MULGA ROCK URANIUM PROJECT

RESULTS OF SOLUTE TRANSPORT MODELLING FOR IN-PIT TAILINGS STORAGE

REPORT FOR VIMY RESOURCES LTD

OCTOBER 2015

Mulga Rock Uranium Project - Public Environmental Review - December 2015
Appendix D - Hydrological Processes / Inland Waters Environmental Quality

D10

Rockwater
HYDROGEOLOGICAL AND ENVIRONMENTAL CONSULTANTS

Report No. 345.0/15/07b

76 Jersey Street Jolimont 6014 Western Australia Postal: PO Box 201 Wembley 6913 Western Australia
Ph: 61 8 9284 0222 Fax: 61 8 9284 1785 Email: consult@rockwater.com.au www.rockwater.com.au ABN: 43 008 804 653

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Rev 0	PHW	JRP	1/10/15
Rev 1	MJT		7/10/15
Rev 2	PHW	MJT	29/10/15

1 INTRODUCTION

The Mulga Rock Uranium Project (MRUP) lies approximately 240km east-north-east of Kalgoorlie-Boulder in the Shire of Menzies (Figure 1). The area is remote, located on the western flank of the Great Victoria Desert, comprising series of large, generally parallel sand dunes, with inter-dunal swales and broad flat plains.

Access to the Project area is limited and is only possible using four-wheel-drive vehicles. The nearest residential town to the Project is Laverton which lies approximately 200 km to the north-west. Other regional residential communities include Pinjin Station homestead located approximately 100km to the west, Coonana Aboriginal community situated approximately 130km to the south-south-west, Kanandah Station homestead positioned approximately 150km to the south-east and the Tropicana Gold Mine lying approximately 110km to the north-east of the Project (Figure 1).

The MRUP covers approximately 102,000 hectares on granted mining tenure (primarily M39/1080 and M39/1081) within Unallocated Crown Land (UCL). It includes two distinct mining centres, Mulga Rock East (MRE) comprising the Princess and Ambassador resources and Mulga Rock West (MRW) comprising the Emperor and Shogun resources, which are approximately 20km apart (Figures 2 and 3). MRE contains over 65% of the total recoverable uranium and is of a higher grade than MRW. Mining will commence at MRE which will include the location of the processing plant. Up to 4.5 Million tonnes per annum (Mtpa) of ore will be mined using traditional open cut techniques, crushed, beneficiated and then processed at an acid leach and precipitation treatment plant to produce, on average, 1,360 tonnes of uranium oxide concentrate (UOC) per year over the life of the Project. The anticipated Life-of-Mine (LOM) is up to 16 years, based on the currently identified resource.

Other metal concentrates will be extracted using sulphide precipitation after the uranium has been removed and sold separately. These metal concentrates will not be classified as radioactive. The UOC product will be sealed in drums and transported by road from the mine site in sealed sea-containers to a suitable port (expected to be Port Adelaide) which is approved to receive and ship Class 7 materials for export.

The MRUP will require the clearing of vegetation, borefield abstraction, mine dewatering and reinjection, the creation of above-ground and in-pit overburden (non-mineralised) and tailings landforms and the construction of on-site processing facilities and associated infrastructure. Key Project infrastructure will include mine administration and workshop facilities, fuel and chemical storage depots, a diesel-fired power plant of up to 20 megawatt (MW) capacity and distribution network, a saline abstraction borefield and a saline mine water reinjection borefield with associated pipelines and power supply units, an accommodation village servicing a fly-in/fly-out workforce, an airstrip, laydown areas and other supporting ancillary infrastructure including communications systems, roads, a waste water treatment plant and solid waste landfill facilities. Transport to site for consumables, bulk materials and general supply items will be via existing public road systems linked to dedicated Project site roads, branching off the Tropicana Gold Mine access road.

At the completion of operations, the Project site will be decommissioned and rehabilitated in accordance with an approved Mine Closure Plan.

1.1 MODELLING OBJECTIVES

The objectives of the solute transport modelling are to determine the potential impacts of seepage from in-pit tailings storages, using the metals of concern at the expected maximum concentrations identified from leaching tests conducted by ANSTO and reported by GHD (2015a) – these metals are uranium, copper, cobalt and zinc. Tailings may also be stored in a lined, above-ground storage (TSF) early on the project life (GHD, 2015b): the lining should prevent any seepage from that facility.

The modelling is to include the effects of variable densities arising from variations in salinity, and up to 10,000 years of groundwater flow.

This report presents the results of solute transport modelling to determine the potential impacts of seepage from an in-pit TSF. The model inputs and parameters have been adopted to ensure the model is conservative in calculating metal concentrations.

2 PREVIOUS INVESTIGATION

Rockwater (2015) carried out numerical flow modelling of the project area to assess dewatering requirements and the potential impacts of re-injection. That model was used as the basis for the SEAWAT/MT3DMS density and solute transport modelling described herein.

3 HYDROGEOLOGICAL SETTING

3.1 CLIMATE

The MRUP is located in the Great Victoria Desert and has an arid climate with hot dry summers and cool to mild winters. The nearest long-term climate station is at Edjudina (BoM Station 012027), 145 km to the west of the Ambassador deposit. Average rainfall data for the station (1900 to 2014) are given in Table 1.

Table 1: Average Monthly Rainfall (mm) Edjudina (BoM Station 012027)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
22.4	28.2	26.1	19.6	22.0	22.1	19.2	16.7	9.7	11.8	14.0	12.8	222.6

Most of the rain falls in irregular thunderstorm events or during the passage of the remnants of cyclones, with some frontal systems in winter. Daily rainfalls have been up to 98 mm (in February). No other climate data are available for the station.

The MRUP has maintained climate stations at the airstrip and at the Emperor and Shogun deposits since March 2009. A suite of climatic measurements has been made including rainfall, maximum and minimum air temperature, and pan evaporation.

Rainfall at the MRUP airstrip from 2010 to November 2014 can be compared with those at Edjudina in Table 2.

Table 2: Comparison of Annual Rainfall, Edjudina and Mulga Rock Airstrip

Year	Total Rainfall (mm)	
	Edjudina	Mulga Rock Airstrip
2010	222	173
2011	503	433
2012	337	129
2013	284	170
2014 to Nov.	469	160

The comparison of annual rainfall amounts over the period shown in Table 2 suggests that the climate at the MRUP is substantially drier than at Edjudina. Monthly rainfall data for the three MRUP climate stations are shown in Table 3. These also show a general decrease in rainfall from west (Emperor) to east (Airstrip).

Pan evaporation at the MRUP airstrip station from Dec-13 to Nov-14 was significantly lower than the average for Kalgoorlie (Luke, Burke and O'Brien, 1988), as shown in Table 4.

