna artemisioides* subsp. *helmsii*, *Eremophila latrobei* subsp. *filiformis* over open to sparse grasses.

v) Isolated trees or shrubs of *Acacia aneura* over open shrubland of *Senna glutinosa* subsp. *luerssenii* and *Eremophila cuneifolia* over sparse grasses.

vi) Isolated clumps of tall *Acacia aneura* shrubs over open low shrubs of *Ptilotus schwartzii*.

4. Miscellaneous shrublands:

i) Rocky crests of hills: *Acacia rhodophloia* shrubland over sparse mixed shrubs and isolated herbs, and grasses.

ii) Isolated shrubs of *Acacia synchronicia* over open and diverse herbs and grasses.

As defined by the vegetation monitoring plan (RHIO 2011) and subsequent vegetation monitoring reports for the project area, vegetation association 2 includes vegetation referred to as riparian and groundwater dependent vegetation (RGDV), while association 3 includes vegetation referred to as sheet flow mulga vegetation (SFMV). In this study, associations 1 and 4 are referred to as all other vegetation (AOV).
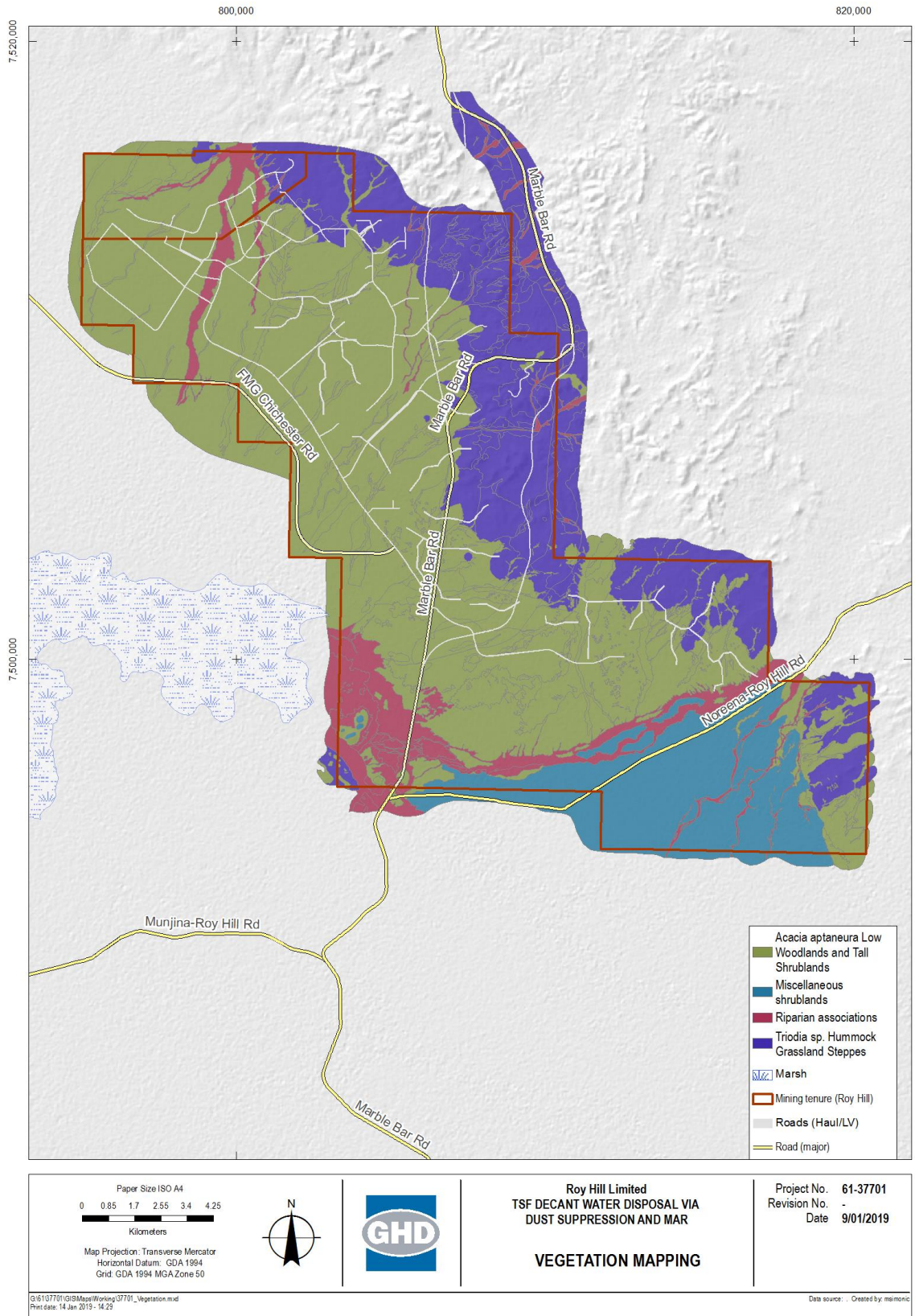
Figure 3-4: Vegetation mapping

4. Dust suppression conceptual model and risk assessment

The purpose of this section is to assess the level of risk to the environment and human health associated with the application of TSF decant water as dust suppression. To do this a conceptual model is developed identifying source, pathway, receptor interactions. Where source, pathway receptor linkages are considered complete, potential risks are screened based on published guideline criteria for water and soil quality.

4.1 Conceptual model

A conceptual model for the use of TSF decant water for dust suppression outlining the source, pathway, receptor interaction is depicted in Figure 1 below. The following section discusses key aspects of the conceptual model.

4.1.1 Sources

Potential sources of contaminants include mined ore and associated waste rock, additives to the ore processing operations and processing water. The ore and associated waste rock have the potential to result in elevated metals, sulphides and nutrients in the tailings decant water. The ore processing operations are described in previous sections, and are limited to physical processes without addition of chemical enhancement. Process water is sourced from groundwater and re-circulated.

The potential contaminants of concern in the TSF decant water include:

Inorganics (metals) – Metals concentrations in TSF decant water above the laboratory limits of reporting (LOR) are shown in Table 4-1. All metal concentrations anlaysed in the TSF decant water are provided in **Appendix B**.

Table 4-1: Metals above laboratory limits of reporting (LOR) (decant water)

Analyte	Median concentration (mg/L)
Ba	0.0285
B	0.41
Ca	445
Cl	835
Cr	0.0495
Mg	180
K	33
Se	0.021
S	22
Na	390
Sr	1.5
Zn	0.007

Nutrients – Nutrients represented by total nitrogen ranged up to 81 mg/L in the TSF decant water, with a mean of 42.5 mg/L.

Total Dissolved Solids – As outlined in Section 2, TDS concentrations in the TSF decant water ranged from 2,700 to 5,200 mg/L. These concentrations are considered to be low to moderate salinity levels. RHIO has approval to use saline water up to 40,000 mg/L TDS from dewatering

for dust suppression. TDS concentrations are not considered to be a potential contaminant of concern.

Acidity - As outlined in Section 2, pH in the TSF decant water ranged from 7.6 to 8.0. The TSF decant water is near-neutral / slightly alkaline. Acidity is not considered to be a potential contaminant of concern.

4.1.2   Potential migration pathways

The application of decant water for dust suppression will result in the direct addition of the potential contaminants of concern to the surface material / soils on the haulage roads, light vehicle roads and road bund. In addition, the dust suppression water may be influenced by wind drift resulting in dispersion within a 10 m radius. Once deposited in the road material and soil profile, potential contaminants of concern may migrate via the following pathways:

• Migration of contaminants via dust generated during high wind events or other surface disturbance

• Migration of contaminants via splashing of wetted soils by site traffic

• Overland flow during heavy rainfall events, across adjacent alluvial plains and ultimately to Fortescue Marsh

Vertical migration of contamination present in soils into underlying groundwater is not considered a potential pathway due to the large depth to groundwater, which is between 30-40 mBGL for the majority of the road network requiring dust suppression.

4.1.3   Exposure routes

Potential exposure routes include:

• Native vegetation uptake of potential contaminants of concern present in soil. This exposure route is considered likely in the area directly adjacent to the roads.

• Native vegetation located at greater than 10 m from the roads may be exposed to metals concentrations, however only during rain events / runoff events, where the concentrations of metals would be highly diluted by the volume of rain resulting in overland flow.

• Ingestion by local fauna if pooling occurs. Pooling is considered unlikely, due to dust suppression operational practices and past experience with dust suppression at the site.

• Dermal contact and ingestion of surface soils if mine workers are present on or adjacent to roads. Human inhalation of dust during high wind events or earthworks.

4.1.4   Sensitive receptors

Sensitive receptors that may be affected by potential contaminants of concern include:

• Native vegetation located directly adjacent (ie within 10m) to roads

• Local mine workers

• Local fauna ingesting the water if pooling occurs

• Native vegetation located in Fortescue Marsh

Figure 4-1: Conceptual site model – dust suppression

4.2 Metals mass balance in soil

A metals mass balance in soil has been developed for the use of TSF decant water for dust suppression application. This mass balance has been used to assess the potential risk to native vegetation located directly adjacent to the haul and light vehicle roads. The model considers the annual accumulation of all metals with concentrations above LOR in the surface profile of road material and soil. The mass balance model is based on the following key assumptions.

Table 4-2: Mass balance input assumptions

Parameter	Value	Rationale
Metals concentration in decant water	Mean concentration values	The mean concentration from analysis of 38 water samples has been applied. The water samples were collected over the period April – September 2018.
Length of road requiring dust suppression	Haul roads: 68 km Light vehicle roads: 8 km	The active haul road length (straight runs, no ramps going into pits/dumps) at RHIO is 59.6 km, and the active pit/dump access haul road length (ramp type roads going in/out of pits/dumps) is 20.6 km. Future haul road planned in CY 2019 & 2020 (until June 2020) is 4.8 km. In total is equates to 85 km by 2020. The site also includes approximately 10 km of active light vehicle road networks. At least 80% of total haul and light vehicle roads will require dust suppression, equating to 68 km of haul road and 8 km of light vehicle roads at the 2020 length of haul road plan. RHIO note that from CY 2021 & CY 2022 the haul road increases to 95 km and from CY 2023 105 km.
Width of road	Haul road: 42.66 m Light vehicle road: 9 m	Refer to Appendix D Road Design Specifications
Depth of infiltration	0.5 m	An estimation of water infiltration depth of less than 0.5 m has been applied
Mass of 1 m^3 soil	1.8 tonne	A conversion factor of 1.8 has been applied for the sandy loam (www.thecalculatorsite.com)
Maximum rate of TSF decant water	20 ML/d	RHIO planned maximum TSF decant water volume
Days of operations	365 d/yr	The actual days of operation is likely to be around 345 d/yr however to allow flexibility 365 d/yr has been applied
Annual loss in metals concentration in soil due to runoff	50%	During rain events it is assumed that 50% of metals concentrations accumulated in the soil profile will be lost due to runoff.
Duration	13 years	A duration of 13 years has been applied to consider cumulative impacts over the life of mine to 2031.

Table 4-3: Mass balance for metals above LOR in TSF decant water

	Ba	B	Ca	Cl	Cr	Mg	K	Se	S	Na	Sr	Zn
Median concentration in TSF decant water mg/L	0.028	0.41	445	835	0.049	180	33	0.02	22	390	1.5	0.007
Max volume of water applied per year (L)						7,300,000,000						
Mass of contaminant added per year (kg)	208	2,993	3,248,500	6,095,500	361	1,314,000	240,900	153	160,600	,2847,000	10,950	51
Road area (m²)						2,972,880						
Infiltration depth						0.5						
Volume of soil (m³)						1,486,440						
Mass of soil (kg)						2,675,592,000						
Change in concentration per year (mg/kg)	0.08	1.12	1214.12	2278.19	0.14	491.11	90.04	0.06	60.02	1064.06	4.09	0.02
Average background soil concentrations (mg/kg)	117	5	No data	No data	68.75	966	No data	3	No data	No data	No data	48.66
Annual % change	0.1%	22.4%	-	-	0.2%	50.8%	-	1.9%	-	-	-	0.04%
Accumulative % change over 13 years, closed system	1%	29.1%	-	-	3%	661%	-	25%	-	-	-	0.51%
Accumulative %change over 13 years, 50% loss due to runoff per year	0.5%	145%	-	-	1%	330%	-	12%	-	-	-	0.26%
Estimated concentration in 13 years (mg/kg)	117.5	12.3	-	-	69.6	4,158	-	3.4	-	-	-	48.8

Based on the parameters outlined above, the mass balance shows that:

- Barium concentrations will increase by 0.1% per year compared to background soil concentrations, under a closed system (ie no runoff of barium). Accumulation over 13 years, considering a 50% annual loss due to runoff, is expected to result in an increase in barium concentrations of 0.5%.

- Boron concentrations will increase by 22.4% per year compared to background soil concentrations, under a closed system (ie no runoff of boron). Accumulation over 13 years, considering a 50% annual loss due to runoff, is expected to result in an increase in boron concentrations of 145%.

- Chromium concentrations will increase by 0.2% per year compared to background soil concentrations, under a closed system (ie no runoff of chromium). Accumulation over 13 years, considering a 50% annual loss due to migration/dispersion, is expected to result in an increase in chromium concentrations of 1%.

- Magnesium concentrations will increase by 50.8% per year compared to background soil concentrations, under a closed system (ie no runoff of boron). Accumulation over 13 years, considering a 50% annual loss due to migration/ magnesium, is expected to result in an increase in magnesium concentrations of 330%.

- Selenium concentrations will increase by 1.9% per year compared to background soil concentrations, under a closed system (ie no runoff of selenium). Accumulation over 13 years, considering a 50% annual loss due to runoff, is expected to result in an increase in selenium concentrations of 3.4%.

- Zinc concentrations will increase by 0.03% per year compared to background soil concentrations, under a closed system (ie no runoff of zinc). Accumulation over 13 years, considering a 50% annual loss due to runoff, is expected to result in an increase in zinc concentrations of 0.26%.

- Calcium, chloride, potassium, sulphur, sodium are likely to be present in significant concentrations in natural soils within the region.

Calcium, chloride, potassium, sulphur, sodium, and strontium concentrations in soil will increase as a result of addition of TSF decant water. However, information regarding the background concentrations of these metals in soil at the site was not available and therefore, percentage increases could not be calculated.

4.3 Risk assessment - Tier 1 screening criteria

It is important to note that exceedance of a Tier 1 assessment level does not indicate that a contaminant poses a risk; rather that further qualitative or quantitative risk assessment may be required. This section considers the significance of relevant potential contaminants of concern to determine if there are any complete source-pathway-receptor linkages that may pose a significant risk to relevant receptors under the current or intended future land use scenario.

4.3.1 Risk to native vegetation located directly adjacent to roads

A tier 1 risk screening assessment has been conducted for potential impact on native vegetation located adjacent to the roads. The overarching reference used for Tier 1 screening is the National Environment Protection (Assessment of Site Contamination) Measure 1999, as amended by the National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (No. 1), herein referred to as the NEPM. NEPM Schedule B1 "Guidelines on investigation levels for soil and groundwater" contains investigation and

screening levels suitable for the assessment of the potential contaminants of concern in the soil at the site.

As defined in the NEPM, investigation levels and screening levels are the concentrations of a contaminant above which further investigation and evaluation will be required.

The following risk assessment assesses potential risk to vegetation on accumulated metals concentrations in soil. These risks are associated with potential exposure routes including native vegetation uptake of potential contaminants of concern present in soil, which is considered likely in the area directly adjacent to the roads.

Ecological Investigation Levels (EILs) as defined in the NEPM (NEPC 1999), are considered here as a Tier 1 screening criteria for the potential impact of metals concentrations on the local ecology. EILs exist for barium, chromium and zinc, however not for boron, magnesium and selenium. Note, total chromium concentrations in soil at the site are assumed to be chromium III speciation. The following table provides a summary of potential contaminants of concern in soil against generic EILs.

Table 4-4: Comparison of metals concentrations in soil against EILs

COPC	NEPM EIL	Site specific background concentrations (mean)	Estimated concentration after 13 years of dust suppression
units	mg/kg	mg/kg	mg/kg
Barium	300	117	117
Boron	No EIL published	5	12
Chromium (III)	400	69	70
Magnesium	No EIL published	966	4,158
Selenium	No EIL published	3	3.3
Zinc	200	49	49

Estimated concentrations for chromium and zinc in soil after 13 years of dust suppression using TSF decant water are below the generic EILs, suggesting a lower risk of negative impact to native vegetation.

Comments are provided on boron, selenium, major ions (calcium, chloride, magnesium, potassium, sulphur, and sodium) and nutrients with regard to risk to native vegetation located directly adjacent to roads in the section below.

Selenium

Selenium is essential for plant health (Gupta, 2016). Studies have shown that selenium at low doses protect the plants from variety of abiotic stresses such as drought (Hasanuzzaman and Fujita, 2011) and metal stress (Kumar et al., 2012). However, selenium toxicity occurs in plants when optimum concentration of Se are exceeded. Selenium causes toxicity by two mechanisms, malformed selenoproteins and by inducing oxidative stress. Both the mechanisms are known to be harmful for plants.

The median background concentration of selenium in Australian soils is 0.5 mg/kg, values ranging from 0.05 to 3.2 mg/kg (ANZECC, 2000b). Estimated concentrations for selenium in soil after 10 years of dust suppression using TSF decant water are 3.3 mg/kg, marginally above the median background range for Australian soils.

GHD is not aware of publically available studies on the specific impacts of selenium on native vegetation in the Pilbara. Without these specific studies, native vegetation tolerance to increases in selenium concentrations is soil is difficult to quantify.

However, based on the above qualitative lines of evidence the risk of negative impact to native vegetation is considered low as the accumulative increase in selenium concentrations in soil over 13 years is expected to be less than 10%.

Boron

Boron is an essential element that occurs naturally in soil, usually in low concentrations that present no risk to plants. Small quantities of boron are necessary for plant growth. However, signs of boron toxicity may appear when plants are exposed to higher concentrations.

Boron toxicity symptoms usually aren't the result of small amounts of boron generally found in soil. Plants with too much boron initially display yellowing or browning of foliage. Leaf tips become dry, with the symptoms eventually taking over entire leaves.

Most research on boron toxicity relates to agricultural crops. ANZECC (2000b) shows that very sensitive crops (such as blackberries) can tolerate irrigation water with boron concentrations of 0.5 mg/L, similar to concentrations in the TSF decant water. The scale ranges up to very tolerant cops (such as asparagus) that can tolerate up to 15 mg/L boron in irrigation waters, which is 28 times higher than boron concentrations in the TSF decant water.

While ANZECC (2000b) refers to agricultural crops, the tolerable range of boron concentrations in irrigation waters up to 15 mg/L suggests concentrations of 0.53 mg/L in TSF decant water have a low risk of impacting vegetation at the site.

Calcium, chloride, potassium, sulphur, and sodium

Calcium, chloride, magnesium, potassium, sulphur, and sodium are likely to be present in significant concentrations in natural soils within the region, and are not considered as potential contaminants. Saline dewater with significantly higher calcium, chloride, potassium, sulphur, and sodium concentrations has been approved for use. TSF decant water calcium, chloride, potassium, sulphur, and sodium concentration soil accumulation risk to native vegetation is significantly lower than for the saline dewater.

Nutrients

The TSF decant water contains elevated nutrient concentrations. Nutrients are essential for plant growth. While no site specific studies are available with regard to nutrient impact on local vegetation, ANZECC (2000b) provides a recommended trigger range for nitrogen concentrations in irrigations waters for agricultural crops of 25 to 125 mg/L for irrigation over 20 years. These values are based on maintaining crop yield and minimising off-site impacts. Concentrations in irrigation water should be less than the recommended trigger values. Applying these values as a screening criteria for comparison, the TSF decant water has mean nitrogen concentration of 42.5 mg/L which is within the acceptable range defined by ANZECC (2000b). As such, nutrients within the TSF decant water are expected to poise a low risk of negative impact to local vegetation.

4.3.2 Risk to local mine workers

The following risk assessment assesses potential risk to human health based on accumulated metals concentrations in soil. These risks are associated with potential exposure routes including inhalation of dust during high wind events or earthworks. This exposure pathway is considered likely.

HILs have been developed for metals and organic substances, and are applicable for assessing human health risk via all relevant pathways of exposure (NEPC 1999). The NEPM advises that HILs are generic across all soil types, and are generally applicable to a depth of 3 m for residential use, although site-specific conditions will determine the depth to which they apply within other land-use scenarios. Contamination detected in excess of the HILs does not indicate

that unacceptable health risks are present and immediate action must be taken to remediate the affected area, but rather means that further investigation and site-specific assessment may be required.

HILs, where available, for potential contaminants of concern are:

Table 4-5: Comparison of metals concentrations in soil against Health Investigation Levels (commercial/industrial)

COPC	NEPM HIL-D	Background concentrations (mean)	Estimated concentration after 10 years
	mg/kg	mg/kg	mg/kg
Barium	190,000	117	117.5
Boron	300,000	5	12.2
Chromium (III)	480,000	68.75	69.6
Selenium	10,000	3	3.3
Zinc	400,000	48.66	48.8

Estimated concentrations for barium, boron, chromium, selenium and zinc in soil after 13 years of dust suppression using TSF decant water are well below the generic HIL-D values, suggesting a lower risk of negative human health.

4.3.3 Risk to local fauna ingesting the water if pooling occurs

The following risk assessment considers the risk of pooled water resulting in negative impact to livestock or native animals that may drink the water. This exposure pathway is considered unlikely to occur.

With regard to potential impact on fauna drinking pooled water, ANZECC 2000b provide the following comments on concentration limits for potential contaminants of concern with regard to livestock. In the absence of published screening criteria for drinking water for local fauna, these criteria have been applied as an initial screen. The table below summarises TSF decant water concentrations again livestock drinking water limits.

Table 4-6: Comparison of ANZECC livestock and supernatant

PCOC	ANZECC Livestock drinking limit	Average TSF water concentrations
	mg/L	mg/L
Boron	5	0.53
Chromium (III)	1	0.07
Selenium	0.02	0.023
Zinc	20	0.006

Potential contaminants of concern are below the ANZECC livestock drinking water guidelines with exception of selenium, which is marginally above. The criteria is based on sole use of the water for livestock, but in this scenario it is unlikely that pooled water will be the sole water source for fauna and as such the risk is considered low.

Nutrients within the TSF decant water have the potential to result in algal bloom in the pooled water. The ANZECC 95% protection level trigger value for nitrate is 0.7 mg/L which is several orders of magnitude lower than the concentrations in the TSF decant water. However, pooling is considered unlikely, due to dust suppression operational practices limiting the potential for pooling and past experience with dust suppression at the site demonstrating limited pooling. As pooling is considered unlikely the risk is considered low.

4.3.4   Risk to Fortescue Marsh ecology

The Fortescue Marsh is located greater than 5 km from the RHIO road network. While the Fortescue Marsh is a potential receptor for dust suppression waters, the likelihood of an unacceptable risk to the ecology of the marsh is considered low. This conclusion is based on the rationale that the migration of potential contaminants of concern on or adjacent to the road may occur during significant rainfall run-off events. However, the significant distances between the roads and the marsh will result in dispersion of the potential contaminants of concern over areas in the order of several square km (km^2). The resulting concentrations are expected to be negligible.

4.4   Summary of dust suppression risk assessment

The following table presents a summary of the risk assessment and risk ranking for each sensitive receptor.

Table 4-7: Use of TSF decant water for dust suppression - risk matrix summary of findings

Potential contaminant of concern	Pathway	Receptor	Likelihood of complete pathway-receptor linkage	Risk
Metals	Direct accumulation in road base and soil within 10m from road	**Local vegetation** - Native vegetation uptake of accumulated metals in soil	**High** – The application of decant water for dust suppression will result in the direct addition of metals to the surface material / soils on the haulage roads, light vehicle roads and road bund. In addition, the dust suppression water may be influenced by wind drift resulting in dispersion within a 10 m radius.	**Low** – mass balance shows that concentrations of metals in soil after 13 years area unlikely to exceed with Tier 1 risk screening criteria (EIL).
	Migration of contaminants via dust generated during high wind events or other surface disturbance	**Local mine workers** - inhalation of dust during high wind events or earthworks	**Moderate** – Exposure of local mine works to dust will be mitigated while workers are within vehicles. Exposure will only be high during high wind events while workers are outside their vehicles, which is an infrequent occurrence.	**Low** – mass balance shows that concentrations of metals in soil after 13 years area unlikely to exceed with Tier 1 risk screening criteria (HIL).
	Dermal contact with surface soils may occur if mine workers are present on or adjacent to roads.	**Local mine workers** – dermal contact with soil during earth works	**Moderate** – Dermal contact with metals in soil is only expected during earthworks on or adjacent to the road. Earth works on the road are infrequent events.	**Low** – the concentrations of metals in TSF decant water are well below the Tier 1 risk screening criteria (HIL-D), suggesting a lower risk of negative human health
	Ingestion of water pooled at edge of road	**Livestock and local fauna** – ingestion of water from pools	**Low** - Pooling is considered unlikely, due to dust suppression operational practices limiting the potential for pooling and past experience with dust suppression at the site demonstrating limited pooling.	**Low** - The ANZECC 95% protection level trigger value for nitrate is 0.7 mg/L which is several orders of magnitude lower than the concentrations in the TSF decant water. However, pooling is considered unlikely, due to dust suppression operational practices limiting the potential for pooling and past experience with dust suppression at the site demonstrating limited pooling. As pooling is considered unlikely the risk is considered low.
	Run-off during heavy rain events	**Fortescue Marsh ecology**	**Low** - The Fortescue Marsh is located greater than 5 km from the RHIO road network. The migration of metals on or adjacent to the road may occur during significant rainfall run-off events. However, the significant distances between the roads and the marsh will result in dispersion of the potential contaminants of concern over areas in the order of several square km (km2). The resulting concentrations are expected to be negligible.	**Low** – the risk is considered low due to the low likelihood of metals concentrations at the road reaching the Fortescue Marsh.
	Vertical migration of contamination present in soils into underlying groundwater	**Groundwater**	**Incomplete** - Vertical migration of contamination present in soils into underlying groundwater is not considered a potential pathway due to the large depth to groundwater, which is between 30-40 mBGL for the majority of the road network requiring dust suppression.	**Very Low** - due to the incomplete pathway

Potential contaminant of concern	Pathway	Receptor	Likelihood of complete pathway-receptor linkage	Risk
Nutrients	Direct accumulation in road base and soil within 10m from road	**Local vegetation**	**High** – The application of decant water for dust suppression will result in the direct addition of nutrients to the surface material / soils on the haulage roads, light vehicle roads and road bund. In addition, the dust suppression water may be influenced by wind drift resulting in dispersion within a 10 m radius.	**Low** - While no site specific studies are available with regard to nutrient impact on local vegetation, ANZECC (2000b) provides a recommended trigger range for nitrogen concentrations in irrigations waters for agricultural crops of 25 to 125 mg/L for irrigation over 20 years. These values are based on maintaining crop yield and minimising off-site impacts. Concentrations in irrigation water should be less than the recommended trigger values. Applying these values as a screening criteria for comparison, the TSF decant water has mean nitrogen concentration of 42.5 mg/L which is within the acceptable range defined by ANZECC (2000b). As such, nutrients within the TSF decant water are expected to poise a low risk of negative impact to local vegetation.
	Ingestion of water pooled at edge of road	**Livestock and local fauna –** ingestion of water from pools	**Low** - Pooling is considered unlikely, due to dust suppression operational practices limiting the potential for pooling and past experience with dust suppression at the site demonstrating limited pooling.	**Low** - Potential contaminants of concern are below the Tier 1 risk screening criteria (ANZECC livestock drinking water guidelines) with exception of selenium, which is marginally above. The criteria is based on sole use of the water for livestock, but in this scenario it is unlikely that pooled water will be the sole water source for fauna and as such the risk is considered low
	Run-off during heavy rain events	**Fortescue Marsh ecology**	**Low** - The Fortescue Marsh is located greater than 5 km from the RHIO road network. The migration of accumulated nutrients on or adjacent to the road may occur during significant rainfall run-off events. However, the significant distances between the roads and the marsh will result in dispersion of the potential contaminants of concern over areas in the order of several square km (km2). The resulting concentrations are expected to be negligible	**Low** – The risk is considered low due to the low likelihood of nutrient concentrations within soils at the road reaching the Fortescue Marsh.
	Vertical migration of contamination present in soils into underlying groundwater	**Groundwater**	**Incomplete** - Vertical migration of accumulated nutrients present in soils into underlying groundwater is not considered a potential pathway due to the large depth to groundwater, which is between 30-40 mBGL for the majority of the road network requiring dust suppression	**Very Low** - The risk is considered very low due to the incomplete pathway.

5. Use of TSF decant water for MAR

5.1 Introduction

This assessment considers groundwater level and quality changes with regards to injecting TSF decant water into south-west injection borefield.

Injection will take place during mining and will cease in March 2031. The changes to groundwater regime and some of the water quality parameters were assessed with the use of a numerical groundwater flow model (MODFLOW-NWT) developed for life of mine (Simonic, 2018).

For water quality predictions a subdomain of the regional model with higher spatial resolution was extracted and adapted to a solute transport model (MT3DMS-USGS). Solute fate and transport was simulated for selected potential contaminants (selenium, chromium and nitrate) but learnings from these simulations can be extrapolated to other dissolved metals since they would be migrating in the same groundwater system with minor differences to be attributable to their specific attenuation properties.

The mounding and water quality effects were then assessed with respect to potentially affected vegetation and the Fortescue Marsh.

5.2 Conceptual model

The conceptual model is presented in the risk assessment context, within the source – pathway – receptor framework:

• Source – SWIB MAR, injection of dewater/decant mix, which has the potential to create localised mounding and introduce changes to groundwater quality

• Pathway – the receiving aquifer system, with injection into the deeper part of the aquifer system (generally to a depth of 70 to 80 m bgl)

• Receptor – in particular phreatophytic vegetation (where applicable), Fortescue Marsh, and to some degree groundwater, in terms of its present or future beneficial use.

A brief description of the conceptual elements is provide in the following sections.

5.2.1 SWIB borefield

While there are several areas proposed for MAR (Figure 5-1), this assessment focuses on the south-west injection borefield (SWIB) which is permitted to receive saline water of up to 40,000 mg/L.

The SWIB is situated south of the Zulu and Bravo and east of Echo areas on the western perimeter portion of RHIO's mining tenement. The injection bores are on average 70 m deep, targeting the Marra Mamba Formation and potentially the onlapping weathered dolomite aquifer (Figure 5-3).

The borefield has started to receive water from dewatering area and over life of mine it is estimated to receive on average 67 ML/d of surplus dewater, with peaks up to 109 ML/d (Simonic, 2018). In this evaluation the TSF decant component may form up to 20 ML/d of the total injected volume. The SWIB will under this scenario receive a mix of excess dewater and TSF decant water.

5.2.2   Groundwater system - natural regime

The changes to the groundwater system at a regional scale but including the region of MAR were the subject of the life of mine groundwater change assessment (Simonic, 2018), conducted to assess the impacts of dewatering and various MAR areas from mining at Roy Hill. The subsequent sections draw from this assessment. The groundwater system relevant to MAR at SWIB is briefly described as follows:

- The Quaternary and Tertiary sediments which overlie the basement form a surficial (shallow) regional aquifer in the southern part of the Roy Hill tenement and extend further south to the Fortescue Valley. This aquifer extends towards the Fortescue Marsh area which is situated 6 to 7 km south of the SWIB (Figure 5-2).

- Near the surface, and outcropping in the Fortescue valley near the Marsh, permeable silcrete and calcrete, chemically deposited as valley-fill material, is the main host of water (MWH, 2015). Calcrete is known, however, to form several depositional layers which are not contiguous and separated by low permeability lacustrine sediments

- In the SWIB area the combined thickness of Cainozoic sediments is up to 60 m, of which the calcrete/silcrete unit may be up to 30 m thick. Immediately to the west of the SWIB the area is overlain by a large alluvial fan which provides reasonable groundwater storage.

- The Cainozoic sediments are underlain by the mineralised and non-mineralised Namuldi Member of the Marra Mamba Formation which is mined further to the north in the mining pits (Zulu area). The Marra Mamba Formation dips to the south underneath the Wittenoom Formation formed by dolomite which is weathered in its top horizon of 15 to 30 m (Figure 5-3). Further south to the Fortescue Valley the Wittenoom Formation is hydraulically separated from surficial sediments by low permeability clay at the base of the Tertiary detrital sequence (Figure 5-9). In the SWIB borefield however the detrital units are understood to mostly reside directly on the Marra Mamba Formation.

- Natural groundwater flow occurs in a south-westerly direction towards the Fortescue Marsh, under low groundwater flow gradients (approximately 0.5 m groundwater level difference over 1 km) (Figure 5-4).

- The shallowest depth to groundwater (between 2 and 4 m bgl) is encountered within the Fortescue Marsh, and deepens towards the Chichester Range (MWH, 2015). The natural depth to groundwater in the SWIB area varies between 15 to 20 m BGL

- Recharge to groundwater is a function of both rainfall and evaporation. Seasonal rainfall is highly variable, with the majority recharge occurring from cyclonic storm events between December and March.

- Extreme cyclonic rainfall events often over-top existing surface drainage features, evident through the presence of vegetation communities which have historically established on break of slope areas (MWH, 2015). Drainage channels in upland regions of the Fortescue Valley are characterised by small recharge rates. Freshwater recharge via surface water drainage into the marsh area, coupled with cyclonic rainfall events, and subsequent fast evapotranspiration has resulted in the development of a saline groundwater beneath the marsh which extends close to the tenement boundary in the SWIB area..

5.2.3   Groundwater system during mining and post closure

The groundwater system reflective of MAR at SWIB and mining in the Roy Hill tenement is depicted in Figure 5-9. Groundwater flow represents the typical flowpath component of the source-pathway-receptor framework. It is characterised by its continuously changing flow

directions and water levels during mining and after mining ceases. In particular the following changes are material to the change assessment

- Development of a large cone of depression due to dewatering. Due to the removal of over 600 GL of water from groundwater storage during mining a large cone of depression (Simonic, 2018) will develop to the north and east of the SWIB (Figure 5-5). It will function as a large groundwater sink during mining and post closure with flow directions centred towards it until the new equilibrium water levels re-establish. Within the cone of depression flow directions will be changing depending on which part of the mining area is dewatered at a time. Directions towards the cone of depression will also affect transport of contaminants introduced on the periphery or within the cone of depression.

- Under MAR operational conditions, the sustained injection will result in an increase of the groundwater flow gradients in the SWIB area, and a groundwater mound about 7 km long and 3 to 4 km wide is predicted form (Figure 5-5) during re-injection. The mound is predicted to rise over 10 m above the natural groundwater level. It will be partly offset by dewatering which will be occurring up to March 2031 to the north and east of the SWIB (Figure 5-5), while injection will occur within dewatering footprint. During that time the groundwater flow rates will increase due to the temporarily increased groundwater gradient.

- After dewatering and re-injection ceases in 2031, the groundwater level will slowly recover to its new equilibrium ('steady state'). The mound is predicted to recede within several years. During that time it will be absorbed by the footprint of the previously dewatered area. It will take approximately 20 years after closure for groundwater flow from the SWIB area to resume its direction towards the Fortescue Marsh.

5.2.4   Groundwater chemistry

The SWIB area is characterised by TDS (and EC) variations of several orders of magnitude in both lateral and vertical directions (Figure 5-6). In all units TDS generally decreases upgradient from the Fortescue Marsh and towards the Chichester Range.

TDS increase at depth to the south of the tenement is related to the presence of the saline interface extending from the Fortescue Marsh. Samples in the SWIB area from the deepest sampled sections, in the Jeerinah and Wittenoom Formations, have TDS in excess of 100,000 mg/L, while samples from the Nammuldi Member of the Marra Mamba Formation have TDS between 50,000 to 100,000 mg/L (Simonic, 2018).

Shallow horizons (Quaternary sediments) contain relatively fresh groundwater with the majority of samples below 2,000 mg/L, but also samples in the range of 2,000 to 5,000 mg/L. The samples close to the Fortescue Marsh but south of the SWIB, within 2 to 3 km from the marsh, are hypersaline with TDS in excess of 50,000 mg/L. Tertiary detritals show greater variability in salinity and larger concentrations that the Quaternary sediments (Figure 5-6) and vary between less than 2,000 to more than 20,000 mg/L, with a few samples in the 20,000 to 50,000 mg/L range.

Groundwater undergoes hydrogeochemical processes as it moves in a southwesterly direction towards the Fortescue Marsh, predominantly due to mixing with saline, Na-Cl groundwater beneath and fringing the Fortescue Marsh (Figure 5-7). Groundwater begins as predominantly Na-Mg-Cl-SO4, transitioning to Na-Cl type waters closer to the Marsh. The original recharge signature of calcium bicarbonate type is seldom seen in the Roy Hill area.

Hydrochemical composition of major ions of samples in the SWIB and neighbouring areas is suggestive of dominance of sulphate in the mining areas and chloride in areas closer to the

marsh. Sulphate is indicative of oxidation of sulphides, known to be present within the aquifer materials, especially at depth associated with the Jeerinah Formation.

Sulphate and chloride generally exceed bicarbonate concentrations indicating that groundwater collects additional salinity through mixing along its natural flowpath, a process which masks the original recharge, bicarbonate-dominant, signature of these samples. Alluvium samples in the mining area typically have no dominant cations, however sodium is dominant in the samples from the floodplains and marsh areas.

Two distinct groups can be delineated spatially based on dominance of the major ions:

• Mixed hydrochemical signatures in the mining area to be dewatered and/or injected into, with slight dominance of sulphate as major anion and calcium or magnesium as major cations, with possible oxidation of sulphides to sulphates in the deeper sections

• Sulphate reducing redox environment, with chloride being the dominant anion in the Jeerinah Formation

• Sodium chloride signature in areas proximal to the Fortescue Marsh.

Groundwater contains small concentrations of trace metals, however a number of trace metals are in concentrations below their respective detection limits. This suggests that under natural conditions and prevailing neutral pH conditions trace metals present in the groundwater environment are commonly bound to the rock matrix.

Nitrate appears to be ubiquitous in the mining area in elevated concentrations (Figure 5-8). A lower range nitrate concentrations (up to 20 mg/L) is found on the perimeter of the mining tenement while higher nitrate concentrations (20 to 45 mg/L) generally tend to be found closer to the centre axis of the tenement.

Concentrations above 45 mg/L are infrequent and mainly in the centre of the tenement, with an occurrence also in the SWIB.

Nitrate and sulphate concentrations present in the mining tenement indicate the presence of redox zonation with depth. Nitrate is likely to undergo reduction at depth and is used to oxidise sulphide into sulphate which is often the dominant ion in Marra Mamba Formation bores.