Table 3: Monthly Rainfall (mm) at the MRUP Climate Stations

Month	Airstrip					Emperor					Shogun				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
January	9.3	58.7	23.6	15.2	65.7	0	108.2	55.4	20.8	128.8	3	105.8	62.6	15.2	116.6
February	10.3	191.3	13.7	7.5	31.3	12.6	252.4	23	3.8	51.8	15	247.4	21.6	10.2	49.2
March	5.9	9.3	20.7	36.6	3.3	3.6	17	47.4	70	11.8	11.2	18.2	48.8	58.2	12.2
April	31.3	20.3	0.7	8.6	0.9	38.2	28.8	0.2	14.6	21.4	53	33.8	0.2	16.6	12
May	8	11.2	2.6	18.7	17.2	7.3	17.4	2.6	18.2	38.4	9.1	19.8	3	31	31.6
June	7.8	57.2	6.9	4.5	4.6	7.8	85.2	10	5.8	6.6	9.6	82.2	13.2	7.2	7.2
July	8.8	21	2.1	8.1	2.5	13.2	38.4	2.4	14.7	4	12	36.2	3.4	13	4
August	55.1	1.9	0.6	2.1	0.4	86.8	3	1.4	3.4	1.2	79.2	3	0.8	1.8	1.2
September	27.4	2.1	0.6	5.8	5.1	36.4	5.6	1	13.2	7.6	36.2	4	0.8	10	6.8
October	1.5	36.7	3.8	0.9	9	0.6	61.4	9.4	1.2	19.2	1.8	59.2	6.4	2.8	17.4
November	1.9	12.2	35.1	47.9	21.6	2	24.4	48	65.4	30	1	24.2	50.8	57.2	32
December	7.7	12.7	17.5	15	N/A	7.4	28.8	53.8	16.8	N/A	9	22.8	28.4	16	N/A
Annual Total	175	434.6	127.9	170.9	161.6	215.9	670.6	254.6	247.9	320.8	240.1	656.6	240	239.2	290.2

Table 4: Comparison between Average Pan Evaporation at Kalgoorlie and the MRUP (2014)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
MRUP (2014)	306	280	225	211	150	91	81	90	140	206	255	276	2309
Kalgoorlie (Av.)	431	346	306	199	133	93	103	130	181	271	326	424	2943

Maximum and minimum air temperatures at the three MRUP weather stations are shown with monthly rainfalls in Figure 4. The temperatures are very similar at all three stations. In 2014, average maximum air temperatures ranged from 18.6 ^{o}C in June to 34.6 ^{o}C in January; and average minimum temperatures ranged from 1.1 ^{o}C in July to 18.0 ^{o}C in January.

3.2 REGIONAL GEOLOGICAL SETTING

Mineral exploration holes drilled by Vimy and its predecessor PNC, as well as other companies including Uranerz and Paladin, have shown that the Mulga Rock palaeodrainage is about 8 to 10 km wide. The eastern arm of the palaeodrainage is probably continuous over a length of at least 65 km, and is interpreted in plans and sections in Uranerz (1986) to be hydraulically connected to a trunk palaeodrainage that follows Ponton Creek to the south and is downstream of the confluence of the Lake Raeside, Lake Rebecca and Roe palaeodrainages (Fig. 5).

The palaeodrainage skirts a southerly extension of the Gunbarrel Basin, which contains sediments of Carboniferous to Pleistocene age, and is bounded by crystalline rocks of the Yilgarn Craton of Archaean age to the west and the Albany Fraser Province of Proterozoic age to the east (Fig. 5).

3.3 LOCAL GEOLOGY

The geology of the eastern part of the MRUP, from information provided by Vimy, can be summarised as follows.

Ambassador is a sediment-hosted uranium deposit. This deposit, together with the other MRUP deposits, occurs within the Narnoo Basin, a local name for the host structure. The mineralisation is primarily in geochemically reduced sediments of Eocene age, preserved within a complex set of sedimentary troughs overlying an extensive paleodrainage referred to as the Mulga Rock palaeodrainage, which is probably an isolated oxbow channel of the Lake Raeside regional paleodrainage that remains after the capture of three trunk palaeodrainages by the Ponton Creek palaeodrainage The Mulga Rock palaeodrainage is probably still hydraulically connected to the Ponton Creek palaeodrainage some 65 km to the south along the eastern arm.

The reduced sediments that contain the Ambassador and other deposits are part of a sedimentary package named the Narnoo Basin Sequence. This sequence consists of multiple fining-upwards units including sandstone, claystone (typically carbonaceous) and lignite which were deposited in alluvial and lacustrine environments.

Sedimentation within the Eocene palaeodrainage is interpreted as a transgressive sequence. The lowest part of the sequence is dominated by medium to coarse, marginally carbonaceous sands. These sands are mostly devoid of clay and are highly transmissive to groundwater flow. The central portion of the sequence is dominated by fine textured, organic-rich sediments (highly carbonaceous fine sands, lignitic clays and lignite) containing humic macerals of low reflectance (huminite). These fine-textured sediments occur at and near the maximum flooding surface of the transgression. The upper portion of the sediments are dominated by stacked beds of reverse graded (upward coarsening) sands that represent the progradational portion of the transgression.

The main sequence of Late Eocene lacustrine sediments correlates regionally with the third-order transgressive sequences of the Tortachilla cycle (~39 Ma) whilst the youngest Late Eocene sediments correlate with the Tuketja (~36 Ma) transgressive cycle.

Cretaceous sediments are dominant in the north-eastern part of the Ambassador deposit and also occur around the deposit margins. Although superficially similar to the late-Eocene palaeodrainage sediments, they do not have the regular transgressive sequence of the later sediments and are characterised by beds of black, mature forms of carbonaceous material such as inertinite and glassy vitrinite. The Cretaceous sediments are probably remnants of a formerly deeply buried sequence that covered much of southern Australia prior to the Late Cretaceous (Albian-Maastrichtian) uplift.

Overlying the Narnoo Basin Sequence is a succession of oxidised sediments which at Ambassador are about 36 to 55 m thick. Pre-Cretaceous and Eocene basement in the Ambassador area consists of a Carboniferous sedimentary succession, as well as Paleoproterozoic metasediments to the east of the Gunbarrel fault. The Carboniferous sediments are assigned to the Paterson Formation and understood to be part of the Gunbarrel Basin.

Mineralisation is believed to have formed via biogenic processes, through the fixation of metals in solution that were mobilised in the course of repeated weathering episodes, resulting in the leaching of the upper part of the Eocene and thick sections of Cretaceous sediments up-gradient of the deposits. This weathering is akin to acid-sulphate weathering processes, oxidising sulphides and organic matter and organic carbon resulting in very aggressive groundwater conditions (low pH and elevated temperature), and thereby mobilising metals and metalloids (including silica) from the overburden. The remnant, highly altered material is typically strongly bleached and characterised by a kaolinite fraction of notably high crystallinity (due to dissolution and recrystallisation of the clay).

The uranium mineralisation is assumed to be similar in nature to that studied at Ambassador via multiple recent spectral, mineralogical, deportment and metallurgical studies, showing that the bulk of the uranium is in a hexavalent ionic state and adsorbed onto organic matter, with a negligible fraction contained in refractory minerals.

Similarly, the majority of base metals in the deposits are expected to be bound to organic matter, with a significant fraction in sulphate phases and a lesser fraction in supergene sulphide phases.

3.4 HYDROGEOLOGY

The water table at the Ambassador deposit is 29 m to 49 m deep, and generally lies within fine-grained, carbonaceous sediments of Eocene age; and in the north-east, of Cretaceous age. The mineralised zones are mainly just below the water table, but some extend down into the coarse-grained sediments towards the base of the palaeodrainage (see the geological sections in Appendix I).

Reduced groundwater levels within the palaeodrainage that have been measured at various times are shown in Fig. 6, with values shown for representative bores that were used to calibrate the groundwater model described in Section 4 below. They show that in most of the Narnoo Basin/paleodrainage the water table is very flat, at an elevation of about 288 to 290 m AHD, and that there is very little flow into the basin (or recharge) and out of the basin (discharge). Hydraulic gradients suggest there is minor flow into the basin from the north-eastern tributary that includes the Ambassador deposit; and a small component of flow into the basin from the north-west.

Limited data suggest there is flow from north to south in the western arm under a low hydraulic gradient. There is also indicated to be flow to the south in the eastern arm, south of about 6655000 mN – the steeper hydraulic gradient there is attributed to a narrowing of the channel containing coarse-grained sediments and lower transmissivity as indicated by Uranerz Section 92,500 N, which is at about 6655700 mN (GDA) (Appendix I). There, much of the channel is filled with fine-grained sediments.

Water-level measurements taken in April 2014 in the Ambassador area (Fig. 7) show that the water table is very flat in Ambassador East at about 299 m AHD; and there is a low hydraulic gradient from 291 m to 293 m AHD in Ambassador West. There is a relatively steep gradient between these two parts of Ambassador due to the presence of a fault and a high of Permian sediments separating the Eocene sediments in each area. This is shown by the Long Section N30 in Appendix I.

Seasonal and annual water-level variations are very small, showing there is very little recharge to the aquifer and no extraction or significant flow out of the basin. Groundwater levels were monitored every one to three months in 38 bores in the Ambassador area from 2010 to 2014. Most of the August 2012 measurements were in error, presumably due to a faulty probe. Without those measurements, the range in water-level fluctuations in the bores was from 0.05 m to 0.76 m, and averaged 0.25 m. The higher ranges probably included some measurement errors and the impacts of pumping for sampling, and so the actual range and average would have been lower.

The results of pumping tests of three bores screened in the basal Eocene palaeodrainage sediments (Rockwater, 2015) indicate that these sediments are moderately to highly permeable, with hydraulic conductivities ranging from 9 to 140 m/d. The low value is typical of these sediments where tested elsewhere in the Eastern Goldfields. The high values at bores NWB1 and 2 in the planned injection area reflect the local gravels screened by the bores. Hydrogeological sections through these bores are presented in Figs 8 and 9. The section lines are shown in Fig. 6.

The fine-grained sediments higher in the palaeodrainage, generally associated with the mineralised zones, will have low hydraulic conductivity as shown by the results of slug tests (Rockwater, 2015).

The groundwater is unconfined at the water table, but confined below by the fine-grained sediments above and within the basal sands and gravels.

3.5 GROUNDWATER CHEMISTRY

Details of the groundwater chemistry are given in Rockwater (2015). Some details relevant to the solute-transport modelling are given below.

3.5.1 Ambassador/Princess

Water analyses show that the water ranges in salinity from 7,500 to 80,000 mg/L TDS (generally 20,000 to 30,000 mg/L TDS). Most of the high salinity water was in holes west of Ambassador. The water is moderately acidic to neutral with pH ranging from 3.0 to 8.0 (generally 5.5 to 6.6); and is of a sodium chloride type with elevated magnesium and sulphate. Metals and other elements that were analysed-for were generally at low concentrations. Exceptions were moderate to high concentrations of iron in several holes (up to 56 mg/L); and high bromine concentrations (up to 23 mg/L). Uranium concentrations were mostly below the limit of detection (0.002 mg/L), with a maximum of 0.038 mg/L.

Copper is up to 2.8 mg/L; cobalt up to 4 mg/L; and zinc up to 13 mg/L.

Water samples taken from the Princess deposit have been measured in the field in 2012 and 2013 for salinity and pH. The water is acidic, with pH generally ranging from 5.0 to 6.5. Lower pHs of around 3 have been measured in one hole, NNA5623. Salinities are lower than most at Ambassador, ranging from 8,700 to 21,400 mg/L TDS, as the deposit is up-gradient of Ambassador.

3.5.2 Reinjection Area

Water in the main palaeodrainage in the reinjection area, 10 to 15 km south of Ambassador, is moderately acidic with pH ranging from 4.0 to 6.9, and is generally between 4.5 and 5.0. It is of a sodium chloride type, with relatively high magnesium and sulphate concentrations. Salinity ranges from 20,000 to 73,000 mg/L TDS and averages 51,500 mg/L TDS; generally significantly higher than for groundwater in the Ambassador/Princess area.

There is a good correlation between sample depth and salinity (Fig. 10). Seepage from in-pit tailings will infiltrate to shallow groundwater of similar salinity to that at the Ambassador deposit. The zone where any seepage would reach the water table includes reactive carbon-rich layers that will tend to fix any metals in the leachate.

Where analysed, metals and trace elements in groundwater in the reinjection area were at low levels or below the limits of reporting. There were some elevated boron concentrations of 4.2 to 7.2 mg/L in seven of the bores. Copper was up to 0.98 mg/L; cobalt up to 0.024 mg/L; and zinc up to 2.4 mg/L.

4 NUMERICAL GROUNDWATER MODELLING

The numerical groundwater flow and solute transport model is based on the local hydrogeology, described in Section 3 above, that is generalised in the conceptual site model.

4.1 CONCEPTUAL SITE MODEL

The area modelled covers the Princess and Ambassador deposits, which lie in a tributary to the Mulga Rock palaeodrainage, and the eastern arm of the Mulga Rock palaeodrainage. The water table ranges from about 29 m depth at Princess to 49 m deep in the main palaeodrainage, and is overlain by mainly fine-grained sediments. The fine-grained sediments restrict vertical flow of groundwater within the palaeodrainage.

There is interpreted to be fault and a basement high resulting in restricted groundwater flow between the eastern and western parts of the Ambassador deposit. This is shown by geological sections prepared by Vimy (Appendix I); and there is a step in groundwater levels on each side of this structure (Fig. 7).

The proportion of coarse grained sediments in the palaeodrainage increases with depth, particularly in the main palaeodrainage, and there are larger thicknesses of coarse, well-sorted sand and gravel in the planned reinjection area. A diagram of the generalised geology at Ambassador is shown in Fig. 11.

Under baseline conditions, there are very low hydraulic gradients within the tributary and main palaeodrainages indicating very low rates of recharge and groundwater throughflow. This is consistent with the high groundwater salinities. The hydraulic gradients indicate minor groundwater inflow to the tributary palaeodrainage from the north, and possibly minor recharge in the Princess/Ambassador area.