Figure 5-1: Key water management areas

Figure 5-2: Surface geology
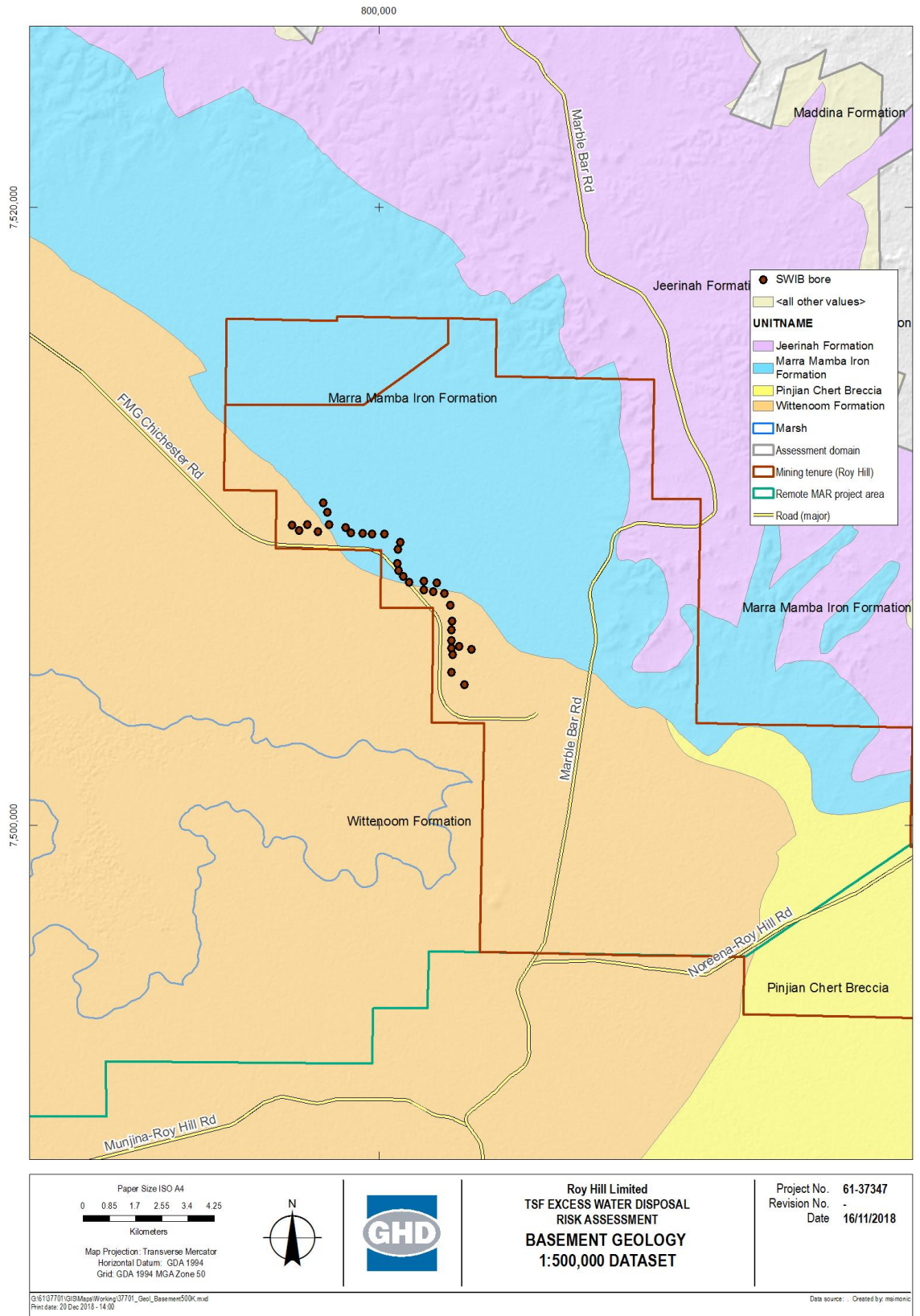
Figure 5-3: Basement geology
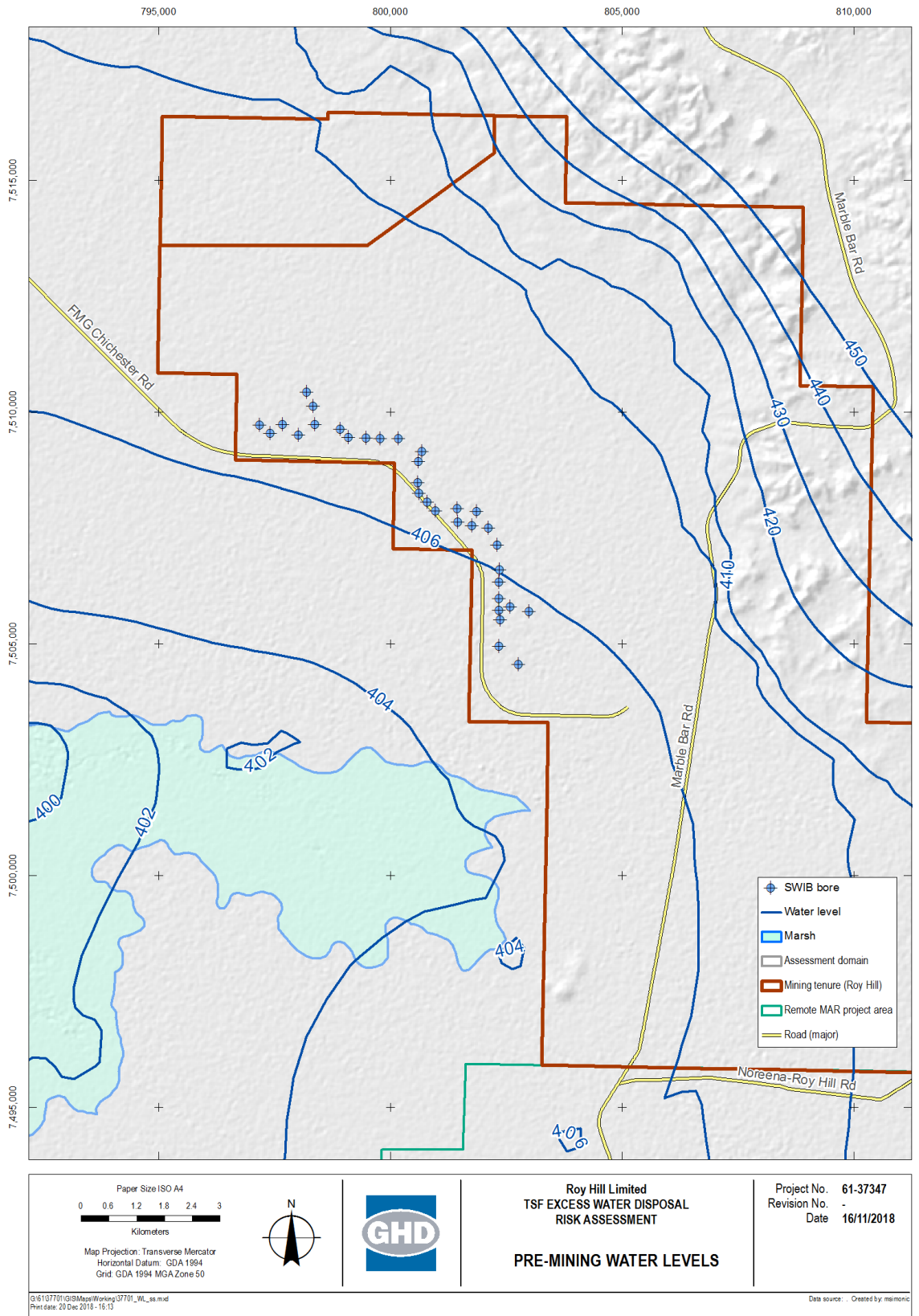
Figure 5-4: Groundwater level, pre-mining, with low flow gradient around SWIB area
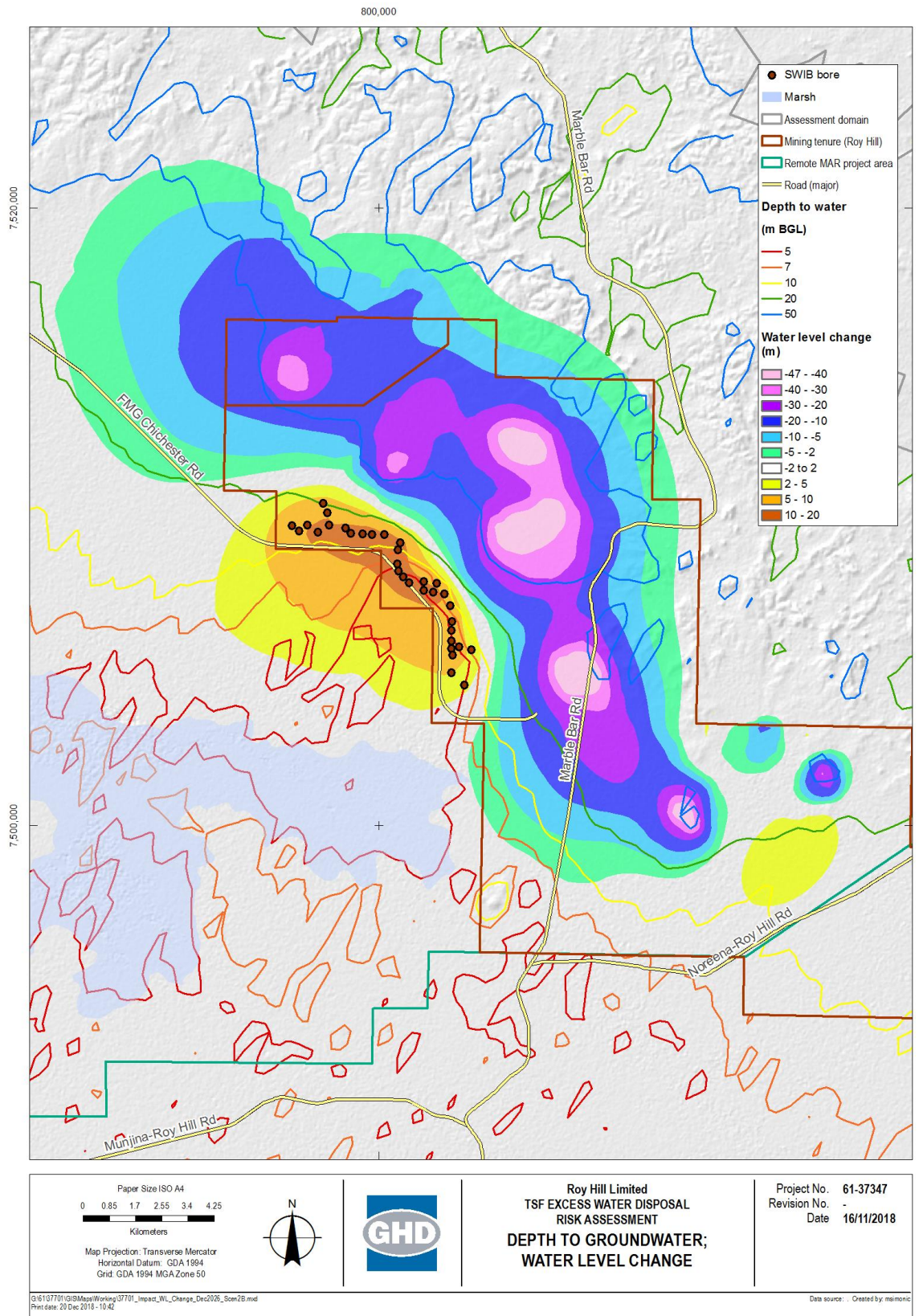
Figure 5-5: Groundwater mounding in SWIB borefield, as predicted for 2026
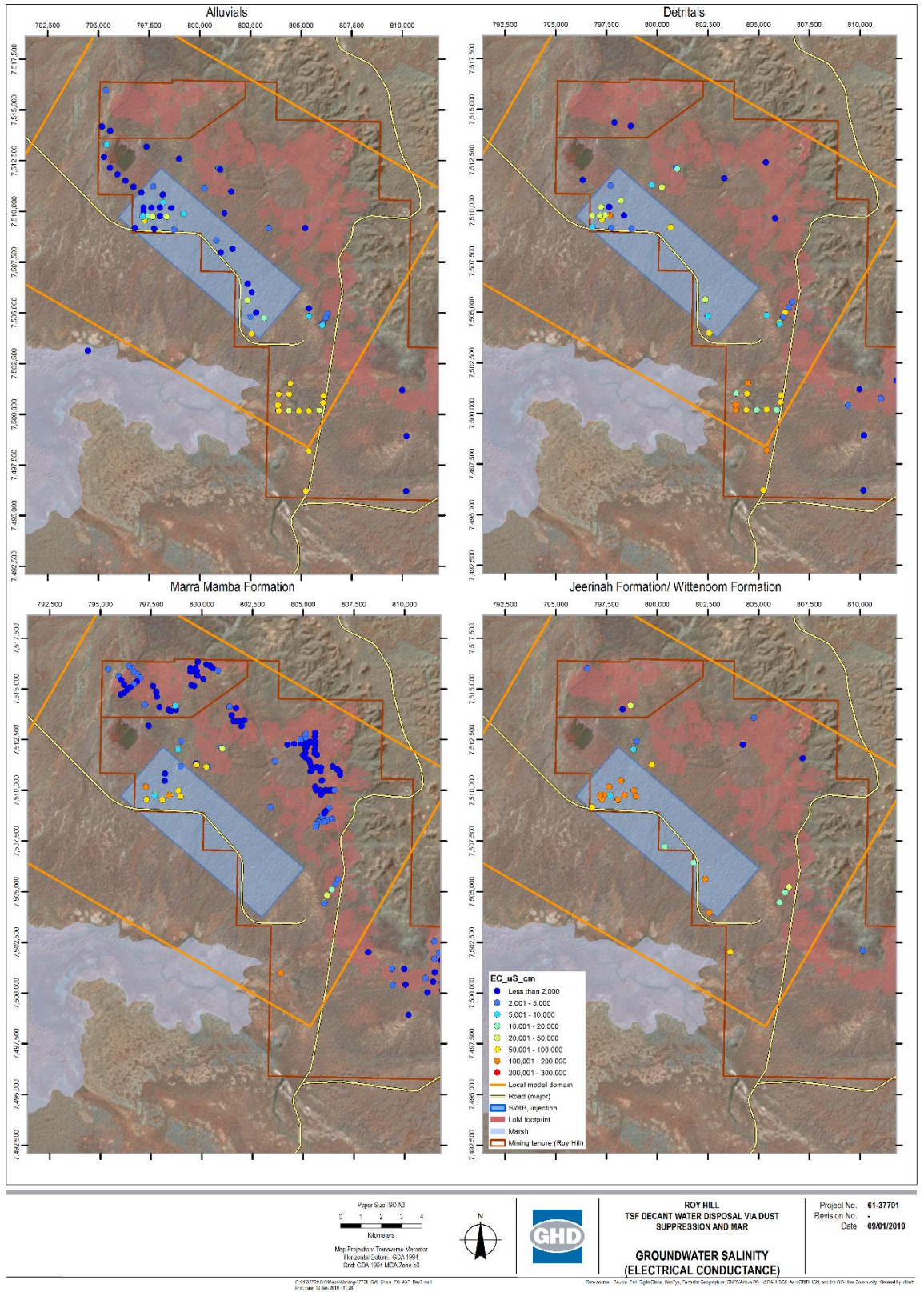
Figure 5-6: Groundwater salinity

Figure 5-7: Major ion chemistry – hydrochemical types
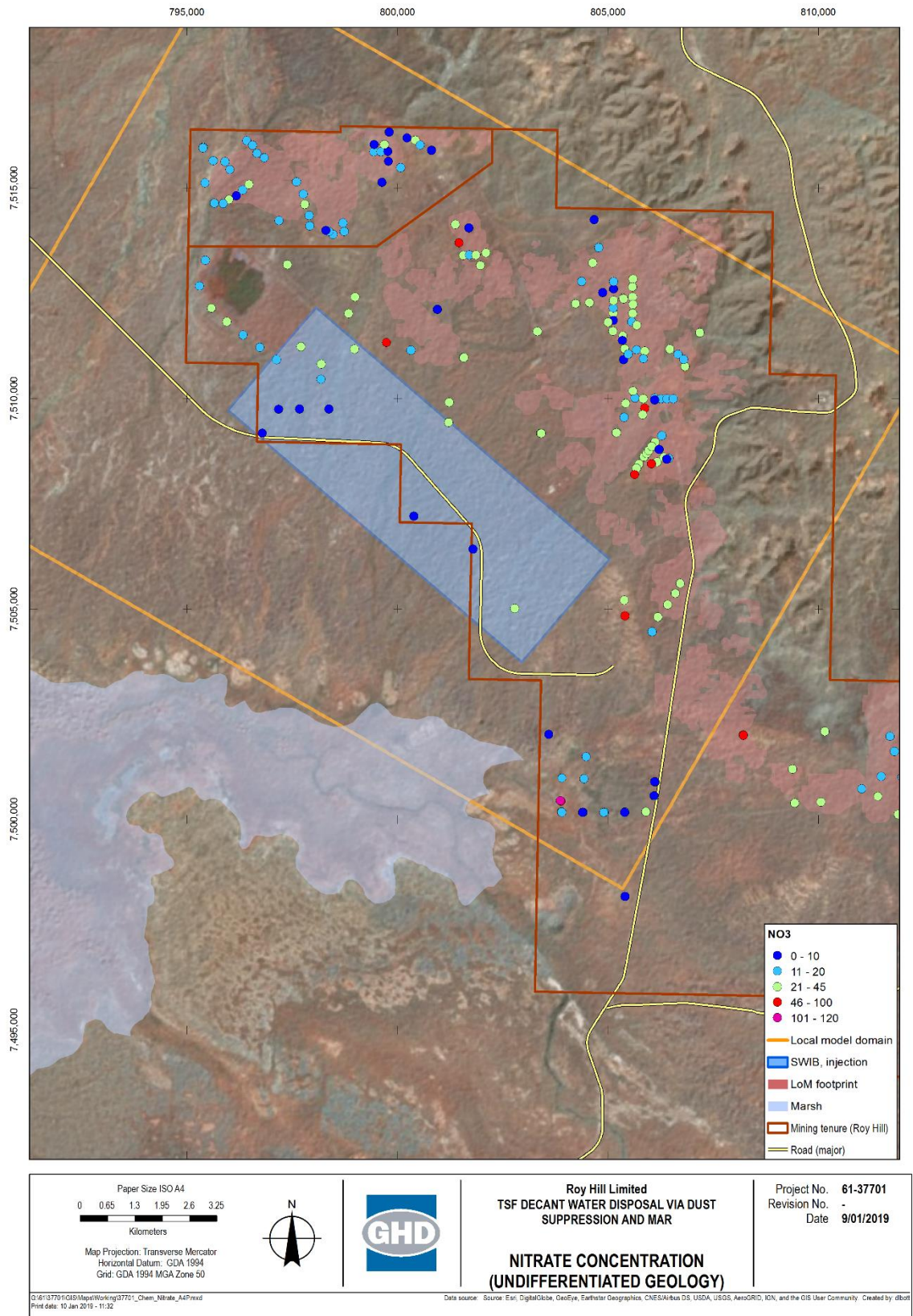
Figure 5-8: Nitrate concentrations in groundwater

5.2.5   Exposure routes

Potential exposure routes are:

● Effects of the change in water quality in the shallow aquifer on phreatophytic and riparian vegetation;

● Mounding (changing groundwater levels) effect on phreatophytic and riparian vegetation within the area of groundwater mounding.

5.2.6   Environmental receptors

Potentially sensitive receptors with regards to MAR in the SWIB are:

● Surficial aquifer – water quality, and effects on vegetation communities in areas with shallow depth to groundwater

● Native and riparian vegetation in the area of developing groundwater mound;

● Fortescue Marsh

The links within the source-pathway-receptor framework are shown in Figure 5-9.
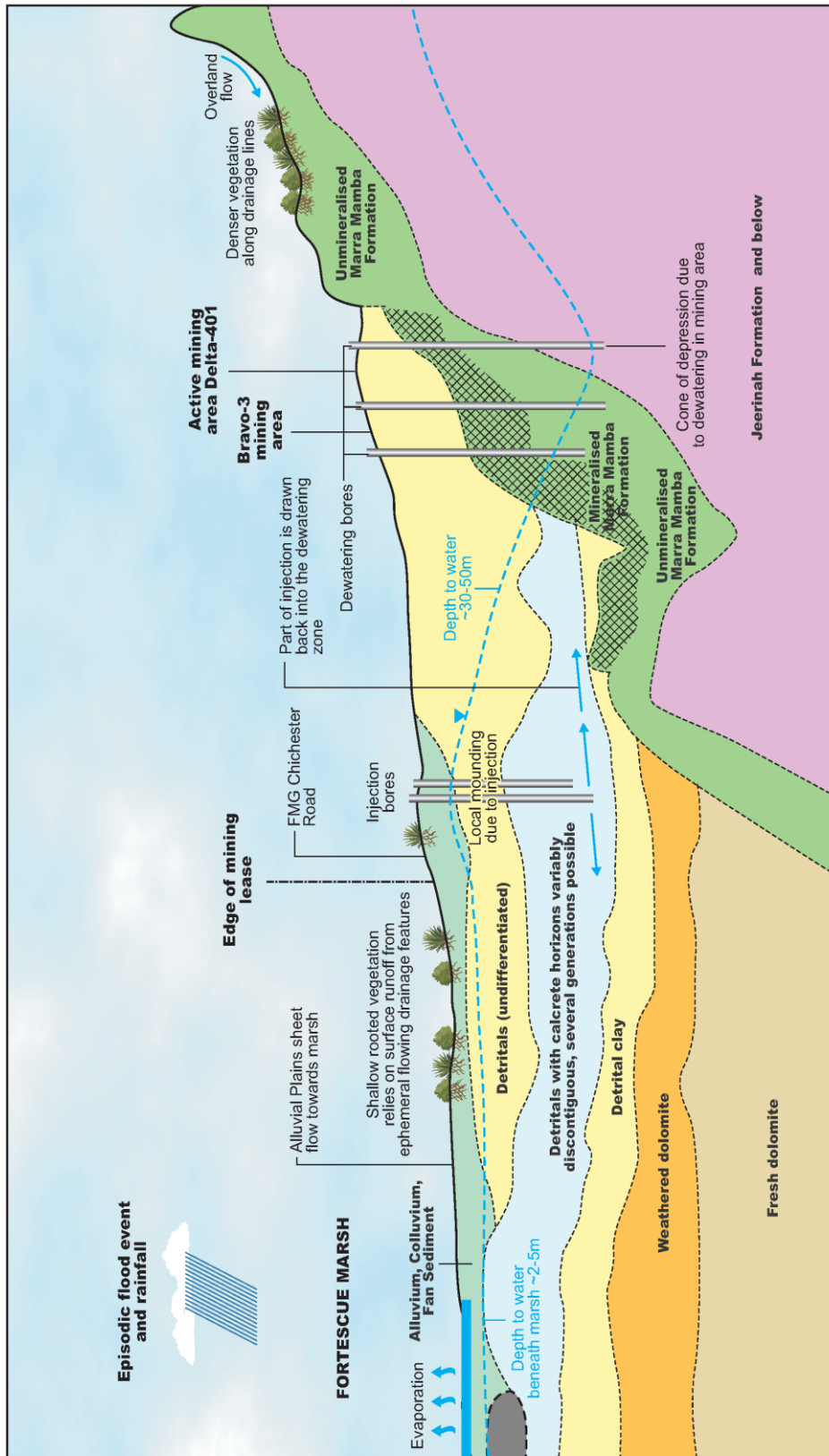
Figure 5-9: Hydrogeological conceptualisation of MAR, and dewatering, and connectivity to the Fortescue Marsh

5.3 Groundwater change assessment

5.3.1 Introduction

The potential changes associated with construction, operation and closure of the MAR in the SWIB area include:

* Changes of groundwater levels around SWIB area due to the injection into the aquifer system. The water levels to the north the SWIB area would be generally depressed due to on-going dewatering. Reinjection (MAR) would create a localised but pronounced mound within the dewatered footprint. Groundwater impact assessment has determined that depressed groundwater levels in the mining area will remain below their pre-mining levels during mining and it would take potentially up to 100 years or more for them to recover to their pre-mining levels. This suggests that significant part of the injected water in the SWIB area will report to the regional drawdown to the north of the SWIB.

* Introduction of solutes, into the groundwater system in the SWIB area.

The change assessment therefore focuses on:

* Change in groundwater levels, in particular depth to groundwater in areas affected by re-injection and whether this occur in environmental receptor areas;

* Change in groundwater quality, in particular selected trace metals and nitrate, and whether these manifest in or have an adverse effect on environmental receptors.