There are higher hydraulic gradients indicated south of the reinjection area that are interpreted to result from the narrowing of the palaeodrainage, and lower hydraulic conductivities of the basal palaeodrainage sediments. These gradients indicate that groundwater continues to flow to the south out of the modelled area.

Groundwater salinities generally increase with depth, and down-gradient to the south in the paleodrainage.

4.2 DESCRIPTION OF NUMERICAL MODEL

The numerical groundwater flow model which was constructed to represent the Mulga Rock palaeodrainage and to estimate dewatering flow rates (Rockwater, 2015) consists of a rectangular grid of 142 rows, 104 columns and three layers covering an area of 45 km east–west by 65 km north–south. Cell sizes are 500 m by 500 m in general, and 250 m by 250 m in the Ambassador area. Layer 1 represents fine-grained sediments near the water table; Layer 2 consists of interbedded sands and clays and admixtures; and Layer 3 represents the basal sand/gravel.

In order to run the SEAWAT/MT3DMS density and solute-transport model for the present modelling operation, it was necessary to increase the number of layers to make vertical density changes more gradual. The flow model was sub-divided into six layers, with Layer 1 of the original model divided into Layers 1 and 2 of the new model; Layer 2 becoming

Layer 3 in the new model; and Layer 3 divided into Layers 4 to 6 of the new model. The model layers at Ambassador West are shown with the geology in Fig 11.

The new model had to predict changes over 10,000 years to meet the requirements of the Environmental Protection Authority (EPA) and Department of Environment Regulation (DER). Initial model runs showed that the new model would not converge, and so it was necessary to regularise the model grid and the top and base elevations, as well as to limit the model to the tributary palaeodrainage which includes Ambassador and the eastern arm of the main palaeodrainage, and straighten a section of that drainage.

The new flow-density coupled model consists of a regular rectangular grid of 225 rows, 33 columns and six layers covering an area of 8.25 km north-west to south-east and 56.4 km north-east to south-west (Fig. 12). The cell sizes are 250 m by 250 m.

4.2.1 Boundary Conditions

The model boundaries are generally no-flow, representing the edges of the palaeodrainage. There is a constant-head boundary north of Ambassador to represent flow into the model area in the tributary palaeodrainage (Layers 1 to 5); and another in Layer 6 at the southern end of the model to simulate flow out of the modelled area.

4.2.2 Modelling Process

The model utilises Processing Modflow Pro version 8.0.42 (Simcore Software, 2010), which includes Modflow-2005, finite difference groundwater flow modelling software designed by the U.S. Geological Survey (Harbaugh, 2005); variable-density modelling software SEAWAT Version 4 (Langevin et. al., 2007); and solute-transport modelling software MT3DMS Version 5 (Zheng, 2010). Modflow calculates groundwater flows using the hydraulic gradients and aquifer parameters (principally vertical and horizontal hydraulic conductivities). SEAWAT alters hydraulic heads to account for density differences resulting from variations in salinity, and is coupled with MT3DMS which models the transport of dissolved chemical constituents and includes the impacts of dilution, dispersion and adsorption/desorption. Chemical reactions can also impact solute transport – these can be broadly represented using distribution coefficients that also cover retardation by adsorption/desorption.

4.2.3 Sink-Source Terms, Flow Pathways, and Receptors

Sources represented in the model include:

- Flow into the modelled area represented by constant heads at the northern end of the model in Layers 1 to 5. Concentrations for these cells were generally set to be zero, except for salinity where they were set at the value adopted for the corresponding layer; and uranium for the 0.02 mg/L background scenario;
- Minor recharge in the Princess/Ambassador area. Concentrations applied to recharge were generally zero, except for salinity where the Layer 1 value was used, and 0.02 mg/L uranium for the 0.02 mg/L background scenario;
- Seepage from a nominal in-pit TSF in the Ambassador deposit, with relatively high rates of seepage during active tailings disposal and low rates of seepage following tailings consolidation. Seepage during tailings disposal will be enhanced by the deposition of sand in the base of the mine pit during in-pit beneficiation of the ore; and
- Re-injection of surplus water will also be a source, but that was not modelled as it will be very short-term when compared with TSF seepage, and the total period modelled (10,000 years).

Flow pathways will be almost entirely through lensoid and continuous beds of sand and fine gravel within the palaeodrainage; and horizontal flows will be much greater than vertical flows. Clay and clayey sand layers will impede both vertical and horizontal flow. Carbonaceous sediments will result in chemical reactions which will impede the transport of components of concern (U, Cu, Co and Zn), but as a conservative approach, this has been ignored in the modelling.

System sinks include dewatering bores and sumps but these were not modelled as any impacts will be for a very short period (16 years). The only other sink is flow out of the modelled area that is simulated using constant-head cells in Layer 6. It is very unlikely that there will ever be any groundwater extraction post-mining from the palaeodrainage, and there are no other receptors such as areas of groundwater discharge within the 10,000-year flow-path.

4.3 MODEL PARAMETERS

The new flow-density coupled model was initially set up with parameters determined from the pumping and slug tests (Rockwater, 2015); and assumed values based on grain sizes and our experience in modelling similar hydrogeological environments. The parameters, particularly horizontal hydraulic conductivity of the main aquifer in Layers 4 to 6, were varied in the calibration of the model. Parameters adopted on calibration of the model are given in Table 5.

Horizontal hydraulic conductivity values are predominantly 0.1 m/d in Layers 1 and 2, 1 m/d in Layer 3, and 2.1 to 8 m/d in Layers 4 to 6. A value of 5 m/d, typical of fine to medium sand was used in Layer 2 in the Ambassador area to represent sand that will remain in mined-out areas after in-pit beneficiation of the ore. Also, a value of 0.12 m/d was used where a low-permeability fault zone lies between Ambassador West and Ambassador East. In Layers 4 to 6, there are higher values (up to 74 m/d) in the planned injection area.

Table 5: Adopted Aquifer Parameters

Parameter	Units	Layer 1	Layer 2	Layer 3	Layers 4 to 6
Horiz. Hydraulic Cond.	m/d	0.1	0.1, 5	1	1.3-74
Vert. Hydraulic Cond.	m/d	0.01	0.01	0.1	0.5
Specific Yield	v/v	0.05	0.05	0.1	0.15
Storage Coefficient	v/v	NA	0.0008	0.0008	0.0008
Recharge	m/d	0, 0.000001			

Recharge was assumed to be zero for much of the modelled area, except for a very low rate of 0.000001 m/d in part of the north-eastern tributary that contains Ambassador.

Initial water levels were those calculated in steady-state calibration to the measured water levels shown in Figs. 6 and 7.

4.4 MODEL CALIBRATION

Minor re-calibration was required for the new flow-density coupled model in steady-state mode, to replicate groundwater levels measured at various times in representative bores/holes along the palaeodrainage (Fig. 6). This was achieved by varying the horizontal hydraulic conductivity of the main, basal sand aquifer (Layers 4 to 6). The parameters adopted for the minor aquifers/aquitards and aquicludes of Layers 1 and 2 have negligible impact on the calibration; and storativity (specific yield and storage coefficient) is not part of a steady-state simulation.