The technical work on depth to groundwater assessment has been done as part of the LoM study (Simonic, 2018) and the results are drawn from it to support this assessment.

Groundwater and supernatant sample are compared to identify potential contaminants of concern. While it is understood the decant water quality has generally lower concentrations than groundwater samples in the target aquifer of the SWIB, there are selected constituents which are elevated above groundwater concentrations.

Numerical transport simulations are performed for selected contaminants of concern and their spatial distribution over time (during mining and post closure) is assessed with respect to their potential effect on environmental receptors.

5.3.2 Predicted change to groundwater levels

Re-injection will cause mounding in the SWIB area. Groundwater level rise may have undesirable effects on some vegetation communities and threshold levels of depth to groundwater are often applied to minimise these effects.

In this case the 5 m depth to groundwater criterion was considered to be the minimum allowable depth and consequently modelled injection rates were optimised to maintain at that level. Optimisation resulted in rate increase or decrease for individual re-injection bores from the average applied rate. In general bores to the north of the SWIB have higher injection rates while bores on the perimeter boundary have lower rates.

The computed/predicted depth to water in the SWIB is shown in Figure 5-10.

While modelling suggests that the threshold depth is achieved in all parts of the modelled domain these would need to be confirmed by on-going water level monitoring. Flexibility in rate adjustment, where necessary, based on the actual water level performance, is likely to be needed.

The modelling results indicate that provided the 5 m threshold is acceptable, MAR operation should not have adverse effects on vegetation communities or the Fortescue Marsh.
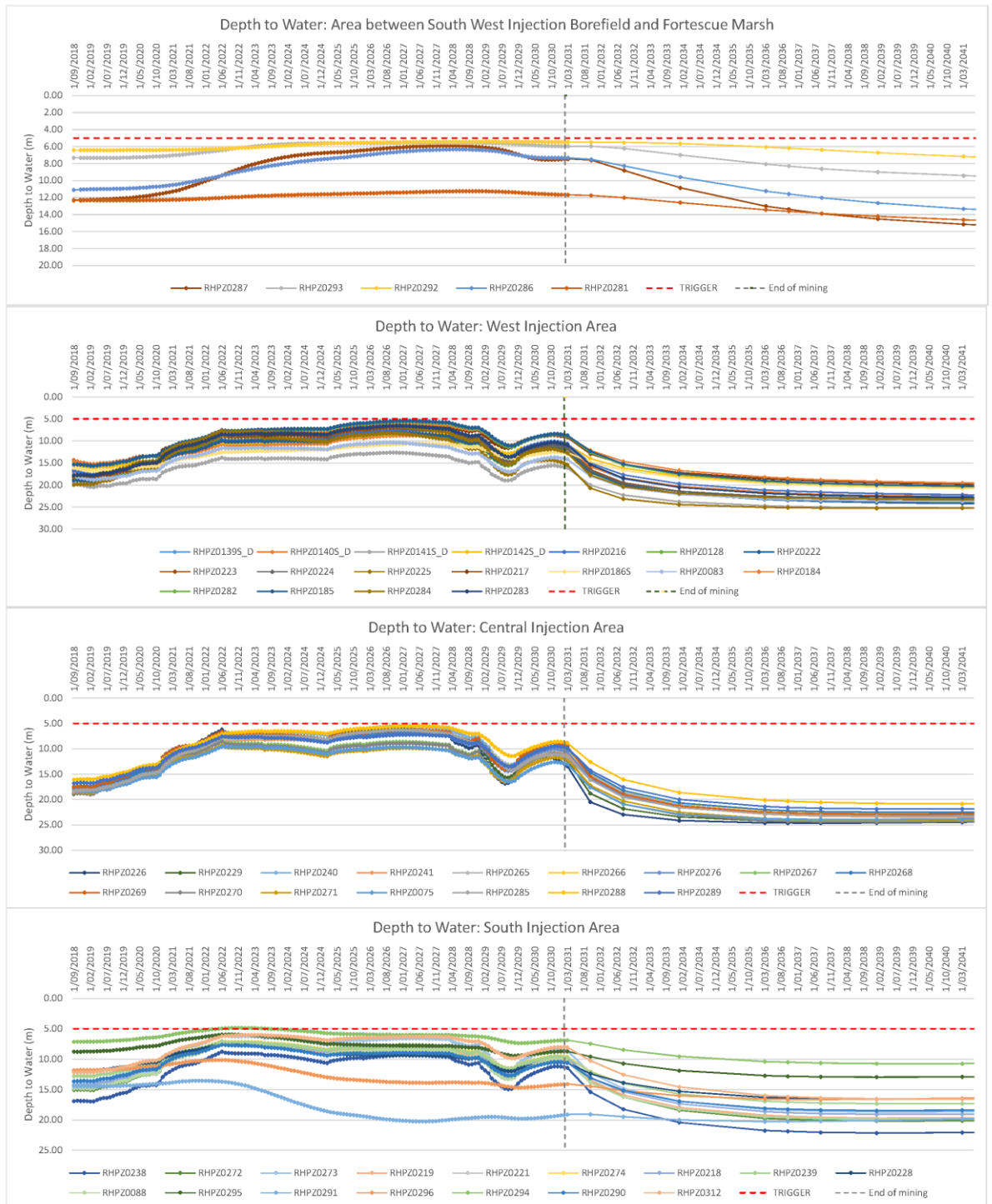
Figure 5-10: Hydrographs of predicted water levels in the SWIB and between SWIB and Fortescue Marsh

5.3.3　Comparison of decant and groundwater quality

A comparison of major ions between the recent AG TSF decant samples and selected bores from the Roy Hill Injection Bore (RHIB) series, is summarised in table 6 below. The RHIB data was sourced from the following bores: RHIB0128, RHIB0129, RHIB0130, RHIB0131, RHIB0236, RHPZ0082, RHPZ2056, RHPZ2373, and RHPZ4782.

Water quality parameters highlighted yellow in table Table 5-1 indicate groundwater concentrations exceeding the maximum median concentrations, while cells highlighted in red indicate decant concentrations which exceed the groundwater concentrations.

Based on the above criteria and highlighting, the following comments can be made regarding the difference between the decant water median values and the existing aquifer water quality:

- The majority of recorded groundwater pH levels are similar to the TSF decant water median pH (7.50);

- The EC of the supernatant (1,886 μS/cm) is an order of magnitude lower than receiving aquifer (18,500 μS/cm);

- Concentrations of major cations and anions are generally lower in the supernatant compared to RHIB groundwater. For instance maximum decant sodium concentration (610 mg/L) is orders of magnitude lower than the maximum groundwater concentration (45,000 mg/L);

- Concentrations of trace elements in the supernatant, with exception of selenium and chromium, are generally lower than in groundwater in the RHIB area, with a number of measured trace metals consistently below the detection limit;

- Nitrate nitrogen median concentration exceeds groundwater concentrations.

Chromium, selenium and nitrate will be further assessed in the following sections as proxies for other potentially similar CoCs.

Table 5-1: Comparison of decant water quality and groundwater quality in SWIB

Sample ID (Constituent)	Unit	Count	Minimum	Maximum	Mean	% of Samples BDL	Median	RHIB0128	RHIB0129	RHIB0130	RHIB0131	RHIB0236	RHP20082	RHP22056	RHP22373	RHP24782
								Decant water →				Groundwater - RHIB Area →				
EC	[µS/cm]	50	3900	6800	4974	0%	4,600	130,000	150,000	160,000	150,000	51,000	520	63,000	22,000	18,000
pH	none	50	7.6	8.1	7.75	0%	7.7	7.1	7.0	7.1	6.9	7.4	7.7	7.7	7.7	8
TDS	[mg/L]	50	2700	5200	3742	0%	3,350	110,000	120,000	140,000	120,000	36,000	360	47,000	14,000	11,000
Hardness	[mg/L]	50	1400	2900	1980	0%	1,800	15,000	17,000	18,000	17,000	8,600	200	8,000	1,900	1800
TSS	[mg/L]	50	5	49	9.66	42%	10	2,300	760	460	860	10.00	520	30	95	1,100
Aluminium	[mg/L]	50	0.005	0.01	0.0051	100%	BDL	<0.25	<0.25	<0.5	<0.25	<0.05	0.024	<0.1	<0.025	<0.025
Arsenic	[mg/L]	50	0.001	0.002	0.001	96%	0.001	<0.05	<0.05	<0.1	<0.05	<0.01	0.001	<0.02	<0.005	<0.005
Barium	[mg/L]	50	0.018	0.04	0.029	0%	0.029	<0.05	<0.05	<0.1	<0.05	<0.01	0.048	0.03	0.029	0.028
Beryllium	[mg/L]	50	0.001	0.002	0.001	100%	BDL	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Bicarbonate	[mg/L]	50	86	110	98.88	0%	98	260	220	260	250	170	180	220	170	190
Boron	[mg/L]	50	0.15	1.200	0.51	0%	0.41	3.2	5.5	5.6	4.6	0.39	0.28	3.1	0.73	0.84
Cadmium	[mg/L]	50	0.0001	0.0002	0.0001	100%	BDL	<0.005	<0.005	<0.01	<0.005	<0.001	<0.0001	<0.002	<0.0005	<0.0005
Calcium	[mg/L]	50	330	680	459.6	0%	430	610	630	530	620	1100	45	510	210	200
Carbonate	[mg/L]	50	1	5	1.16	100%	BDL	1	1	1	1	1	1	1	1	1
Chloride	[mg/L]	50	630	1300	897	0%	880	57,000	65,000	73,000	63,000	17,000	28	22,000	6,800	5,400
Chromium	[mg/L]	50	0.034	0.14	0.071	0%	0.05	<0.05	<0.05	<0.1	<0.05	0.025	0.004	<0.02	0.006	0.009
Cobalt	[mg/L]	50	0.001	0.002	0.001	100%	BDL	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Copper	[mg/L]	50	0.001	0.002	0.001	98%	0.001	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Hydroxide	[mg/L]	2	5	5	5	100%	BDL									
Iron	[mg/L]	50	0.005	0.046	0.0065	92%	0.02	<0.25	0.54	<0.5	2.8	<0.05	0.039	<0.1	<0.025	<0.025
Lead	[mg/L]	50	0.001	0.002	0.001	98%	0.002	<0.4	<0.4	<0.4	<0.4	<0.01	<0.001	<0.02	<0.02	<0.005
Magnesium	[mg/L]	50	140	300	204.2	0%	185	3300	3800	4000	3700	1400	22	1600	340	320
Manganese	[mg/L]	50	0.001	0.006	0.0015	62%	0.002	0.73	10	1.9	5.1	<0.01	<0.001	<0.02	0.17	<0.005
Molybdenum	[mg/L]	50	0.001	0.004	0.002	36%	0.002	<0.05	<0.05	<0.1	<0.05	<0.01	0.001	<0.02	<0.005	<0.005
Nickel	[mg/L]	50	0.001	0.002	0.001	30%	0.001	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Nitrate (NO3)	[mg/L]	48	1.5	360	193.14	0%	190									
Nitrate Nitrogen (NO3)	[mg/L]	22	18	81	48.73	0%	45.5	2.6	1.2	15	1.2		39	8.3	15	21
Nitrite (NO2)	[mg/L]	46	0.05	4.8	0.83	48%	1.8							<0.05	<0.05	<0.05
Nitrite Nitrogen (NO2)	[mg/L]	22	0.05	1.5	0.20	54%	0.11						<0.05			
Nitrogen (NOx)	[mg/L]	24	18	81	47.29	0%	45.5						1.80	8.7		
Phosphorus	[mg/L]	50	0.05	0.050	0.05	100%	BDL						0.1	<0.25		<0.05
Potassium	[mg/L]	50	25	56.000	36.98	0%	33	2400	2800	2800	2700	440	5	800	210	250
Selenium	[mg/L]	50	0.012	0.041	0.02	0%	0.019	<0.05	<0.05	<0.1	<0.05	<0.01	0.003	<0.02	<0.01	<0.005
Silicon	[mg/L]	50	19	38	23.94	0%	23	11	10	7	10	18	33	20	15	14
Silver	[mg/L]	50	0.001	0.002	0.001	98%	0.001	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Sodium	[mg/L]	50	320	610	430.2	0%	410	39,000	45,000	45,000	45,000	6,800	19	13,000	3,100	3,300
Strontium	[mg/L]	50	1	3	1.62	0%	1.5	10	13	12	12	5.4	0.1	4.6	1	1.0
Sulphate	[mg/L]	50	930	2300	1409	0%	1,300	19,000	22,000	25,000	22,000	5,400	43	7,800	2,300	1,600
Sulphur	[mg/L]	50	290	810	497.8	0%	430	8,500	8,700	8,300	8,900	2,000	14	2,900	540	2,300
Thallium	[mg/L]	50	0.001	0.002	0.001	100%	BDL	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Tin	[mg/L]	50	0.001	0.002	0.001	100%	BDL	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Titanium	[mg/L]	50	0.001	0.002	0.001	94%	0.001	<0.05	<0.05	<0.1	<0.05	<0.01	<0.001	<0.02	<0.005	<0.005
Total Alkalinity	[mg/L]	50	71	93	81.16	0%	80.5	210	180	220	200	140	150	180	140	150
Total Iron	[mg/L]	50	0.03	6	0.43	0%	0.1						22			
TKN	[mg/L]	20	0.05	0.34	0.08	24%	0.08						3			
Total Nitrogen	[mg/L]	46	0.35	81	43.62	0%	42.5							2.4	3.5	5.3
Vanadium	[mg/L]	50	0.001	0.003	0.0011	72%	0.001	<0.05	<0.05	<0.1	<0.05	<0.01	0.004	<0.02	<0.005	<0.005
Zinc	[mg/L]	50	0.005	0.078	0.007	78%	0.008	<0.25	<0.25	<0.5	<0.25	<0.05	<0.005	<0.1	<0.025	<0.025

exceeding groundwater concentrations
exceeding decant median concentrations
no data available

5.3.4 Solute transport model

An indicative assessment of the concentration change associated with MAR into the SWIB at current decant concentrations can be presented using the existing life of mine assessment model developed for evaluating the changes in the aquifer system associated with dewatering and managed aquifer recharge.

The life of mine (LoM) groundwater impact assessment of Roy Hill mining operation using the LoM July 2018 plan has been prepared using a recently developed numerical modelling tool at a sub-regional to regional scale. A MODFLOW model covering an area of over 4,600 km^2, with 1,109,685 active square cells, each 250 m, in 15 layers informed by Leapfrog geological model, simulated the groundwater levels changes and groundwater flows associated with dewatering, reinjection of dewater into the aquifer system (MAR) and additional groundwater abstraction in the remote borefield (Stage 2 borefield).

This regional model includes the area of the Fortescue Marsh, and one of the advantages of the existing LoM model is the explicit derivation of cumulative and transient groundwater level and flow change associated with mining and MAR over and outside of the mining footprint.

A subdomain of the LoM model was adapted to support these additional assessment needs.

A strip approximately 11 km wide (east-west) and 17.5 km long (north-south) was adopted from the LoM model and set up as an assessment model for this project (Figure 5-11) (further referred to as MAR submodel). The grid spacing in the MAR submodel was enhanced from 250 m to 100 m to better discretise the local area and provide better resolution to contaminant transport modelling.

The subdomain model boundaries are set as fixed head boundaries with water level information taken at monthly time step during LoM from the regional model, to fully include concurrent and cumulative impacts from dewatering and MAR. In that way the MAR submodel retains information from the overall mining which are effected beyond the boundaries of the strip model but their effect is carried by groundwater heads regionally.

The input decant concentrations simulated in the reinjected water to the SWIB were derived from the GOLDSIM model (Yoong, 2018). Simulated decant concentrations increase during the operational period of 2018 to 2031 as follows:

- Chromium: from 0.05 to 0.100 mg/L

- Selenium: from to 0.02 to 0.04 mg/L

- Nitrate: from 115 to 240 mg/L

Input decant concentrations in injected water were 'diluted' when injected rates were above 20 ML/d. When injected rates were below 20 ML/d, it was assumed all injectant came from decant and full undiluted decant concentrations were assumed. The decant concentration values increase by a factor of 2 between 2018 and 2031.

Concentrations contours, reflective of conservative advection and dispersion were computed using the MAR submodel.

5.3.5 Reactive transport considerations

Trace metals and nitrate are known to undergo reactive changes in the aquifer system given to complex reactions of solution and precipitation in response to pH and redox condition changes. In particular redox changes are assumed to be driving the reactive nature of transport of metals and nitrate in the aquifer system.

Changing the balance between sources (injected) water and natural (aquifer) water can contribute to chemical reactions within the aquifer. Some examples of possible major ion disruptions include:

- Solubility of the input parameters given the receiving environment conditions (i.e. pH and EC of aquifer),
- Dissolution of carbonate minerals,
- Mineral dissolution, if occurring, can increase hardness,
- Anaerobic zone can develop around the injection well (leading to dissolution of iron),
- Aerobic zone can develop around the injection well (leading to precipitation of some metals, e.g. iron)
- Metals will often accumulate near the point of injection.

The potential processes contributing to groundwater / injected decant mix / aquifer matrix interaction and reactivity were examined using equilibrium PHREEQC2 simulations. These simulations assume simple mixing between the supernatant and groundwater at differing proportions, i.e. the supernatant forming 10%, 20%, 30%, 50%, and 70% of the mixed sample. The reactivity in this simple model is indicated by the changes in saturation indices for the major rock-forming minerals.

The following reactive changes are indicated by PHREEQC2 simulations:

- Solubility of carbonate minerals will be affected only slightly. Introduction of supernatant leads to small dissolution of calcite and dolomite from the aquifer matrix, however it will remain close to solubility limits also reflected in a very small change in partial pCO_2;
- Groundwater will remain saturated with respect to iron oxides and hydro-oxides, i.e any input iron will tend to precipitate out of groundwater irrespective of prevailing proportion mix. This is important for transport of trace metals as they too, tend to co-precipitate with ferrous and ferric hydro-oxides;
- Introduction of decant will tend to precipitate chromium in areas where proportion of supernatant will be more than 50%, in natural groundwater Cr minerals are indicated to be undersaturated.
- Introduction of supernatant may promote a decrease in dissolution of silica minerals.

The rate of solute removal from groundwater, referred to as attenuation rate, includes a number The rate of solute removal from groundwater, referred to as attenuation rate, includes a number of reactions, some of which can be microbially mediated, including co-precipitation with other minerals in particular iron and carbonate minerals, sorption on mineral surface (in particular clay minerals), precipitation due to pH and redox conditions, oxidation and reduction and others.

Attenuation rates are usually derived from kinetic testing, from well-instrumented field data often followed and confirmed by subsequent fitting using numerical transport models. Since such data is not available for this study, literature values were collated and used in this assessment.

A generally lower range of attenuation rates collated from literature was used partly to account for site differences, scale from lab to field conditions (where applicable) but mainly to maintain the degree of conservatism and caution. Attenuation factors are assumed to account, as lump parameters, for all key processes leading to removal of solutes from groundwater. As a consequence distribution coefficients were not used in this study, since sorption of Cr and Se may not be as important due to its preferred speciation into anions for neutral pH conditions

The following attenuation values are used in this study:

Table 5-2: Attenuation rates applied in transport modelling

Constituent	Low range from literature	Mean range from literature	Adopted in this study	Source
Chromium	0.297 yr^{-1}	0.693 yr^{-1}	0.297 yr^{-1}	Truex et al, 2015; Harwood, 2016
Selenium	0.365 yr^{-1}	2.6 yr^{-1}	0.365 yr^{-1}	Schultz et al, 2018, Bailey et al, 2013
Nitrate	0.07 yr^{-1}	0.7 yr^{-1}	0.07 / 0.7 yr^{-1}	Lee at al, 2006; Shultz et al 2018, Bailey et al, 2013; Carroll et al, 2009

Advective-dispersive flux is modelled with longitudinal dispersivity value of 30 m, consistent with Xu and Eckstein (1995). Transversal and vertical values of dispersivity tensor are set at 0.1 and 0.01 of longitudinal value, respectively.
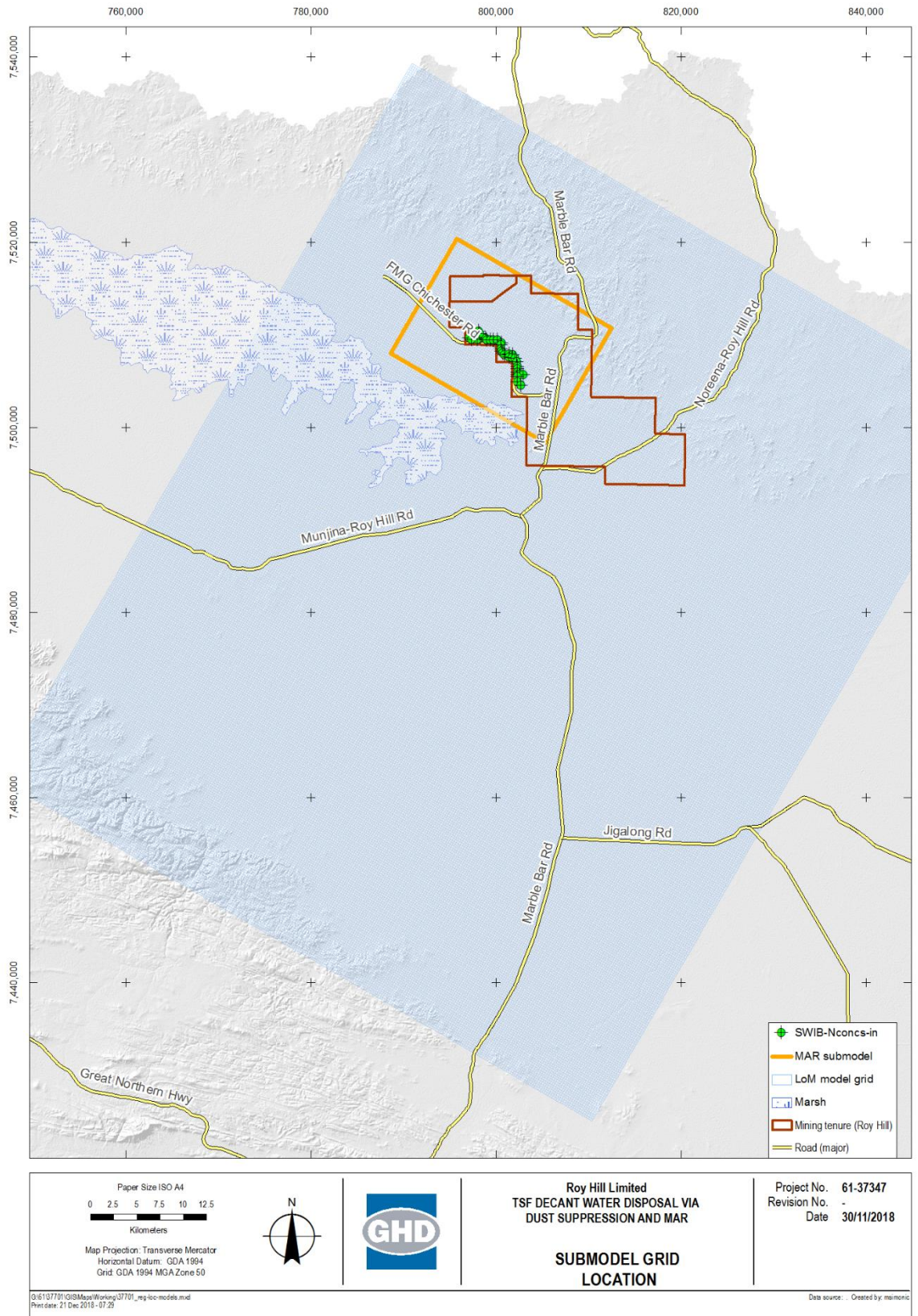
Figure 5-11: Location of model domains, LoM model and MAR submodel

5.3.6   Predicted changes to Se concentrations

Selenium naturally exists in different oxidation states, including oxyanions selenate and selenite, reduced selenium (selenide) and elemental selenium. Selenate and selenite oxyanions, common in oxic environments are the most mobile and toxic of selenium species. The presence of aluminium and iron species in the solid phase may result in substantially higher Se sorption on e.g. FeO(OH). Decreased Se mobility is favoured in a reducing environment.

Injection of excess decant water will take place at depth, into Marra Mamba Formation and the overlying detritals. While conditions at depth may be reducing shallow groundwater is likely to be oxic and within normal pH range with low impact on reducing Se mobility. The majority of Se load will be injected at depth and only part of it will eventually migrate to the shallower sections of the aquifer system.

The ANZECC trigger values of Se for health and stock purposes are 0.01 and 0.02 mg/L, while 95% ecological trigger level is 0.011 mg/L. Background groundwater concentrations are below detection limit, and consequently assumed to be also below the trigger levels.

The modelled Se concentrations are presented in a series of maps of contours in Figure 5-9. The contour maps (Figure 5-12) are presented for year 2023, 2027, 2031, 2032 and 2033 covering the mining operation and three years after (selenium concentrations are predicted to be negligible afterwards).

Development of Se concentrations as a result of MAR in the SWIB can be characterised as follows:

- Injection of supernatant will result in a Se plume around the SWIB with the majority of its footprint in the tenement in the direction of Bravo section, up to 8 km long and 3 km wide. The extent of the plume south of the tenement boundary will be limited to a maximum of few hundred metres.

- The stabilisation of the plume in the mining area will be driven by an on-going dewatering during mining and the presence of depressed water level in the mining footprint during closure.

- The highest Se concentrations in groundwater at the end of mining will fall in the range of 0.005 mg/L to 0.01 mg/L.

- The period of closure shows a gradual and relatively rapid dissipation of the se plume. The plume will disappear within several years after closure without migrating towards the Fortescue Marsh.

- Considering the ANZECC trigger levels (0.01 mg/L) Se groundwater concentrations are predicted to remain within the threshold values.

5.3.7   Predicted changes to chromium concentrations

Chromium is found in the environment primarily in +3 and +6 oxidation states. The geochemical behaviour and biological toxicity of chromium in these two oxidation states are profoundly different. Hexavalent (+6) chromium tends to be soluble, forms anions or neutral dissolved species, can be mobile and is acutely toxic. In contrast trivalent chromium (+3) tends to precipitate, forms cationic dissolved species and is immobile under moderately alkaline to slightly acidic conditions and is relatively non-toxic.

As with other metals chromium, especially trivalent species, can coprecipitate with iron oxides and hydroxo-oxides and concentrations of Cr are typically controlled by dissolution/precipitation reactions. Increasing pH decreases adsorption of Cr(+6) on minerals and the redox state also affects chromium adsorption. Mn oxides oxidise trivalent Cr into hexavalent and reduces

adsorption of chromium. The transport of chromium was therefore modelled as reactive, with a low-end attenuation rate.

The ANZECC trigger values of Cr for health and stock purposes are 0.05 and 0.1 mg/L, respectively, while 95% ecological trigger level is 0.0004 mg/L. Background groundwater concentrations SWIB bores are 0.004 to 0.025 mg/L (where detected), and consequently below the trigger levels, however that is not the case for the ecological trigger level. Values reported from groundwater and supernatant monitoring do not distinguish between the different valency states of Cr, they are understood to be representative of total chromium.

Evolution of the modelled modelled Cr plume is similar to that of selenium, excpt the extent of the plume is predicted to be slightly larger presumably due to the lower attenuation rate. The contour maps are presented for years 2021, 2023, 2025, 2027, 2029 and 2031, at the end of mining; and years 2032, 2033, 2034 and 2035 post closure. These results are shown in Figure 5-13, and Figure 5-14, respectively.

- The predicted Cr concentrations will reach 0.02 mg/L within the mining area around the injection points by the time the mining operations ceases. The majority of the plume will be situated within the mining area with margins of the plume stretching to the south, to a distance of up to 1 km from the tenement boundary.

- After closure the plume will remain in place due to the on-going drawdown effect of mining and will gradually shrink both in are and concentration. It is predicted to not migrate south within its lifespan, since the plume will effectively disappear after 2035.

5.3.8   Predicted changes to nitrate concentrations

Nitrogen species in groundwater include several forms of which nitrate is the most table and of concern to regulatory agencies. Since this form of nitrogen is in anionic form it is readily transported in groundwater and stable over a considerable range of conditions. Nitrogen forms are affected by redox conditions and bacterial activity which can lead to denitrification if there is suitable source of organic carbon.

In contrast with chromium and selenium which are generally below detection limit in groundwater in the mining tenement there are already appreciable background concentrations of nitrate in groundwater in the broader area of the mining tenement. These vary up to 120 mg/L of nitrate but are generally between 20 to 40 mg/L.

The ANZECC trigger values of nitrate for health and stock purposes are 50 and 90 mg/L, respectively while 95% ecological trigger level is 0.7 mg/L, the value which is clearly not feasible in the current environment.

The estimated concentration contours obtained from the transport model represent additional concentrations to already existing background concentrations. Nitrate transport is modelled using the lower and mid-range attenuation rate values.

The low range of attenuation rate results in an extensive plume (Figure 5-15) developed around the injection mound by 2031, at the end of mining. At this stage the plume will be 13 km long and 7 to 8 km wide, extending up to 3 km south of the tenement boundary. At its closest point to the marsh the plume edge will be approximately 1 km away from the marsh. The maximum concentrations will in the range of 20 to 50 mg/L, although this range would be limited largely to the mining tenement. The key part of the plume will remain within the mining tenement due to the flow directions exerted by dewatering.

After re-injection ceases in 2031 the plume will start to slowly dissipate (Figure 5-16). In the first ten years dissipation would be driven mainly by decreasing concentrations, after 2041 the plume will also shrink in area until it is predicted to disappear after 2071.

The mid-range attenuation rate results in a relatively compact plume (Figure 5-17), similar in area to chromium, with maximum concentrations just over 20 mg/L N, at the end of mining operation in 2031. The plume will dissipate rapidly by 2035 without effectively migrating beyond the tenement boundary.

5.3.9   Other potential contaminants

The groundwater transport patterns of other potential contaminants, especially metals is estimated to be similar to those modelled. The prevailing groundwater flow gradients due to dewatering during mining and slow rebound after closure are likely to control the plume of any generic solute within the mining tenement. Reactive processes typical for the majority of trace metals and the availability of reactive surfaces and minerals, and redox conditions at the site, are likely to result in removal of trace metals from groundwater.

5.3.10   Contaminant migration from MAR – concluding statement

This preliminary assessment suggests that the concentration increase in these three selected constituents over LoM and post closure will be contained within the mining tenement and is considered of low or negligible risk to areas outside of the mining tenement. Furthermore, other processes affecting the solute transport in the aquifer may lead to additional decrease in concentrations.

5.3.11   Limitations of contaminant transport estimates

The transport simulations are built around several important assumptions which would need to be confirmed by on-going monitoring and/or other investigation work. In particular, input concentration rates and attenuation parameters would need additional confirmation. The existing values were based on relatively conservative low ranges from literature sources, but site-specific data would be of value to this assessment.