As for the original flow model which had been calibrated in both steady-state and transient modes (Rockwater, 2015), there is a close correspondence between measured and model-calculated groundwater levels, with a scaled root mean square error for all of the calibration bores of 3.05 %, much lower than the 5 % limit recommended in the 2000 groundwater modelling guidelines (Middlemis, 2000), and 5 % or 10 % (if achievable) given in the more-recent guidelines (Barnett et. al., 2012).

Note that although calibrated, the model is based on a small data-set and so the modelling results are not unique. Also, there are no data available for calibration of the density and solute transport model. Instead, sensitivity analyses were undertaken to quantify the degree of uncertainty in the modelling results.

4.5 MODEL SIMULATION AND RESULTS

4.5.1 Modelling Method and Assumptions

The model was used to simulate seepage from in-pit tailings, to determine the impacts on groundwater down-gradient in the palaeodrainage.

The mine water balance dated 18 May 2015 indicates that 232.9 m^3/hr (kL/hr) of water will be pumped as tailings to an in-pit tailings storage facility (TSF). Over a 16-year mine life, the total volume of water pumped would be 3.264E7 kL. Assuming there will be open water over an area of 125,000 m^2 throughout the 16 years, and annual net dam evaporation of about 1,670 mm/a, or about 3.340E6 kL, in total could be evaporated over the mining period. This would leave 2.93E7 kL in the tailings. The water balance indicates that seepage from the tailings will be about 28.6 m^3/hr (686 kL/d) while the mine is operating. Consolidation of the tailings will greatly reduce the rate of seepage, and some water, perhaps 15%, will remain bound up in the tailings.

Based on the adopted model parameters, the volume of water in the tailings, and the results of initial model runs, it is estimated that water will continue to seep from the tailings for 284 years (16-year mining case) after the end of mining, after which 15% of the original volume is assumed to remain.

Modflow's River package was used to simulate seepage from a TSF located in Ambassador West (there will also be a TSF at Princess, but it was assumed all seepage would be from Ambassador as a worst case). The adopted location is shown in Fig. 6. The hydraulic conductance term was selected to give a similar rate to that indicated by the water balance for the period of mining, and then reduced markedly for the post-mining period to simulate post-compaction seepage. The head in the TSF was assumed to be 10 m – which with a conductance of 5,000 m^2/d gave a seepage rate of about 686 kL/d.

Parameters used for the solute-transport modelling are those adopted by GHD (2015a) (Appendix II and Table 6) that include maximum source concentrations derived from the results of leachate tests conducted by ANSTO. Those tests indicated that coefficients of adsorption are likely to be low for the metals of concern but could be up to 32 mL/g for uranium, as adopted by GHD. In the modelling coefficients of adsorption were assumed to be zero, although a model run was also made with the above coefficient of adsorption for uranium.

Based on an average extraction rate of 1.8 GL/a from the Kakarook North borefield with a salinity of 6,000 mg/L TDS (Rockwater, 2015a), and 0.7 GL/a of 30,000 mg/L TDS water from dewatering, the tailings salinity could be 12,700 mg/L TDS or 15,000 mg/L TDS after recycling and evaporation. The latter value was used for the density modelling. Background salinity values for the model layers are based on salinity measurements that have been made by Vimy, and the general trend of increasing salinity with depth (Fig. 10). They range from 20,000 mg/L TDS at Ambassador East to 30,000 mg/L in the main palaeodrainage in Layer 1 (Fig. 13), to 30,000 mg/L TDS at Ambassador to 60,000 mg/L TDS in the main palaeodrainage in Layer 6 (Fig. 14).

Initial concentrations were set at zero, except for salinity where values are as described above; and uranium for the 0.02 mg/L background scenario. Consequently, calculated metal values are concentrations above background values.

Parameters adopted for the solute transport modelling are summarised in Table 6.

Table 6: Summary of Solute Transport Parameters

Parameter	Unit	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
Effective Porosity	v/v	0.05	0.05	0.1	0.1	0.1	0.1
Bulk Density	kg/m^3	1,600	1,600	1,600	1,600	1,600	1,600
Salinity Ambassador	mg/L TDS	20,000	20,000	20,000	25,000	30,000	30,000
Salinity main palaeoch.	mg/L TDS	30,000	30,000	32,000	40,000	50,000	60,000
Tailings Salinity	mg/L TDS	15,000					
Tailings Conductance	m^2/d	5,000 mining; 63 post-mining					
Dispersivity	m	25 longitudinal; 2.5 transverse; 0.1 vertical					
Source Concentrations	mg/L	U 0.14; Cu 6; Co 2.2; Zn 10.3					

The solute transport model was first run for the adopted case with density (SEAWAT) and dispersivity active, for a 16-year mine life. Three stress periods (SP) were simulated: SP1 for 16 years with active tailings disposal; SP2 for 284 years with seepage from consolidated tailings; and SP3 for a further 9,700 years with no further source inputs. Sensitivity analyses were also conducted (see Section 4.6).

4.5.2 Modelling Results

Flow-path modelling results which use advective flow only, suggest that groundwater in the most-transmissive basal sand will move about 43 km south of the TSF in 7,000 years (Fig. 15).

The solute-transport modelling results are shown as concentration versus time curves for each of the metals of concern (U, Cu, Co and Zn) and each model layer in Figs 16 to 19, at the southern boundary of the mining tenement M39/1080 (shown in Fig. 6). These concentrations are compared with average and maximum concentrations for the Mulga Rock site, and guideline values for domestic non-potable groundwater use (DoH, 2006). The calculated concentrations are for those above background concentrations. An additional model run with 0.02 mg/L background uranium concentrations gave values 0.02 mg/L higher than for the adopted case, as expected (Fig. 16).

The results indicate that peak concentrations at the mining tenement M39/1080 boundary will occur after about 1,500 years (from the start of tailings emplacement) in layers 3 to 6, and after about 2,000 to 3,000 years in the less-permeable layers 1 and 2. Peak concentrations will generally be above average background concentrations at the MRUP, but much lower than the maximum concentrations. In all cases, the concentrations will be well below the DoH guideline values. Concentrations in the plume from the TSF will continue to decrease as it continues to move south along the East Arm palaeodrainage.

Plots showing distance versus time for the uranium plume-front (concentration 0.02 mg/L) are presented in Fig. 20. These indicate that the front would cross the southern boundary of M39/1080 after between 1,200 years (layers 3 to 6) and 2,000 years (layer 2 – surficial clayey sediments). Concentrations would decrease to less than 0.02 mg/L after 2,000 years and in groundwater crossing the southern boundary of Mulga Rock tenement E39/1148. Low concentrations of uranium (probably undetectable from background levels) would extend to about 50 km south of the TSF after 10,000 years. These distances will also apply to the other metals within the plume front.