It is proposed to instrument and set up a monitoring program which would be used to confirm or update the fate and transport of contaminants assessed in this study.
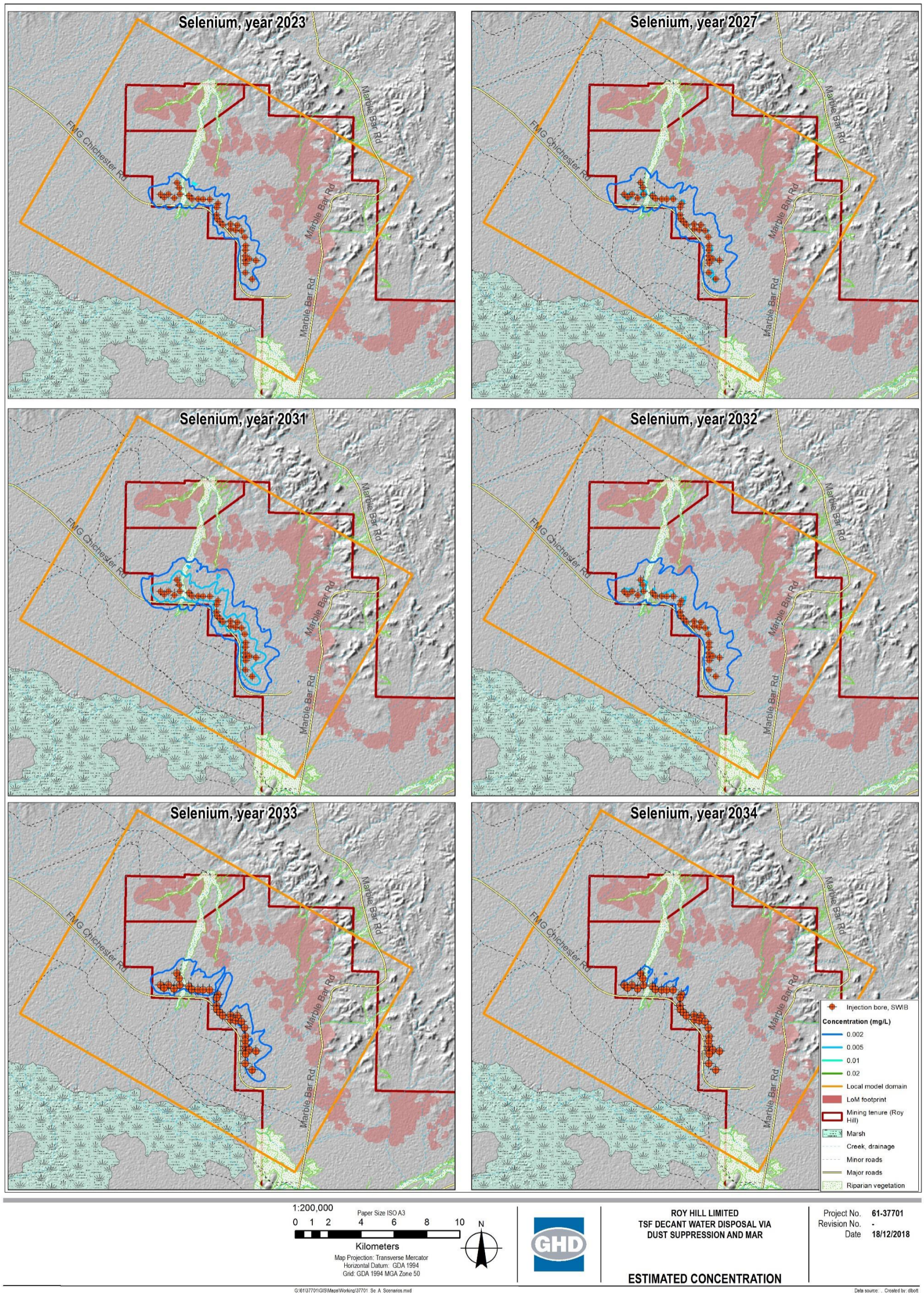
Figure 5-12: Estimated selenium concentrations during and after mining
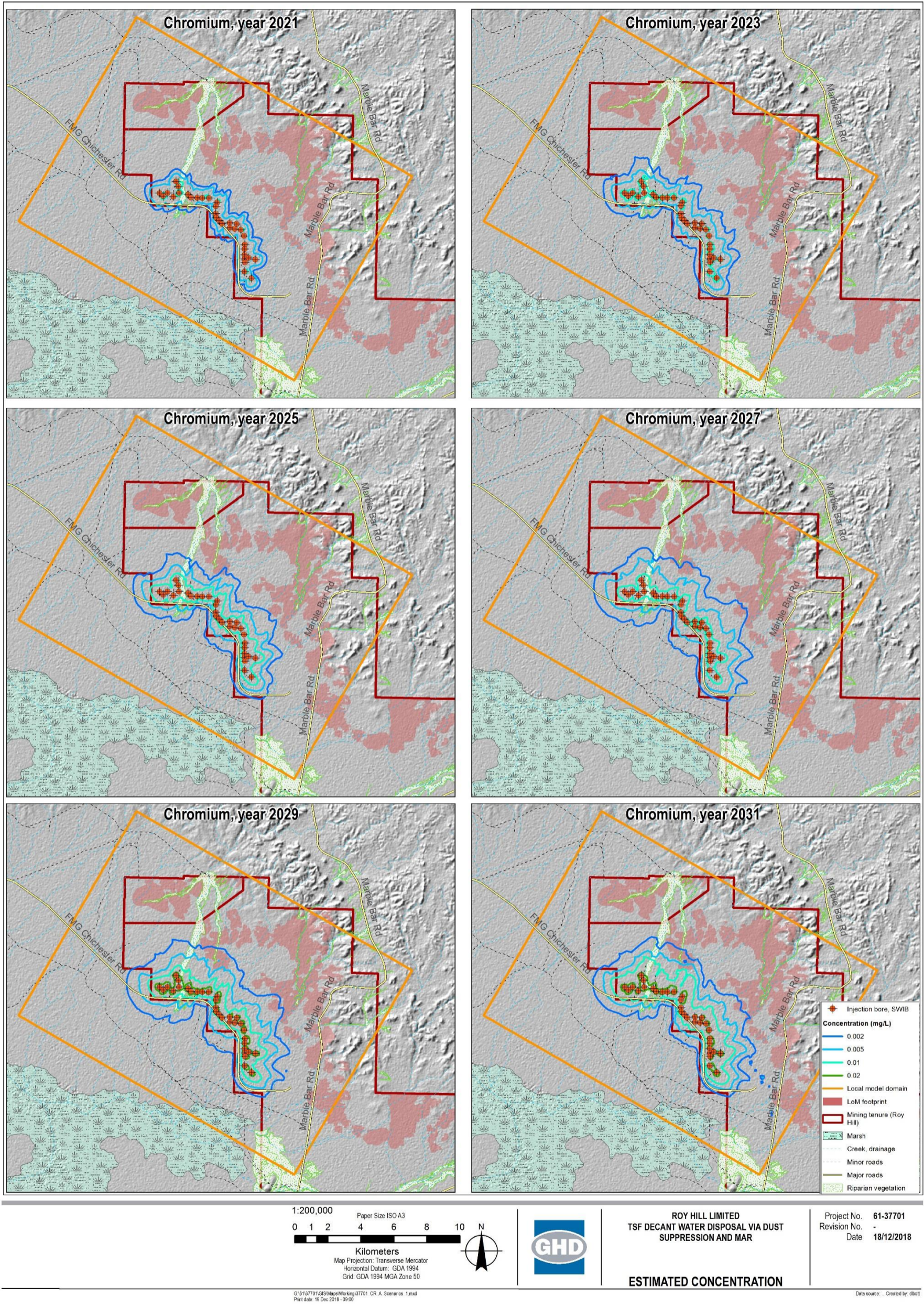
Figure 5-13: Estimated chromium concentrations during mining
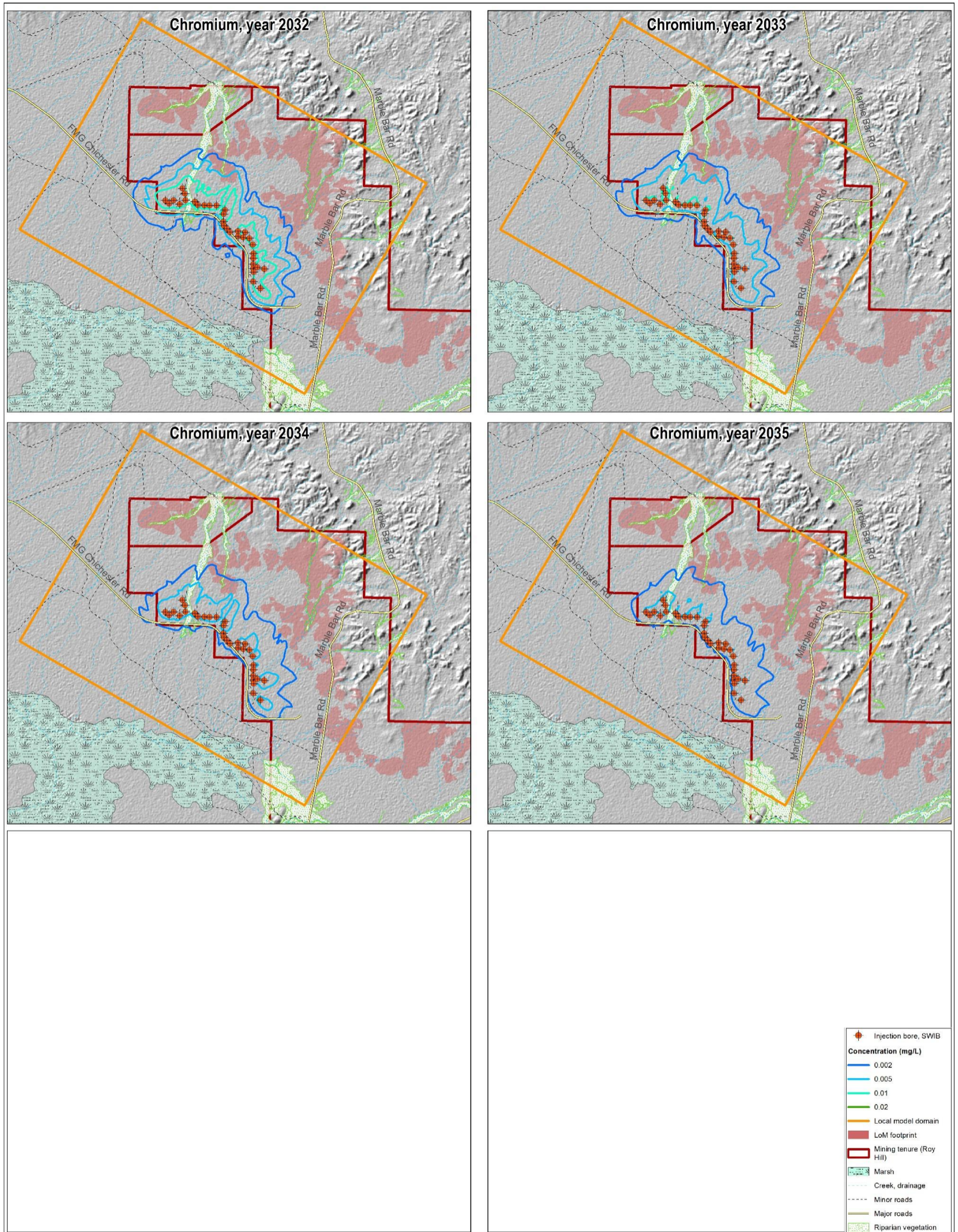
Figure 5-14: Estimated chromium concentrations, after injection ceases
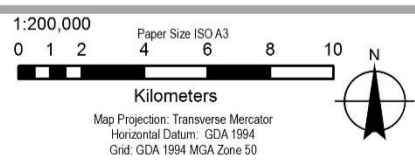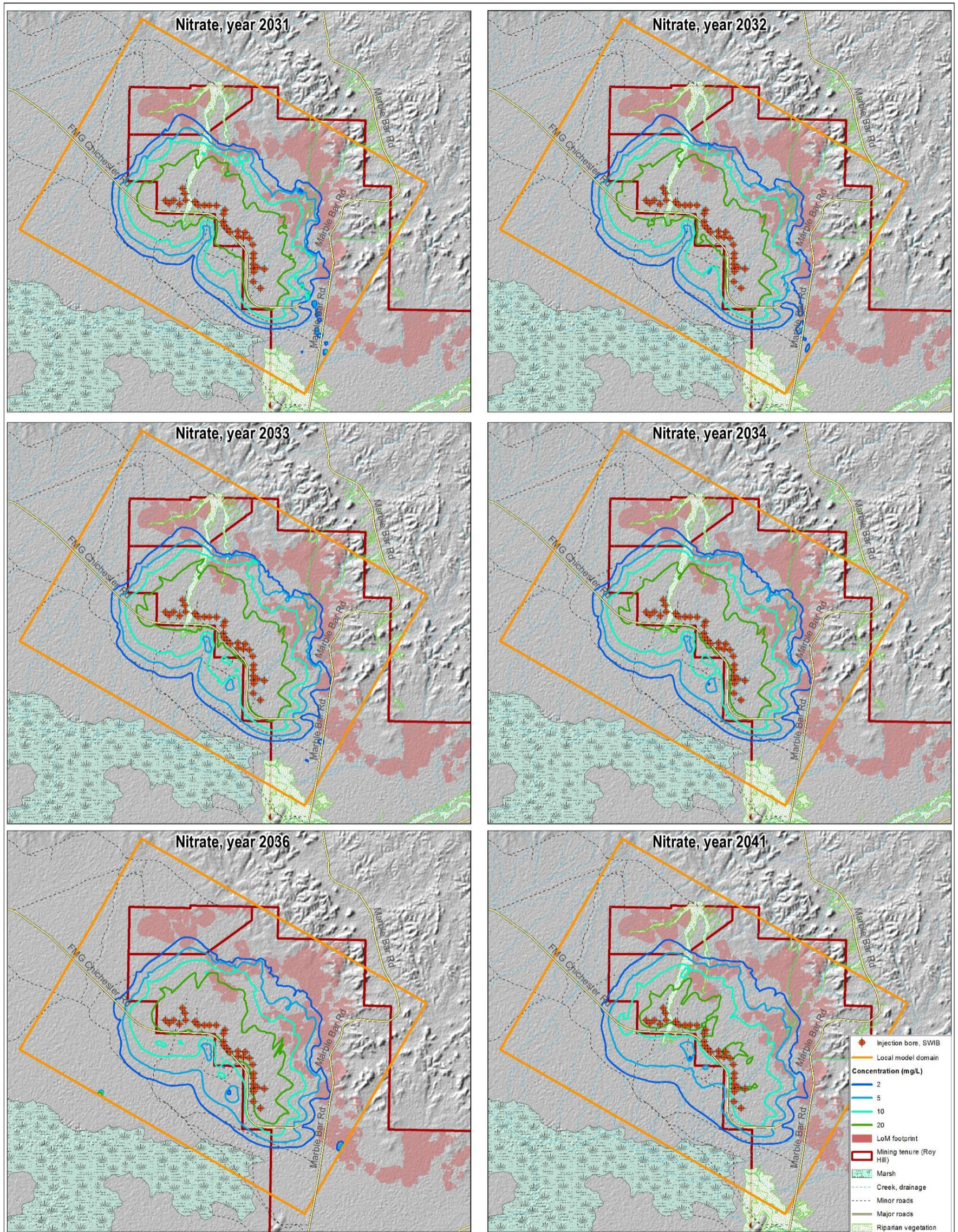
Figure 5-15: Estimated nitrate concentrations up to 2041, low attenuation rate
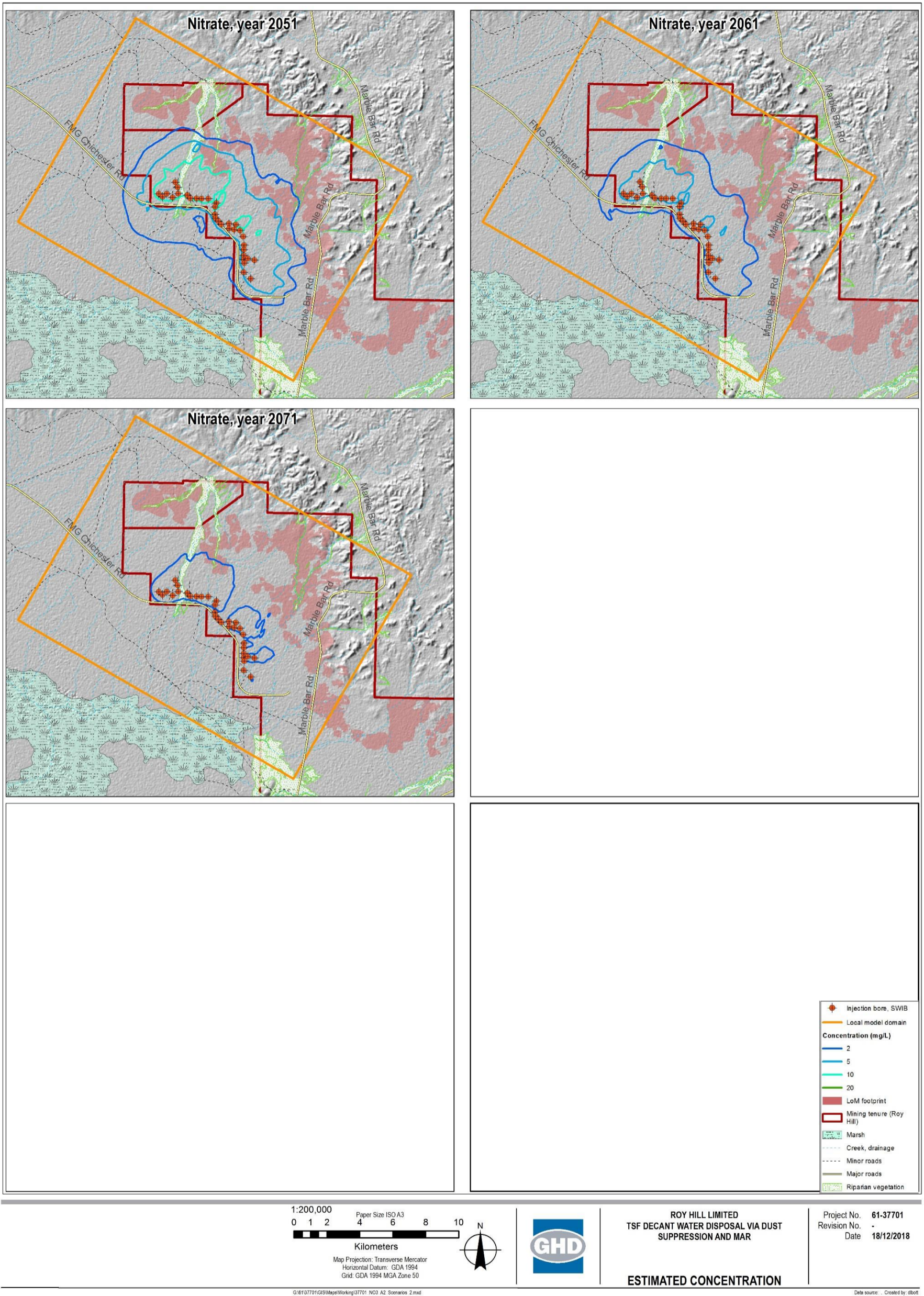
Figure 5-16: Dissipation of estimated nitrate concentrations after 2041, low attenuation rate
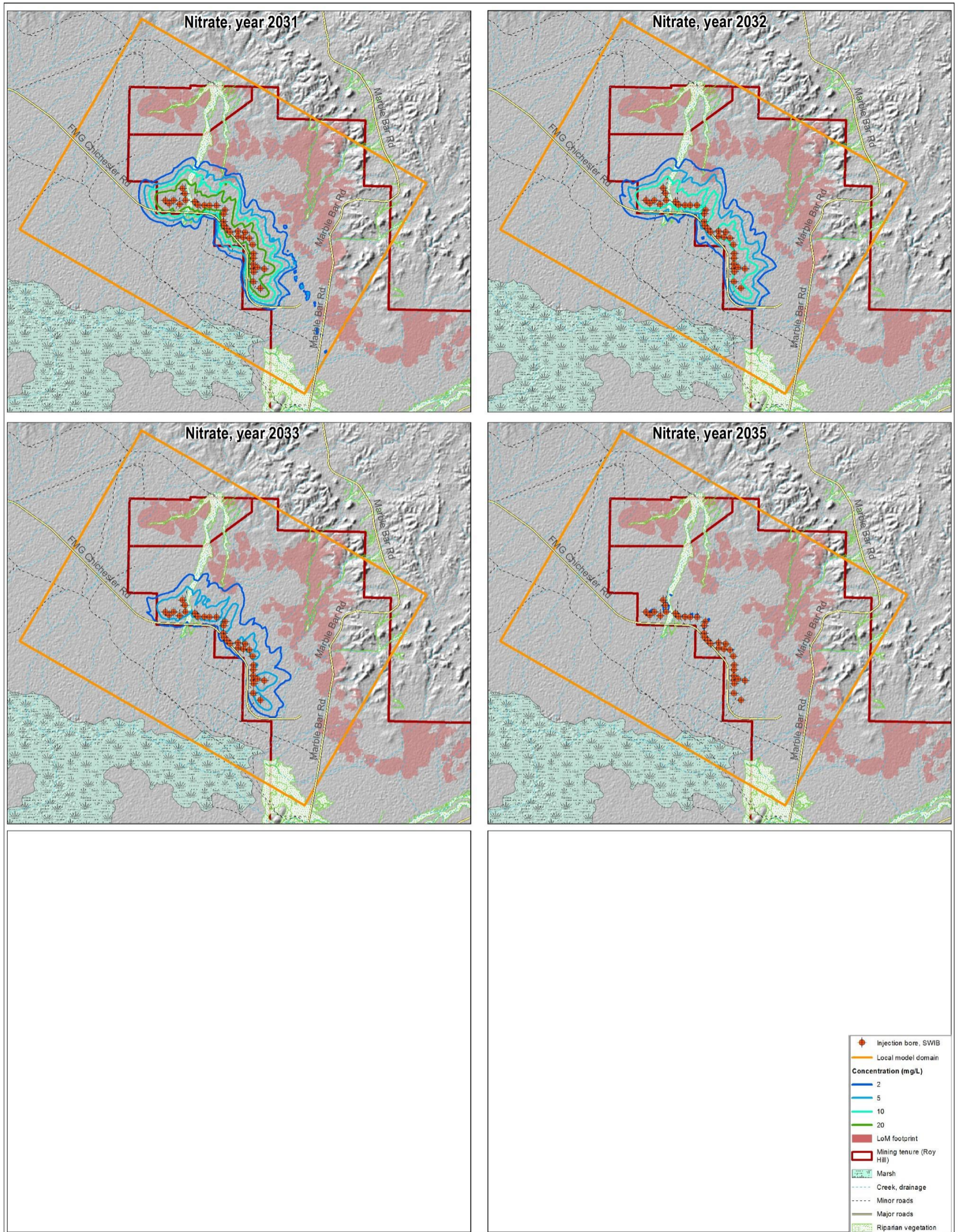
Figure 5-17: Dissipation of estimated nitrate concentrations after re-injection ceases, average attenuation rate

5.4   Summary of MAR impacts

5.4.1   Water level change

Water level will be subject to mounding from re-injection, and water level is predicted to rise over 10 m in the immediate vicinity of injected bores.

Injection rates will have to be optimised and continually monitored to ensure compliance within the threshold depth to water. Modelling results indicate that is possible within fairly narrow margins. The mound is not likely to reach the Fortescue Marsh. This is partly due to the fact that the large volume of injected water is recycled by dewatering which is taking place north and east of the injection borefield.

The mound will dissipate rapidly once injections ceases, the modelling results indicate this will happen within 1 to 2 years.

5.4.2   Groundwater quality change

Injection of decant mix will create a plume of up to 13 km long (along the tenement boundary and 7 km wide (across the boundary). The majority of the plume will remain within the mining tenement in the direction of Bravo area.

Predicted maximum concentrations will be in the range of 0.005 mg/L to 0.01 mg/L of dissolved total selenium; 0.02 mg/L to 0.05 mg/L of dissolved total chromium and 20 mg/L to 50 mg/L of nitrate. With exception of Se this would represent an exceedance of ANZECC trigger values in parts of the plume during mining and up to 30 years after closure (for nitrate with low attenuation rate) largely confined to the mining tenement.

Predictive modelling indicates that the nitrate plume will remain within 1 km from the marsh for up to ten years post closure when assuming low attenuation rate. After that, the plume will dissipate until the concentrations become negligible 40 years post closure.

5.4.3   Riparian vegetation

Introduction of decant mix into groundwater will in result temporary plumes of trace metals (mainly during mining) and nitrate (up to 40 years post closure). The increase of Cr and Se is predicted to remain within the ANZECC trigger levels and therefore the risk associated with disposal of decant water via MAR with respect to Cr and Se is considered negligible, while also taking into account that water levels will be maintained 5 m or deeper in the area of injection.

Nitrate concentration will increase to 20 mg/L to 50 mg/L range N within the mining tenement, which is within the range of the current groundwater values and therefore should not pose additional risk to riparian vegetation.

5.4.4   Fortescue Marsh

The Fortescue Marsh is classified as a Priority Ecological Community (PEC) by the department of Parks and Wildlife (DPaW, 2013), however it does not contain any threatened Ecological Comunities (TECs) (MWH, 2015).

The EPA, now part of DWER, in 2013, defined three conservation significance categories for the Fortescue Marsh Management Area.

Given the distance of approximately 7 km from the SWIB the groundwater concentration changes associated with MAR are considered to be negigible. The plume developed though MAR operation is predicted to remain spatially bound to the mining tenement with only minor extension over the tenement southern boundary. Modelling currently indicates that this plume is not likely to reach the Fortescue Marsh.

In summary, the adverse effects on the Fortescue Marsh from MAR at SWIB are assessed to be negligible with respect to Cr, Se, and N concentrations, both during mining and post closure.

5.5   Summary of MAR risk assessment

Table 5-3 presents a summary of the risk assessment and risk ranking for each sensitive receptor.

Table 5-3: Use of decant water for MAR - risk matrix summary of findings

Receptor	Pathway – receptor linkage	Risk assessment
Riparian/phreatophytic vegetation	**Low** to **moderate** – mounding is likely to result from injection, however linkage will be limited by maintaining minimum depth to water at 5 m bgl. Some phreatophytes may opportunistically (not exclusively) use groundwater even if deeper than 5 m bgl. Metal concentrations (Se, Cr) will increase in groundwater during injection but will dissipate after closure. Nitrate concentrations will increase in groundwater and will dissipate within 40 years post closure.	**Low** – generally incomplete pathway, due to depth of groundwater being generally more than 5 m bgl, except for opportunistic phreatophytes. Chromium concentrations will increase above 95% ecological trigger value during mining but would generally not be accessible to vegetation due to 5 m threshold depth.
Fortescue Marsh	**Low** – mounding is unlikely to reach the marsh. Metal concentrations will increase in groundwater during injection but will dissipate after closure, however they are predicted to not reach the marsh	**Low to very low** – incomplete pathway, due to mounding from injection or contaminants unlikely to reach the marsh.
Groundwater	**Moderate** – mounding is likely to result from injection. Metal concentrations will increase in groundwater during injection but will dissipate after closure. Nitrate concentrations will increase in groundwater around the SWIB but will dissipate within 40 years after closure.	**Moderate** – dewatering and mounding will affect groundwater levels and flow directions during mining and post closure. Predicted metal concentrations (chromium) will exceed ANZECC trigger values during mining in the mining tenement but will decrease to negligible levels after closure. Selenium concentrations will increase during mining but below ANZECC trigger values. Nitrate concentrations will increase in the mining area

Receptor	Pathway – receptor linkage	Risk assessment
		before they return to background levels after 40 years post closure.

6. Conclusions and management options

6.1 Conclusions

Future tailings disposal into in-pit TSFs are proposed requiring quantities of decant water, up to 20 ML/day, to be removed and disposed. RHIO is currently assessing disposal of decant water via dust suppression and MAR. This study has

- Characterised the receiving environment, including sensitive receptors,
- Defined the proposed dust suppression and MAR processes,
- Defined the TSF decant water quality, and
- Assessed the level of risk for negative impact to the receiving environment and human health associated with the proposed reuse of TSF decant water.

Based on the risk assessment the following conclusions are presented.

6.1.1 Dust suppression

The primary source, pathway, receptor linkage was identified to be metals accumulation in soil directly adjacent to the haul roads, having the potential to cause negative impact of native vegetation health.

Potential contaminants of concern in the TSF decant water with regard to potential soil contamination included nutrients and metals.

Nutrients

The TSF decant water contains elevated nutrient concentrations. Nutrients are essential for plant growth. While no site specific studies are available with regard to nutrient impact on local vegetation, ANZECC (2000b) provides a recommended trigger range for nitrogen concentrations in irrigations waters for agricultural crops of 25 – 125 mg/L for irrigation over 20 years. These values are based on maintaining crop yield and minimising off-site impacts. Concentrations in irrigation water should be less than the recommended trigger values. Applying these values as a screening criteria for comparison, the TSF decant water has mean nitrogen concentration of 42.5 mg/L which is within the acceptable range defined by ANZECC (2000b). As such, nutrients within the TSF decant water are expected to poise a low risk of negative impact to local vegetation.

Metals

Comparison of predicted accumulated metals concentrations in soil over the life of mine with tier 1 risk assessment screening criteria showed:

Ecological risk: Estimated concentrations for metals in soil after 13 years of dust suppression using TSF decant water are well below the generic EILs (where available), suggesting a low risk of negative impact to native vegetation. With regard to potential impact of selenium and boron in soil on local ecology where tier 1 screening criteria could not be sourced:

- The median background concentration of selenium in Australian soils is 0.5 mg/kg, values ranging from 0.05 to 3.2 mg/kg (ANZECC, 2000b). Estimated concentrations for selenium in soil after 13 years of dust suppression using TSF decant water are 3.3 mg/kg, marginally above the background range for Australian soils. GHD is not aware of publicly available studies on the specific impacts of selenium on native vegetation in the Pilbara. Without these specific studies, native vegetation tolerance to increases in selenium concentrations is soil is difficult to quantify. However, based on the above qualitative lines of evidence the

risk of negative impact to native vegetation is considered low as the accumulative increase in selenium concentrations in soil over 13 years is expected to be less than 10%.

- Most research on boron toxicity relates to agricultural crops. ANZECC (2000b) shows that very sensitive crops (such as blackberries) can tolerate irrigation water with boron concentrations of 0.5 mg/L, similar to concentrations in the TSF decant water. The scale ranges up to very tolerant cops (such as asparagus) that can tolerate up to 15 mg/L boron in irrigation waters, which is 28 times higher than boron concentrations in the TSF decant water. While ANZECC (2000b) refers to agricultural crops, the tolerable range of boron concentrations in irrigation waters up to 15 mg/L suggests concentrations of 0.53 mg/L in TSF decant water have a low risk of impacting vegetation at the site.

Risk to fauna: Metals concentrations in the supernatant are below the ANZECC livestock drinking water guidelines with exception of selenium, which is marginally above. The criteria is based on sole use of the water for livestock, but in this scenario it is unlikely that pooled water will be the sole water source for fauna and as such the risk is considered low.

Nutrients within the TSF decant water have the potential to result in algal bloom in the pooled water, if ingested have the potential to impact fauna health. The ANZECC 95% protection level trigger value for nitrate is 0.7 mg/L which is several orders of magnitude lower than the concentrations in the TSF decant water. However, pooling is considered unlikely, due to dust suppression operational practices limiting the potential for pooling and past experience with dust suppression at the site demonstrating limited pooling. As pooling is considered unlikely the risk is considered low.

Risk to human health: Estimated concentrations for metals in soil after 13 years of dust suppression using TSF decant water are well below the generic HIL-D values, suggesting a lower risk of negative human health.

Based on the tier 1 risk assessment documented as part of this report, the overall likelihood of negative impact on the environmental as a result of use of TSF decant water for dust suppression is considered to be low.

6.1.2   MAR

The potential contaminants of concerns with regard to groundwater contamination include selenium, chromium and nitrate. The change of groundwater concentration due to Mar at SWIB was assessed using a numerical flow and transport model. While the results are reported for Cr, Se and nitrate, similar conclusions can be made for any generic solute subject to advective-dispersive reactive flux. Modelling include a relatively conservative take on reactive processes and therefore provides pre-cautionary results which may over-predict the actual groundwater concentrations.

The assessment indicates that:

- Injection of supernatant mix with dewater (on average 30% supernatant, 70% dewater) will create a large mound centred along the injection bores. Bore injection rates will have to be optimised and monitored to keep them within threshold depth to groundwater. The mound will dissipate within one following the cessation of injection in 2031.

- Injection of supernatant mix with dewater (on average 30% supernatant, 70% dewater) will result in a relatively extensive plume around the SWIB with the majority of its footprint in the tenement in the direction of Bravo section. The extent of the plume south of the tenement boundary will be limited to a maximum of 1 to 1.5 km, although in the case of very low attenuation factor the plume may arrive up to 1 km from the Fortescue Marsh.

- The stabilisation of the plume in the mining area will be driven by an on-going dewatering during mining and the presence of depressed water level in the mining footprint during closure..

- Predicted maximum concentrations will be in the range of 0.005 mg/L to 0.01 for total Se, 0.02 to 0.05 mg/L of total Cr and 20 to 50 mg/L of nitrate. With exception of Se this would represent a temporary exceedance (up to 40 years post closure for nitrate) of ANZECC trigger values in parts of the plume largely confined to the mining tenement.

- The period of closure shows a gradual redistribution (homogenisation) of concentrations within the plume and rapid dissipation unless low attenuation rates apply in which case the plume will disappear within approximately 40 years after closure.

- There are no indications that the Se, Cr or nitrate plumes would intersect the Fortescue Marsh due to the long-lasting drawdown effect from mining.

6.2   Management options

While risk of negative impact to ecology and/or human health is considered to be low, the existing management measures currently undertaken by RHIO through the use of saline water use for dust suppression management plan and the vegetation condition management plan, will further mitigate the risk. Both existing management plans should be updated to include the application/disposal of TSF decant water.

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Appendices

Appendix A – Soil metal concentrations – analytical results

ANALYTICAL REPORT

Accreditation No. 2562

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Order Number	**4500026000**
Samples	28

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SGS Reference	**PE109932 R0**
Date Received	23 Aug 2016
Date Reported	31 Aug 2016

COMMENTS

Accredited for compliance with ISO/IEC 17025. NATA accredited laboratory 2562(898/20210).

Total Recoverable Metals: Various metal analytes failed spike recovery and MSD RPD due to matrix interference .

SIGNATORIES

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Metals Team Leader

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			Sample Number	PE109932.001	PE109932.002	PE109932.003	PE109932.004
			Sample Matrix	Soil	Soil	Soil	Soil
			Sample Date	18/8/16 15:15	18/8/16 15:15	18/8/16 15:00	18/8/16 14:55
			Sample Name	SS01	SS02	SS03	SS04
Parameter		**Units**	**LOR**				

Moisture Content   Method: AN002   Tested: 26/8/2016

	Units	LOR				
% Moisture	%w/w	0.5	12	16	2.2	1.6

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

	Units	LOR				
pH	pH Units	-	7.5	8.1	8.6	8.5

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

	Units	LOR				
Conductivity of Extract (1:5 as received)	µS/cm	1	1400	620	150	55

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

	Units	LOR				
Aluminium, Al	mg/kg	10	2700	2900	4200	7400
Arsenic, As	mg/kg	1	1	<1	4	5
Barium, Ba	mg/kg	0.5	130	160	57	90
Boron, B	mg/kg	5	6	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	0.9	3.4	1.2	1.0
Chromium, Cr	mg/kg	0.5	33	37	72	81
Cobalt, Co	mg/kg	0.5	7.4	7.7	7.2	16
Copper, Cu	mg/kg	0.5	6.6	8.3	16	28
Lead, Pb	mg/kg	1	9	9	13	14
Manganese, Mn	mg/kg	1	1300	1800	590	840
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	14	13	27	49
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	<3
Vanadium, V	mg/kg	0.5	25	39	30	34
Zinc, Zn	mg/kg	2	21	18	32	46
Antimony, Sb*	mg/kg	3	<3	<3	3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

	Units	LOR				
Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

			Sample Number PE109932.005	PE109932.006	PE109932.007	PE109932.008
			Sample Matrix Soil	Soil	Soil	Soil
			Sample Date 18/8/16 14:40	19/8/16 8:50	19/8/16 9:00	19/8/16 10:40
			Sample Name SS05	SS06	SS07	SS08
Parameter	**Units**	**LOR**				

Moisture Content   Method: AN002   Tested: 26/8/2016

Parameter	Units	LOR	SS05	SS06	SS07	SS08
% Moisture	%w/w	0.5	4.8	2.9	4.2	2.9

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

Parameter	Units	LOR	SS05	SS06	SS07	SS08
pH	pH Units	-	9.0	7.3	6.6	6.9

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

Parameter	Units	LOR	SS05	SS06	SS07	SS08
Conductivity of Extract (1:5 as received)	µS/cm	1	96	23	16	32

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

Parameter	Units	LOR	SS05	SS06	SS07	SS08
Aluminium, Al	mg/kg	10	8200	9700	12000	13000
Arsenic, As	mg/kg	1	6	5	6	6
Barium, Ba	mg/kg	0.5	98	97	110	110
Boron, B	mg/kg	5	<5	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	0.9	1.1	1.2	1.2
Chromium, Cr	mg/kg	0.5	71	83	89	88
Cobalt, Co	mg/kg	0.5	20	22	29	24
Copper, Cu	mg/kg	0.5	33	42	50	53
Lead, Pb	mg/kg	1	16	15	17	15
Manganese, Mn	mg/kg	1	820	1300	1500	1200
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	67	69	73	86
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	<3
Vanadium, V	mg/kg	0.5	45	56	64	73
Zinc, Zn	mg/kg	2	45	83	86	94
Antimony, Sb*	mg/kg	3	<3	<3	<3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

Parameter	Units	LOR	SS05	SS06	SS07	SS08
Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

			Sample Number	PE109932.009	PE109932.010	PE109932.011	PE109932.012
			Sample Matrix	Soil	Soil	Soil	Soil
			Sample Date	19/8/16 10:30	19/8/16 10:20	19/8/16 10:10	19/8/16 9:45
			Sample Name	SS09	SS10	SS11	SS12
Parameter		**Units**	**LOR**				

Moisture Content   Method: AN002   Tested: 26/8/2016

	Units	LOR				
% Moisture	%w/w	0.5	4.1	2.1	2.8	2.3

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

	Units	LOR				
pH	pH Units	-	7.3	6.9	7.1	6.4

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

	Units	LOR				
Conductivity of Extract (1:5 as received)	µS/cm	1	18	25	10	6

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

	Units	LOR				
Aluminium, Al	mg/kg	10	12000	6900	5600	5100
Arsenic, As	mg/kg	1	6	5	4	4
Barium, Ba	mg/kg	0.5	110	110	100	73
Boron, B	mg/kg	5	<5	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	1.0	0.9	0.9	0.8
Chromium, Cr	mg/kg	0.5	89	81	78	73
Cobalt, Co	mg/kg	0.5	29	20	21	15
Copper, Cu	mg/kg	0.5	55	29	28	24
Lead, Pb	mg/kg	1	17	16	16	14
Manganese, Mn	mg/kg	1	1200	1000	1100	830
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	83	43	47	46
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	<3
Vanadium, V	mg/kg	0.5	70	47	43	35
Zinc, Zn	mg/kg	2	75	55	63	57
Antimony, Sb*	mg/kg	3	<3	<3	<3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

	Units	LOR				
Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

Parameter	Units	LOR	Sample Number PE109932.013 Soil 19/8/16 9:25 SS13	Sample Number PE109932.014 Soil 19/8/16 9:15 SS14	Sample Number PE109932.015 Soil 18/8/16 15:30 SS15	Sample Number PE109932.016 Soil 18/8/16 15:30 SS16

Moisture Content   Method: AN002   Tested: 26/8/2016

Parameter	Units	LOR	SS13	SS14	SS15	SS16
% Moisture	%w/w	0.5	3.7	2.6	2.6	2.0

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

Parameter	Units	LOR	SS13	SS14	SS15	SS16
pH	pH Units	-	7.2	6.5	8.3	7.1

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

Parameter	Units	LOR	SS13	SS14	SS15	SS16
Conductivity of Extract (1:5 as received)	µS/cm	1	18	11	68	120

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

Parameter	Units	LOR	SS13	SS14	SS15	SS16
Aluminium, Al	mg/kg	10	8300	7800	5900	4700
Arsenic, As	mg/kg	1	6	7	3	2
Barium, Ba	mg/kg	0.5	110	130	170	220
Boron, B	mg/kg	5	<5	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	1.0	1.0	0.8	0.8
Chromium, Cr	mg/kg	0.5	81	64	50	50
Cobalt, Co	mg/kg	0.5	24	36	10	9.1
Copper, Cu	mg/kg	0.5	36	44	18	16
Lead, Pb	mg/kg	1	20	22	12	11
Manganese, Mn	mg/kg	1	1200	1800	520	550
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	64	42	23	20
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	9
Vanadium, V	mg/kg	0.5	49	53	38	38
Zinc, Zn	mg/kg	2	63	72	24	24
Antimony, Sb*	mg/kg	3	<3	<3	<3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

Parameter	Units	LOR	SS13	SS14	SS15	SS16
Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

SGS

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			PE109932.017 Soil 18/8/16 15:50 SS17	PE109932.018 Soil 18/8/16 15:50 SS18	PE109932.019 Soil 18/8/16 14:35 SS19	PE109932.020 Soil 17/8/16 16:30 SS20
Parameter	**Units**	**LOR**	Sample Number / Matrix / Date / Name			

Moisture Content   Method: AN002   Tested: 26/8/2016

% Moisture	%w/w	0.5	**1.7**	**2.1**	**10**	**3.4**

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

pH	pH Units	-	**8.5**	**8.6**	**8.8**	**8.0**

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

Conductivity of Extract (1:5 as received)	µS/cm	1	**44**	**49**	**220**	**1900**

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

Aluminium, Al	mg/kg	10	**5700**	**4500**	**5800**	**6100**
Arsenic, As	mg/kg	1	**2**	**2**	**3**	**5**
Barium, Ba	mg/kg	0.5	**180**	**130**	**110**	**120**
Boron, B	mg/kg	5	<5	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	**0.8**	**0.7**	**0.9**	**0.9**
Chromium, Cr	mg/kg	0.5	**51**	**45**	**64**	**61**
Cobalt, Co	mg/kg	0.5	**9.4**	**7.4**	**11**	**14**
Copper, Cu	mg/kg	0.5	**18**	**15**	**19**	**23**
Lead, Pb	mg/kg	1	**10**	**9**	**13**	**15**
Manganese, Mn	mg/kg	1	**290**	**230**	**450**	**740**
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	**20**	**16**	**30**	**35**
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	<3
Vanadium, V	mg/kg	0.5	**34**	**29**	**41**	**41**
Zinc, Zn	mg/kg	2	**46**	**27**	**28**	**32**
Antimony, Sb*	mg/kg	3	<3	<3	<3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

	Sample Number		PE109932.021	PE109932.022	PE109932.023	PE109932.024
	Sample Matrix		Soil	Soil	Soil	Soil
	Sample Date		17/8/16 16:30	17/8/16 16:20	17/8/16 17:10	17/8/16 17:15
	Sample Name		SS21	SS22	SS23	SS24
Parameter	**Units**	**LOR**				

Moisture Content   Method: AN002   Tested: 26/8/2016

% Moisture	%w/w	0.5	3.1	1.5	3.7	4.8

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

pH	pH Units	-	8.4	7.5	7.8	8.2

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

Conductivity of Extract (1:5 as received)	µS/cm	1	380	36	19	180

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

Aluminium, Al	mg/kg	10	6300	6400	7000	7800
Arsenic, As	mg/kg	1	4	5	6	7
Barium, Ba	mg/kg	0.5	130	61	79	120
Boron, B	mg/kg	5	<5	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	0.9	0.8	0.8	0.9
Chromium, Cr	mg/kg	0.5	61	82	79	78
Cobalt, Co	mg/kg	0.5	13	14	18	21
Copper, Cu	mg/kg	0.5	22	29	33	34
Lead, Pb	mg/kg	1	14	14	18	19
Manganese, Mn	mg/kg	1	630	730	920	1100
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	34	33	44	55
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	<3
Vanadium, V	mg/kg	0.5	39	51	52	56
Zinc, Zn	mg/kg	2	31	53	49	44
Antimony, Sb*	mg/kg	3	<3	<3	<3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

Mercury	mg/kg	0.05	<0.05	<0.05	<0.05	<0.05

			Sample Number	PE109932.025	PE109932.026	PE109932.027	PE109932.028
			Sample Matrix	Soil	Soil	Soil	Soil
			Sample Date	17/8/16 16:50	18/8/16 16:50	19 Aug 2016	19 Aug 2016
			Sample Name	SS25	SS26	QC1	QC2
Parameter		**Units**	**LOR**				

Moisture Content   Method: AN002   Tested: 26/8/2016

Parameter	Units	LOR	SS25	SS26	QC1	QC2
% Moisture	%w/w	0.5	3.2	2.8	2.0	2.3

pH in soil (1:5)   Method: AN101   Tested: 26/8/2016

Parameter	Units	LOR	SS25	SS26	QC1	QC2
pH	pH Units	-	8.0	8.1	6.9	6.7

Conductivity and TDS by Calculation - Soil   Method: AN106   Tested: 26/8/2016

Parameter	Units	LOR	SS25	SS26	QC1	QC2
Conductivity of Extract (1:5 as received)	µS/cm	1	410	470	25	21

Total Recoverable Metals in Soil by ICPOES   Method: AN/320AN321   Tested: 23/8/2016

Parameter	Units	LOR	SS25	SS26	QC1	QC2
Aluminium, Al	mg/kg	10	12000	13000	6600	6400
Arsenic, As	mg/kg	1	5	4	6	5
Barium, Ba	mg/kg	0.5	87	87	100	91
Boron, B	mg/kg	5	<5	<5	<5	<5
Cadmium, Cd	mg/kg	0.3	1.0	1.2	0.9	0.9
Chromium, Cr	mg/kg	0.5	340	390	78	69
Cobalt, Co	mg/kg	0.5	46	53	22	21
Copper, Cu	mg/kg	0.5	110	120	30	28
Lead, Pb	mg/kg	1	12	12	17	16
Manganese, Mn	mg/kg	1	1000	970	1100	1100
Molybdenum, Mo	mg/kg	1	<1	<1	<1	<1
Nickel, Ni	mg/kg	0.5	330	370	59	55
Selenium, Se	mg/kg	3	<3	<3	<3	<3
Tin, Sn	mg/kg	3	<3	<3	<3	<3
Vanadium, V	mg/kg	0.5	69	68	42	40
Zinc, Zn	mg/kg	2	280	290	61	57
Antimony, Sb*	mg/kg	3	5	6	<3	<3

Mercury in Soil   Method: AN312   Tested: 23/8/2016

Parameter	Units	LOR	SS25	SS26	QC1	QC2
Mercury	mg/kg	0.05	0.08	0.08	<0.05	<0.05

MB blank results are compared to the Limit of Reporting
LCS and MS spike recoveries are measured as the percentage of analyte recovered from the sample compared the the amount of analyte spiked into the sample.
DUP and MSD relative percent differences are measured against their original counterpart samples according to the formula : *the absolute difference of the two results divided by the average of the two results as a percentage*. Where the DUP RPD is 'NA' , the results are less than the LOR and thus the RPD is not applicable.

Conductivity and TDS by Calculation - Soil   Method: ME-(AU)-[ENV]AN106

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Conductivity of Extract (1:5 as received)	LB121772	µS/cm	1	2	1 - 4%	100%

Mercury in Soil   Method: ME-(AU)-[ENV]AN312

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery	MS %Recovery	MSD %RPD
Mercury	LB121608	mg/kg	0.05	<0.05	0%	89%	91%	25%
	LB121609	mg/kg	0.05	<0.05	0 - 13%	86%	88%	21%

Moisture Content   Method: ME-(AU)-[ENV]AN002

Parameter	QC Reference	Units	LOR	DUP %RPD
% Moisture	LB121741	%w/w	0.5	3 - 7%

pH in soil (1:5)   Method: ME-(AU)-[ENV]AN101

Parameter	QC Reference	Units	LOR	DUP %RPD	LCS %Recovery
pH	LB121772	pH Units	-	1 - 3%	100 - 101%

Total Recoverable Metals in Soil by ICPOES   Method: ME-(AU)-[ENV]AN/320AN321

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery	MS %Recovery	MSD %RPD
Aluminium, Al	LB121608	mg/kg	10	<50	2 - 12%	99%	-610%	-408%
	LB121609	mg/kg	10	<50	0 - 4%	101%	8618%	31%
Arsenic, As	LB121608	mg/kg	1	<1	9 - 21%	98%	43%	11%
	LB121609	mg/kg	1	<1	4 - 18%	101%	57%	9%
Barium, Ba	LB121608	mg/kg	0.5	<0.5	2 - 15%	81%	103%	19%
	LB121609	mg/kg	0.5	<0.5	4 - 9%	84%	68%	129%
Boron, B	LB121608	mg/kg	5	<5	0 - 13%	NA	86%	1%
	LB121609	mg/kg	5	<5	0%	NA	71%	9%
Cadmium, Cd	LB121608	mg/kg	0.3	<0.3	5 - 26%	98%	80%	2%
	LB121609	mg/kg	0.3	<0.3	7 - 11%	97%	92%	8%
Chromium, Cr	LB121608	mg/kg	0.5	<0.5	1 - 22%	94%	27%	9%
	LB121609	mg/kg	0.5	<0.5	1%	95%	78%	19%
Cobalt, Co	LB121608	mg/kg	0.5	<0.5	3 - 21%	94%	91%	1%
	LB121609	mg/kg	0.5	<0.5	1 - 13%	97%	91%	11%
Copper, Cu	LB121608	mg/kg	0.5	<0.5	1 - 17%	102%	97%	2%
	LB121609	mg/kg	0.5	<0.5	0 - 3%	103%	102%	12%
Lead, Pb	LB121608	mg/kg	1	<1	2 - 13%	113%	105%	1%
	LB121609	mg/kg	1	<1	2 - 15%	118%	107%	12%
Manganese, Mn	LB121608	mg/kg	1	<1	3 - 18%	98%	-311%	-66%
	LB121609	mg/kg	1	<1	2%	99%	242%	42%
Molybdenum, Mo	LB121608	mg/kg	1	<1	0%	95%	61%	3%
	LB121609	mg/kg	1	<1	0%	97%	50%	4%
Nickel, Ni	LB121608	mg/kg	0.5	<0.5	2 - 23%	106%	95%	2%
	LB121609	mg/kg	0.5	<0.5	3 - 4%	112%	100%	14%
Selenium, Se	LB121608	mg/kg	3	<3	0%	98%	8%	22%
	LB121609	mg/kg	3	<3	0%	99%	18%	23%
Tin, Sn	LB121608	mg/kg	3	<3	0%	112%	94%	1%
	LB121609	mg/kg	3	<3	0%	94%	34%	25%
Vanadium, V	LB121608	mg/kg	0.5	<0.5	2 - 21%	103%	60%	12%
	LB121609	mg/kg	0.5	<0.5	1%	105%	75%	26%
Zinc, Zn	LB121608	mg/kg	2	<2	1 - 16%	94%	83%	4%
	LB121609	mg/kg	2	<2	2 - 5%	96%	99%	11%
Antimony, Sb*	LB121608	mg/kg	3	<3	0%	91%	24%	0%
	LB121609	mg/kg	3	<3	0 - 1%	90%	13%	15%

METHOD	METHODOLOGY SUMMARY
AN002	The test is carried out by drying (at either 40°C or 105°C) a known mass of sample in a weighed evaporating basin. After fully dry the sample is re-weighed. Samples such as sludge and sediment having high percentages of moisture will take some time in a drying oven for complete removal of water.
AN045	A portion of sample is digested with Nitric acid and Hydrogen Peroxide over time and then with Hydrochloric acid through several heating and cooling cycles. It provides a strong oxidising medium for bringing metal analytes into solution according to USEPA3050, after filtration the solution is presented for analysis on AAS or ICP .
AN101	pH in Soil Sludge Sediment and Water: pH is measured electrometrically using a combination electrode and is calibrated against 3 buffers purchased commercially. For soils, sediments and sludges, an extract with water (or 0.01M CaCl2) is made at a ratio of 1:5 and the pH determined and reported on the extract. Reference APHA 4500-H+.
AN106	Conductivity and TDS by Calculation: Conductivity is measured by meter with temperature compensation and is calibrated against a standard solution of potassium chloride. Conductivity is generally reported as µmhos/cm or µS/cm @ 25°C. For soils, an extract with water is made at a ratio of 1:5 and the EC determined and reported on the extract, or calculated back to the as-received sample. Salinity can be estimated from conductivity using a conversion factor, which for natural waters, is in the range 0.55 to 0.75. Reference APHA 2510 B.
AN312	Mercury by Cold Vapour AAS in Soils: After digestion with nitric acid, hydrogen peroxide and hydrochloric acid, mercury ions are reduced by stannous chloride reagent in acidic solution to elemental mercury. This mercury vapour is purged by nitrogen into a cold cell in an atomic absorption spectrometer or mercury analyser. Quantification is made by comparing absorbances to those of the calibration standards. Reference APHA 3112/3500
AN320/AN321	Metals by ICP-OES: Samples are preserved with 10% nitric acid for a wide range of metals and some non-metals. This solution is measured by Inductively Coupled Plasma. Solutions are aspirated into an argon plasma at 8000-10000K and emit characteristic energy or light as a result of electron transitions through unique energy levels. The emitted light is focused onto a diffraction grating where it is separated into components .
AN320/AN321	Photomultipliers or CCDs are used to measure the light intensity at specific wavelengths. This intensity is directly proportional to concentration. Corrections are required to compensate for spectral overlap between elements. Reference USEPA3050, USEPA6010C and APHA 3120 B.