Calculated positions of the plume and uranium concentrations in each layer are shown for 284, 1,000 and 2,000 years in Figures 21 to 23. They indicate that after 2,000 years, uranium in Layer 3 would be about 0.03 mg/L above background levels, and 9 km south of the TSF.

The results described above are for a worst case where all the tailings are in an Ambassador West pit (in practice, some will be further north in Princess); maximum source concentrations indicated from the ANSTO leachate tests; and with no adsorption or chemical reactions reducing the metal concentrations. Vertical hydraulic conductivities are generally taken to be one tenth of the horizontal hydraulic conductivity – in fact they could be one hundredth which would greatly reduce solute transport.

An additional model run was carried out to determine the impact of adsorption on uranium concentrations with a coefficient of adsorption of 32 mL/g (GHD, 2015a). The results indicated that peak uranium concentrations would be less than 0.01 mg/L (above background concentrations), except immediately beneath the TSF. Calculated uranium concentrations at a point 100 m down-gradient of the TSF are shown in Fig. 24. They are indicated to increase to about 0.008 mg/L above background values after 500 years in Layer 2 before gradually declining; and to be at much lower concentrations in the other layers.

4.6 SENSITIVITY ANALYSIS

The modelling described in Section 4.5 above was repeated for uranium, varying the model parameters in turn by the likely degree of variation based on grain sizes, the permeability test results (Rockwater, 2015) and our experience of aquifer parameters in a similar sedimentary environment. They were varied in a direction which would tend to increase metal concentrations (again following the worst-case principle), to determine their sensitivity in calculating concentrations. The variations included:

- No dispersion;
- No simulation of density variations;
- Double source concentrations (to allow for potential errors in the leachate test results);
- Double horizontal hydraulic conductivities (Kh), Layers 1 to 3 (except for the 5 m/d sand);
- Double vertical hydraulic conductivities (Kv);
- Half the specific yields of Layers 1 and 2; and the storage coefficients (storativity); and;
- Half the adopted values of effective porosity.

The results are given in Table 7 for the near-peak concentrations at the southern boundary of M39/1080 after 1,500 years. They indicate that the modelling results are most sensitive to source concentrations followed by effective porosity, and are much less sensitive to dispersion, horizontal hydraulic conductivity, density effects, and vertical hydraulic conductivity; and are insensitive to storativity.

Table 7: Results of Sensitivity Analyses (Uranium Concentrations, mg/L) 1,500 Years

			Differences	
Case	Layer 2	Layer 5	Layer 2	Layer 5
	(Surficial)	(Basal Sands)		
16 Year Base Case	0.014	0.037	-	-
2 x Source Concs	0.028	0.074	0.014	0.037
No Dispersion	0.000	0.040	-0.014	0.003
No Density Effects	0.010	0.040	-0.004	0.003
0.5 * Storativity	0.014	0.036	0.000	-0.001
0.5 * Porosity	0.021	0.004	0.007	-0.033
2 x Kv	0.015	0.038	0.001	0.001
2 x Kh (L1 to L3)	0.026	0.038	0.012	0.001

Calculated uranium concentrations at the southern boundary of M39/1080 are shown for the adopted model and the worst case (two times source concentrations) in Fig. 25. At most, the calculated concentrations could be two times higher if the parameters are different to those adopted. They would still be much lower than the guideline values. Note also that the source concentrations for all four metals of concern are much lower than the guideline values, even without dilution and dispersion in groundwater.

5 CONCLUSIONS

The objectives of the solute transport modelling were to determine the potential impacts of seepage from in-pit tailings storages, with the metals of concern at the expected maximum concentrations identified from leaching tests conducted by ANSTO and reported by GHD (2015a).

A flow-density and solute transport model of the East Arm palaeodrainage was run to determine the impact of the seepage from an in-pit tailings storage, for the four metals of concern that were identified from leachate tests – uranium, copper, cobalt and zinc. Maximum concentrations of these elements within the tailings slurry have been predicted to be 0.14 mg/L (U); 6 mg/L (Cu); 2.2 mg/L (Co); and 10.3 mg/L (Zn). These concentrations are all lower than DoH guideline values for domestic non-potable groundwater use.

The SEAWAT/MT3DMS modelling results predict that peak concentrations of these elements will reach the southern boundary of the Mulga Rock mining tenement M39/1080 after about 1,500 years (from the start of tailings emplacement) in layers 3 to 6, and after about 2,000 to 3,000 years in the less-permeable layers 1 and 2. The rise in concentrations (above background values) will be low, between the average and maximum values for the MRUP site, and will be much lower than the DoH guideline values.

The front of the plume containing elevated metals would first cross the southern boundary of M39/1080 after between 1,200 years (layers 3 to 6) and 2,000 years (layer 2 – surficial clayey sediments). Concentrations would decrease to less than 0.02 mg/L after 2,000 years and in groundwater flowing across the southern boundary of Mulga Rock tenement E39/1148. Low concentrations of uranium (probably undetectable from background levels) would extend to about 50 km south of the TSF after 10,000 years.

The modelling results represent a worst case because they assume:

- All the tailings are in an Ambassador West pit (in practice some will be further north in Princess);
- Maximum source concentrations as indicated from the ANSTO leachate tests;
- No adsorption or chemical reactions which will reduce metal concentrations;
- Vertical hydraulic conductivities of generally one tenth of the horizontal conductivities – in fact they are probably much lower. Bouwer (1978) reports that a ratio of one tenth can occur within a sand bed itself, due to imbrication; and

The results of sensitivity analyses indicate that for the likely worst-case the modelled concentrations could be up to double the calculated values for the adopted model. They would still be much lower than the guideline values.