SGS

IS	Insufficient sample for analysis.	LOR	Limit of Reporting
LNR	Sample listed, but not received.	↑↓	Raised or Lowered Limit of Reporting
*	NATA accreditation does not cover the	QFH	QC result is above the upper tolerance
	performance of this service.	QFL	QC result is below the lower tolerance
**	Indicative data, theoretical holding time exceeded.	-	The sample was not analysed for this analyte
		NVL	Not Validated

Samples analysed as received.
Solid samples expressed on a dry weight basis.

Where "Total" analyte groups are reported (for example, Total PAHs, Total OC Pesticides) the total will be calculated as the sum of the individual analytes, with those analytes that are reported as <LOR being assumed to be zero. The summed (Total) limit of reporting is calcuated by summing the individual analyte LORs and dividing by two. For example, where 16 individual analytes are being summed and each has an LOR of 0.1 mg/kg, the "Totals" LOR will be 1.6 / 2 (0.8 mg/kg). Where only 2 analytes are being summed, the " Total" LOR will be the sum of those two LORs.

Some totals may not appear to add up because the total is rounded after adding up the raw values.

If reported, measurement uncertainty follow the ± sign after the analytical result and is expressed as the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%, unless stated otherwise in the comments section of this report.

Results reported for samples tested under test methods with codes starting with ARS-SOP, radionuclide or gross radioactivity concentrations are expressed in becquerel (Bq) per unit of mass or volume or per wipe as stated on the report. Becquerel is the SI unit for activity and equals one nuclear transformation per second.
Note that in terms of units of radioactivity:
    a.   1 Bq is equivalent to 27 pCi
    b.   37 MBq is equivalent to 1 mCi

For results reported for samples tested under test methods with codes starting with ARS-SOP, less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.

The QC criteria are subject to internal review according to the SGS QAQC plan and may be provided on request or alternatively can be found here : http://www.sgs.com.au/~/media/Local/Australia/Documents/ Technical%20Documents/MP-AU-ENV-QU-022%20QA%20QC%20Plan.pdf

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Appendix B – Decant water quality – analytical results

Sample Point	Sample Date	Lab EC	Lab pH	TDS	Total Hardness	TSS	Al	As	Ba	Be	B	Cd	Ca	Cl	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	P	K	Se	S	Ag	Na	Sr	SO4	S	Tl	Sn	Ti	V	Zn	Total Nitrogen	Nitrate as NO3	Nitrite (NO2)	Alkalinity as HCO3
		(uS/cm)	pH units	mg/L	mgCaCO3/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TSF Decant C1	29/04/2018 14:10:00	4,600	7.6	3,400	1,900	10	<0.005	<0.001	0.04	<0.001	0.55	<0.0001	440	650	0.05	<0.001	<0.001	<0.005	<0.001	190	<0.001	0.0	0.0	<0.05	33	0.03	24	<0.001	390	1.6	1,300	440	<0.001	<0.001	<0.001	<0.001	<0.005	46	200	<0.2	91
TSF Decant C1	13/05/2018 11:00:00	5,400	7.7	4,300	1,800	20	<0.005	<0.001	0.04	<0.001	0.57	<0.0001	450	840	0.05	<0.001	<0.001	<0.005	<0.001	170	<0.001	0.0	0.0	<0.05	33	0.02	21	<0.001	350	1.5	1,700	400	<0.001	<0.001	<0.001	<0.001	0.01	33	150	<0.2	93
TSF Decant C1	20/05/2018 12:17:00	4,500	7.8	3,300	1,800	10	<0.005	<0.001	0.04	<0.001	0.6	<0.0001	420	700	0.05	<0.001	<0.001	<0.005	<0.001	170	<0.001	<0.001	0.0	<0.05	34	0.02	21	<0.001	370	1.4	1,300	460	<0.001	<0.001	<0.001	<0.001	<0.005	0.35	1.5	<0.2	97
TSF Decant C1	27/05/2018 10:00:00	4,600	7.6	3,300	1,700	10	<0.005	<0.001	0.04	<0.001	0.42	<0.0001	410	750	0.05	<0.001	<0.001	<0.005	<0.001	170	0.0	<0.001	0.0	<0.05	30	0.02	19	<0.001	360	1.3	1,200	410	<0.001	<0.001	<0.001	<0.001	0.01	25	110	<0.05	87
TSF Decant C1	03/06/2018 13:22:00	4,400	7.7	3,000	1,900	10	<0.005	<0.001	0.03	<0.001	0.38	<0.0001	460	750	0.05	<0.001	<0.001	<0.005	<0.001	190	0.0	<0.001	0.0	<0.05	33	0.02	23	<0.001	430	1.5	1,200	420	<0.001	<0.001	<0.001	<0.001	0.02	35	150	1.7	89
TSF Decant C1	10/06/2018 10:00:00	4,400	7.8	3,300	1,800	<5	<0.005	<0.001	0.04	<0.001	0.36	<0.0001	420	760	0.05	<0.001	<0.001	<0.005	<0.001	170	0.01	<0.001	0.0	<0.05	30	0.02	20	<0.001	390	1.5	1,200	410	<0.001	<0.001	<0.001	<0.001	<0.005	45	200	0.2	90
TSF Decant C1	17/06/2018 10:00:00	4,100	7.7	2,800	1,400	8	<0.005	<0.001	0.02	<0.001	0.31	<0.0001	330	700	0.05	<0.001	<0.001	<0.005	<0.001	140	0.0	0.0	0.0	<0.05	26	0.02	19	<0.001	320	1.2	1,000	350	<0.001	<0.001	<0.001	<0.001	0.01	36	150	2.3	86
TSF Decant C1	24/06/2018 12:30:00	4,000	7.8	2,800	1,500	<5	<0.005	<0.001	0.02	<0.001	0.32	<0.0001	360	710	0.05	<0.001	<0.001	<0.005	<0.001	160	<0.001	0.0	0.0	<0.05	26	0.01	20	<0.001	340	1.2	980	390	<0.001	<0.001	<0.001	<0.001	<0.005	29	130	1.8	95
TSF Decant C1	30/06/2018 00:00:00	4,000	7.8	2,800	1,500	7	<0.005	<0.001	0.02	<0.001	0.3	<0.0001	350	630	0.05	<0.001	<0.001	<0.005	<0.001	160	0.0	0.0	0.0	<0.05	27	0.02	21	<0.001	350	1.2	960	360	<0.001	<0.001	<0.001	<0.001	<0.005	41	180	3.7	91
TSF Decant C1	08/07/2018 00:00:00	4,100	7.8	2,800	1,500	15	<0.005	<0.001	0.02	<0.001	0.33	<0.0001	340	690	0.05	<0.001	<0.001	<0.005	<0.001	150	0.0	<0.001	0.0	<0.05	25	0.02	21	<0.001	350	1.2	970	360	<0.001	<0.001	<0.001	<0.001	<0.005	42	180	2.9	90
TSF Decant C1	15/07/2018 00:00:00	4,100	7.8	3,100	1,400	7	<0.005	<0.001	0.02	<0.001	0.4	<0.0001	340	670	0.04	<0.001	<0.001	<0.005	<0.001	140	<0.001	0.0	0.0	<0.05	25	0.02	20	<0.001	340	1.1	970	340	<0.001	<0.001	<0.001	<0.001	<0.005	28	120	2.8	91
TSF Decant C1	22/07/2018 08:00:00	3,900	7.6	2,800	1,400	5	<0.005	<0.001	0.03	<0.001	0.15	<0.0001	330	740	0.04	<0.001	<0.001	<0.005	<0.001	150	0.0	<0.001	0.0	<0.05	26	0.01	21	<0.001	340	1.1	940	340	<0.001	<0.001	<0.001	<0.001	<0.005	14	58	1.8	93
TSF Decant C1	30/07/2018 00:00:00	4,000	7.6	2,800	1,400	<5	<0.005	<0.001	0.03	<0.001	0.32	<0.0001	330	760	0.04	<0.001	<0.001	<0.005	<0.001	150	0.0	0.0	0.0	<0.05	26	0.02	21	<0.001	340	1.1	930	350	<0.001	<0.001	<0.001	<0.001	0.01	36	160		89
TSF Decant C1	06/08/2018 09:00:00	4,000	7.6	2,800	1,500	12	<0.005	<0.001	0.03	<0.001	0.28	<0.0001	350	710	0.04	<0.001	<0.001	<0.005	<0.001	150	0.01	0.0	0.0	<0.05	27	0.01	21	<0.001	360	1.2	1,000	340	<0.001	<0.001	<0.001	<0.001	<0.005	43	190	<0.2	93
TSF Decant C1	12/08/2018 10:00:00	4,000	7.7	2,700	1,500	<5	<0.005	<0.001	0.03	<0.001	0.3	<0.0001	340	700	0.04	<0.001	<0.001	<0.005	<0.001	150	0.0	0.0	0.0	<0.05	26	0.01	20	<0.001	340	1	970	290	<0.001	<0.001	<0.001	<0.001	<0.005	38	170	<0.2	93
TSF Decant C1	20/08/2018 09:30:00	4,100	7.7	2,900	1,400	<5	<0.005	<0.001	0.02	<0.001	0.33	<0.0001	340	820	0.04	<0.001	<0.001	<0.005	<0.001	150	0.0	0.0	0.0	<0.05	25	0.01	19	<0.001	360	1.1	940	330	<0.001	<0.001	<0.001	<0.001	<0.005	35	150	3.3	91
TSF Decant C1	26/08/2018 12:57:00	4,100	7.7	3,000	1,400	6	<0.005	<0.001	0.03	<0.001	0.27	<0.0001	340	830	0.04	<0.001	<0.001	<0.005	<0.001	140	0.0	0.0	0.0	<0.05	26	0.01	19	<0.001	370	1.1	950	350	<0.001	<0.001	<0.001	<0.001	<0.005	38	170	<0.2	89
TSF Decant C1	02/09/2018 00:00:00	4,000	7.7	2,900	1,500	<5	<0.005	<0.001	0.03	<0.001	0.29	<0.0001	350	730	0.04	<0.001	<0.001	<0.005	<0.001	150	0.0	0.0	0.0	<0.05	26	0.01	19	<0.001	360	1.1	990	340	<0.001	<0.001	<0.001	<0.001	<0.005	27	120	<0.2	90
TSF Decant C1	09/09/2018 10:00:00	4,200	7.9	3,000	1,500	<5	<0.005	<0.001	0.02	<0.001	0.33	<0.0001	340	870	0.05	<0.001	<0.001	<0.005	<0.001	150	<0.001	0.0	0.0	<0.05	27	0.02	22	<0.001	390	1.1	970	360	<0.001	<0.001	<0.001	<0.001	<0.005	48	200	4.8	96
TSF Decant C1	16/09/2018 10:00:00	4,300	7.6	3,100	1,600	<5	<0.005	<0.001	0.03	<0.001	0.3	<0.0001	360	880	0.05	<0.001	<0.001	<0.005	<0.001	160	0.0	<0.001	0.0	<0.05	29	0.02	21	<0.001	390	1.2	1,100	370	<0.001	<0.001	<0.001	<0.001	0.01				100
TSF Decant C1	23/09/2018 00:00:00	4,300	7.9	3,200	1,500	29	<0.005	<0.001	0.02	<0.001	0.26	<0.0001	350	910	0.05	<0.001	<0.001	0.01	<0.001	160	<0.001	0.0	0.0	<0.05	28	0.02	23	<0.001	410	1.1	1,100	380	<0.001	<0.001	<0.001	<0.001	<0.005	46	200	4.2	110
TSF Decant C2	29/04/2018 14:30:00	5,100	7.7	3,900	2,200	24	<0.005	<0.001	0.04	<0.001	0.58	<0.0001	510	700	0.07	<0.001	<0.001	<0.005	<0.001	230	0.0	0.0	<0.001	<0.05	38	0.03	23	<0.001	420	1.9	1,500	570	<0.001	<0.001	<0.001	<0.001	<0.005	55	240	<0.2	97
TSF Decant C2	13/05/2018 11:00:00	4,400	7.7	3,300	2,300	22	<0.005	<0.001	0.03	<0.001	0.7	<0.0001	550	720	0.09	<0.001	0.0	<0.005	0.0	230	<0.001	0.0	0.0	<0.05	40	0.02	21	<0.001	390	1.9	1,300	550	<0.001	<0.001	0.0	<0.001	<0.005	34	150	<0.2	93
TSF Decant C2	20/05/2018 12:17:00	5,700	7.7	4,500	2,400	11	<0.005	0.001	0.03	<0.001	0.84	<0.0001	560	840	0.11	<0.001	<0.001	<0.005	<0.001	250	<0.001	0.0	0.0	<0.05	46	0.04	24	<0.001	450	2	1,800	630	<0.001	<0.001	0.0	<0.001	<0.005	54	240	<0.2	95
TSF Decant C2	27/05/2018 10:00:00	5,900	7.9	4,600	2,400	21	<0.005	0.0	0.03	<0.001	0.73	<0.0001	560	760	0.11	<0.001	<0.001	0.02	<0.001	250	0.0	<0.001	0.0	<0.05	48	0.04	33	<0.001	470	1.9	1,800	630	<0.001	<0.001	0.0	<0.001	<0.005	33	140	0.16	100
TSF Decant C2	30/06/2018 00:00:00	5,900	7.7	4,600	2,600	8	<0.005	<0.001	0.03	<0.001	0.67	<0.0001	590	860	0.11	<0.001	0.01	<0.005	<0.001	280	0.0	0.0	0.0	<0.05	50	0.04	24	<0.001	510	2.4	1,900	720	<0.001	<0.001	0.0	<0.001	0.01	68	300	<0.2	100
TSF Decant C2	08/07/2018 00:00:00	6,300	8	3,700	2,800	49	<0.005	0.0	0.04	<0.001	0.86	<0.0001	630	1,100	0.14	<0.001	<0.001	<0.005	<0.001	290	<0.001	0.0	0.0	<0.05	52	0.04	38	<0.001	550	2.6	2,100	770	<0.001	<0.001	0.0	<0.001	<0.005	45	200	<0.2	110
TSF Decant C2	15/07/2018 00:00:00	6,200	7.7	5,200	2,500	8	<0.005	<0.001	0.03	<0.001	0.87	<0.0001	580	1,000	0.12	<0.001	<0.001	<0.005	<0.001	260	<0.001	0.0	0.0	<0.05	48	0.03	22	<0.001	490	2.3	2,000	690	<0.001	<0.001	0.0	<0.001	0.01	46	200	<0.2	100
TSF Decant C2	22/07/2018 08:00:00	5,900	7.6	4,800	2,600	<5	<0.005	<0.001	0.03	<0.001	0.4	<0.0001	600	1,000	0.1	<0.001	<0.001	<0.005	<0.001	280	<0.001	0.0	0.0	<0.05	49	0.03	23	<0.001	490	2.4	2,000	720	<0.001	<0.001	0.0	<0.001	<0.005	27	120	<0.2	99
TSF Decant C2	30/07/2018 00:00:00	6,000	7.6	4,800	2,600	<5	<0.005	<0.001	0.03	<0.001	0.52	<0.0001	580	1,000	0.1	<0.001	<0.001	0.05	<0.001	280	0.0	0.0	0.0	<0.05	47	0.03	23	0.0	490	2.4	2,000	730	<0.001	<0.001	0.0	<0.001	<0.005	67	300		100
TSF Decant C2	06/08/2018 09:00:00	6,200	7.6	5,000	2,800	18	<0.005	<0.001	0.03	<0.001	0.5	<0.0001	640	1,100	0.11	<0.001	<0.001	<0.005	<0.001	290	<0.001	0.0	0.0	<0.05	52	0.03	24	<0.001	520	2.4	2,100	740	<0.001	<0.001	0.0	<0.001	<0.005	81	360	<0.2	110
TSF Decant C2	12/08/2018 10:00:00	6,400	7.7	5,200	2,900	<5	<0.005	<0.001	0.03	<0.001	1.2	<0.0001	680	1,100	0.12	<0.001	<0.001	<0.005	<0.001	300	0.0	0.0	0.0	<0.05	56	0.03	25	<0.001	510	2.5	2,300	670	<0.001	<0.001	0.0	<0.001	<0.005	59	260	<0.2	110
TSF Decant C2	20/08/2018 09:30:00	6,300	7.7	4,900	2,700	6	<0.005	<0.001	0.03	<0.001	0.99	<0.0001	620	1,100	0.13	<0.001	<0.001	<0.005	<0.001	280	0.0	0.0	0.0	<0.05	53	0.03	31	<0.001	530	2.5	2,100	810	<0.001	<0.001	0.0	<0.001	<0.005	64	280	0.2	110
TSF Decant C2	26/08/2018 12:42:00	6,300	7.7	5,200	2,700	8	<0.005	<0.001	0.03	<0.001	0.77	<0.0001	610	1,100	0.12	<0.001	<0.001	<0.005	<0.001	280	0.0	0.0	0.0	<0.05	55	0.03	30	<0.001	550	2.4	2,100	770	<0.001	<0.001	0.0	<0.001	<0.005	69	300	<0.2	110
TSF Decant C2	02/09/2018 00:00:00	5,900	7.8	5,100	2,700	<5	<0.005	<0.001	0.03	<0.001	1	<0.0001	630	1,100	0.12	<0.001	<0.001	<0.005	<0.001	280	0.0	0.0	0.0	<0.05	49	0.03	31	<0.001	510	2.3	2,000	690	<0.001	<0.001	0.0	<0.001	<0.005	63	280	<0.2	110
TSF Decant C2	09/09/2018 10:00:00	5,600	7.7	4,600	2,500	6	<0.005	<0.001	0.03	<0.001	0.98	<0.0001	570	1,100	0.1	<0.001	<0.001	<0.005	<0.001	260	0.0	0.0	0.0	<0.05	50	0.03	29	<0.001	530	2.2	1,700	660	<0.001	<0.001	0.0	<0.001	<0.005	74	330	<0.2	110
TSF Decant C2	16/09/2018 10:00:00	5,200	7.7	4,100	2,300	<5	<0.005	<0.001	0.03	<0.001	0.39	<0.0001	530	990	0.09	<0.001	<0.001	<0.005	<0.001	240	0.0	0.0	0.0	<0.05	44	0.03	28	<0.001	480	1.9	1,500	560	<0.001	<0.001	0.0	<0.001	0.01				110
TSF Decant C2	23/09/2018 00:00:00	5,100	7.7	3,900	2,000	24	<0.005	<0.001	0.03	<0.001	0.39	<0.0001	470	1,000	0.08	<0.001	<0.001	<0.005	<0.001	210	<0.001	0.0	0.0	<0.05	39	0.03	26	<0.001	470	1.6	1,500	540	<0.001	<0.001	0.0	<0.001	<0.005	58	260	<0.2	110

Count		38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	36	36	34	38
Minimum		3,900.0	7.6	2,700.0	1,400.0	5.0	0.005	0.001	0.02	0.0	0.15	0.0001	330.0	630.0	0.04	0.0	0.001	0.01	0.001	140.0	0.0	0.0	0.0	0.05	25.0	0.01	19.0	0.0	320.0	1.0	930.0	290.0	0.0	0.0	0.0	0.0	0.01	0.35	1.5	0.05	86.0
Maximum		6,400.0	8.0	5,200.0	2,900.0	49.0	0.005	0.001	0.04	0.0	1.2	0.0001	680.0	1,200.0	0.14	0.0	0.001	0.05	0.002	300.0	0.006	0.0	0.002	0.05	56.0	0.041	38.0	0.001	550.0	2.6	2,300.0	810.0	0.0	0.0	0.0	0.0	0.021	81.0	360.0	4.8	110.0
Average		4,934.21	7.72	3,723.68	1,997.37	11.03	0.005	0.001	0.03	0.0	0.53	0.0001	464.74	858.95	0.07	0.0	0.001	0.01	0.001	205.53	0.002	0.0	0.001	0.05	36.95	0.023	23.47	0.001	421.32	1.67	1,433.42	506.32	0.0	0.0	0.0	0.0	0.006	43.95	193.04	1.0	97.84
Standard Devisation		894.21	0.1	885.75	525.81	10.02	NA	0.0	0.01	NA	0.26	NA	117.47	162.09	0.03	NA	NA	0.02	NA	56.98	NA	0.0	0.0	NA	10.88	0.01	4.39	NA	73.01	0.54	461.25	164.7	NA	NA	0.0	0.0	NA	17.22	76.74	1.52	8.23
Exceedances		0	0	0	0	0	0	0	0	0	0	0.0000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% of Count		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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