Dated: **29 October 2015** **Rockwater Pty Ltd**

P H Wharton
Principal

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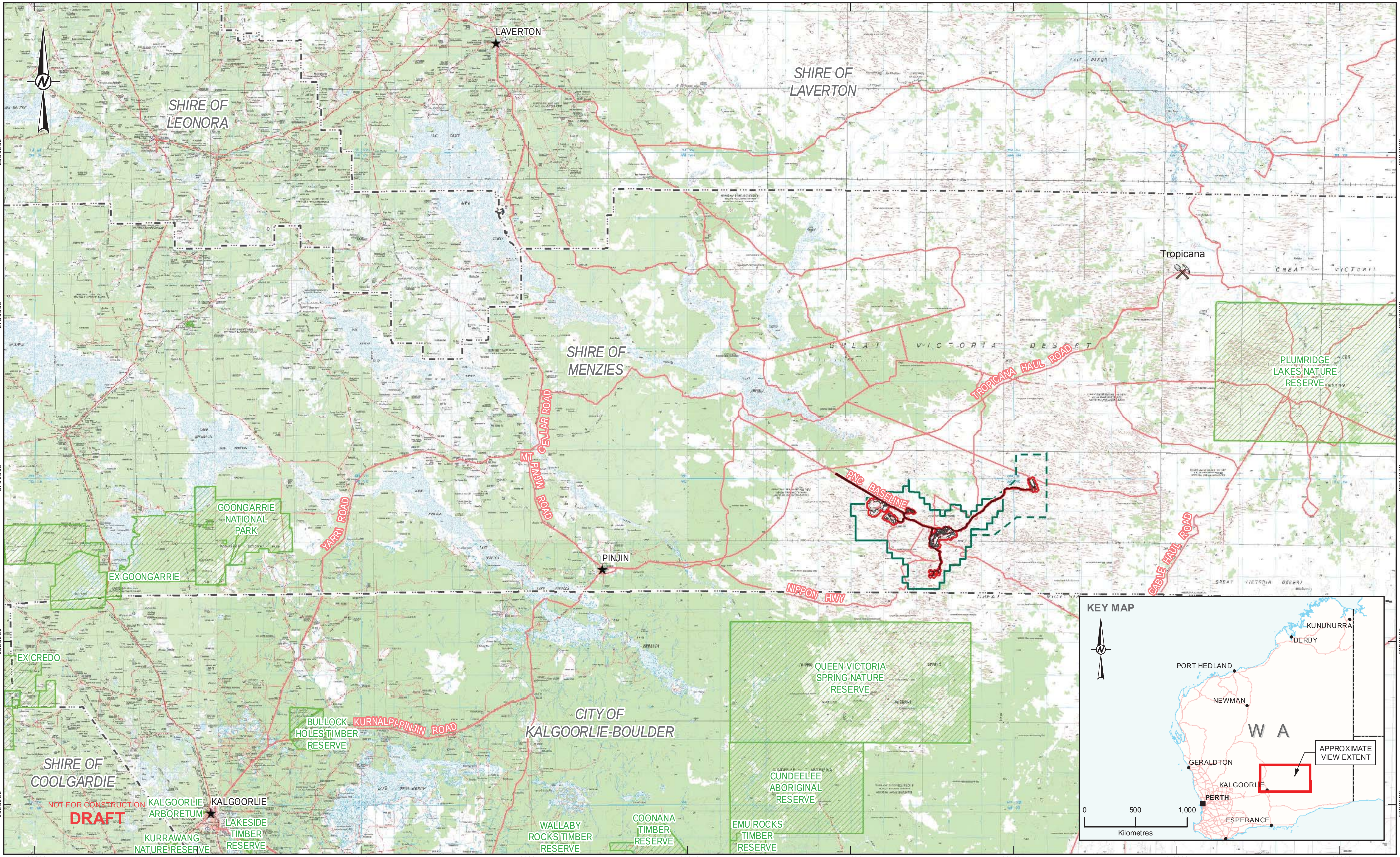
FIGURES



LEGEND

- TROPICANA GOLD MINE
- TOWN
- ROAD
- PROPOSED INFRASTRUCTURE
- MRUP DEVELOPMENT ENVELOPE AREA
- PROJECT BOUNDARY (MINING TENURE)
- PROJECT BOUNDARY (MISCELLANEOUS TENURE)
- CONSERVATION RESERVE
- LOCAL GOVERNMENT AUTHORITY (LGA) BOUNDARY

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 51

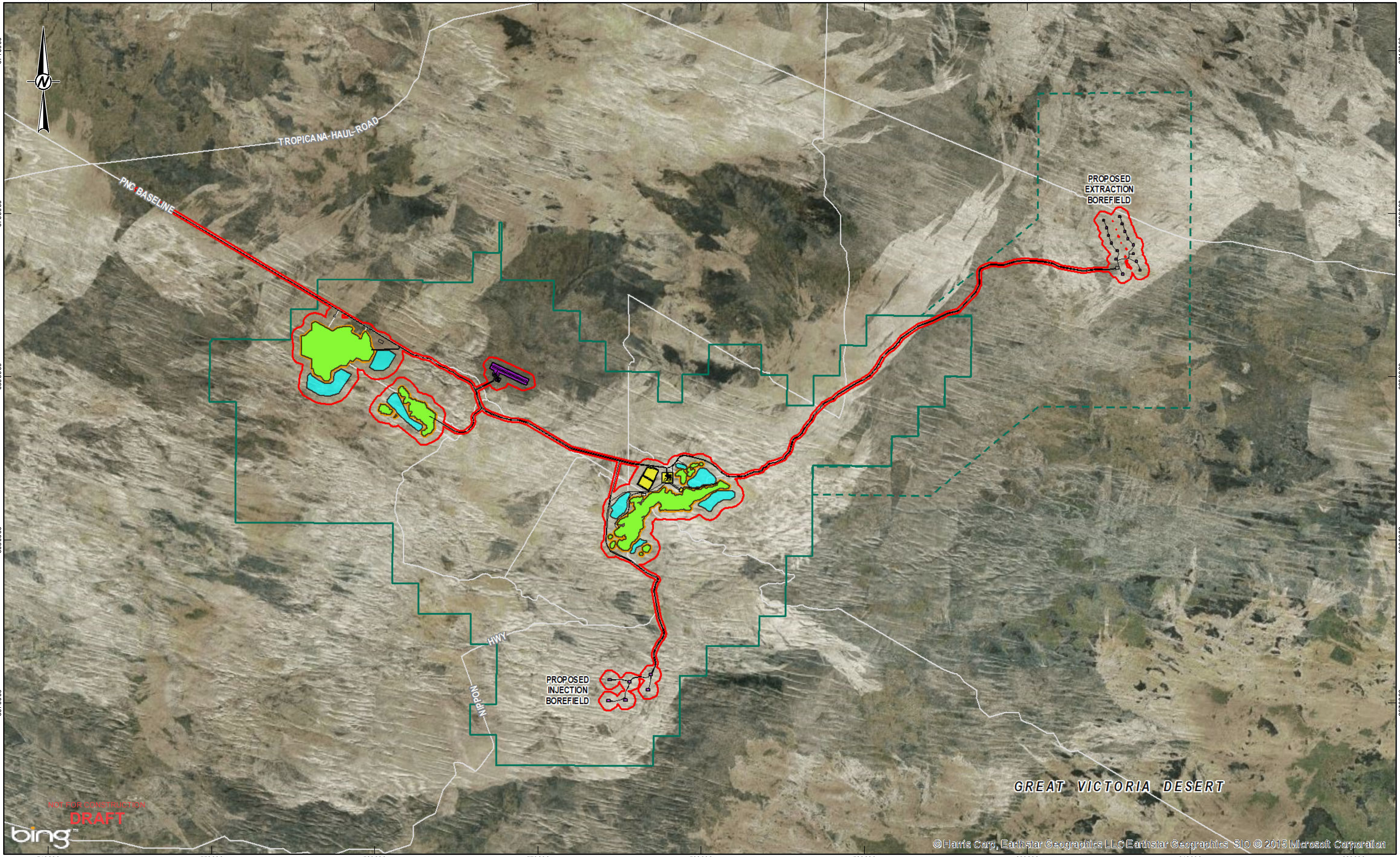
REFERENCE

INFRASTRUCTURE DATA PROVIDED BY CLIENT
BASE DATA © WESTERN AUSTRALIAN LAND INFORMATION AUTHORITY TRADING AS LANDGATE (2015)
IMAGE SOURCED FROM GEOSCIENCE AUSTRALIA 250K TOPO
INSET BASE DATA/ROADS SOURCED FROM STREET PRO DATA 2009

0 25 50
1:1,100,000 KILOMETRES

CLIENT VIMY RESOURCES LIMITED	VIMY RESOURCES	PROJECT MULGA ROCK URANIUM PROJECT	
CONSULTANT Golder Associates	YYYY-MM-DD 2015-09-25 DESIGNED MS PREPARED MS REVIEWED APPROVED	TITLE **LOCATION MAP**	
		PROJECT NO. 1540340	REV. A / FIGURE 1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3 25mm 0



LEGEND

- ROAD
- PROPOSED INFRASTRUCTURE
- PIT
- OVERBURDEN LANDFORM
- PROCESSING INFRASTRUCTURE
- SUPPORTING INFRASTRUCTURE
- 50 M BUFFER
- MRUP DEVELOPMENT ENVELOPE AREA (11120 HA)
- PROJECT BOUNDARY (MINING TENURE)
- PROJECT BOUNDARY (MISCELLANEOUS TENURE)

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 51

REFERENCE

INFRASTRUCTURE DATA PROVIDED BY CLIENT
AERIAL IMAGERY SOURCED FROM ESRI ONLINE
TOPOGRAPHY BASED ON NATIONAL DEM 1 S SOURCED FROM GEOSCIENCE AUSTRALIA

0 5 10
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CLIENT VIMY RESOURCES LIMITED			PROJECT MULGA ROCK URANIUM PROJECT
CONSULTANT Golder Associates	YYYY-MM-DD	2015-09-25	TITLE PROJECT TENURE AND DEVELOPMENT ENVELOPE
	DESIGNED	MS	
	PREPARED	MS	
	REVIEWED		
	APPROVED		PROJECT NO. 1540340 · REV. A · FIGURE 2

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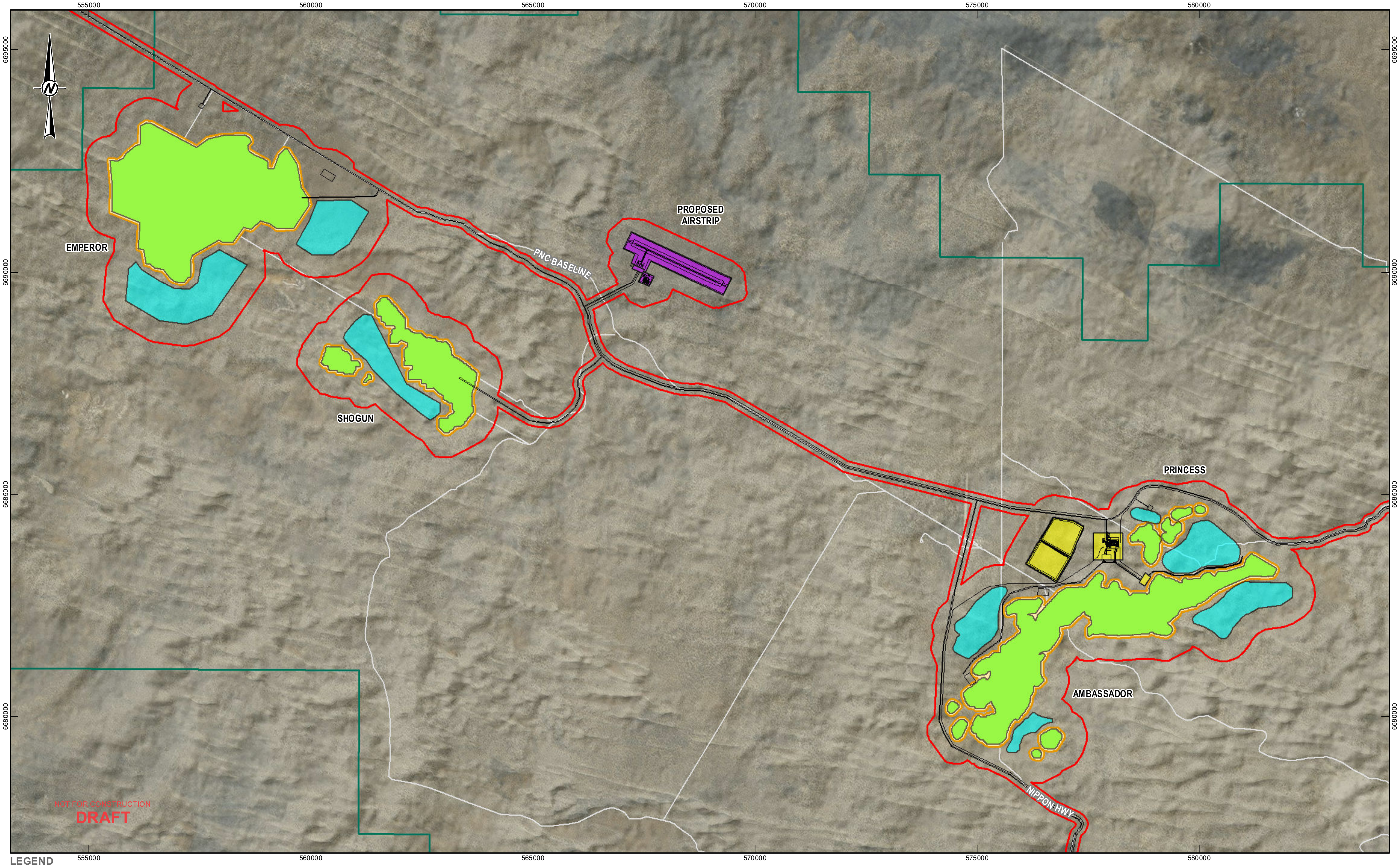

LEGEND

- ROAD
- PROPOSED INFRASTRUCTURE
- PIT
- OVERBURDEN LANDFORM
- PROCESSING INFRASTRUCTURE
- SUPPORTING INFRASTRUCTURE
- 50 M BUFFER
- MRUP DEVELOPMENT ENVELOPE AREA (11120 HA)
- PROJECT BOUNDARY (MINING TENURE)
- PROJECT BOUNDARY (MISCELLANEOUS TENURE)

NOTES

1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 51

REFERENCE

INFRASTRUCTURE DATA PROVIDED BY CLIENT
AERIAL IMAGERY SOURCED FROM ESRI ONLINE
TOPOGRAPHY BASED ON NATIONAL DEM 1 S SOURCED FROM GEOSCIENCE AUSTRALIA

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1:80,000 KILOMETRES

CLIENT
VIMY RESOURCES LIMITED

VIMY RESOURCES

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-09-25
DESIGNED	MS
PREPARED	MS
REVIEWED	
APPROVED	

PROJECT
MULGA ROCK URANIUM PROJECT

TITLE
CONCEPTUAL LAYOUT PLAN

PROJECT NO.	REV.	FIGURE
1540340	A	3

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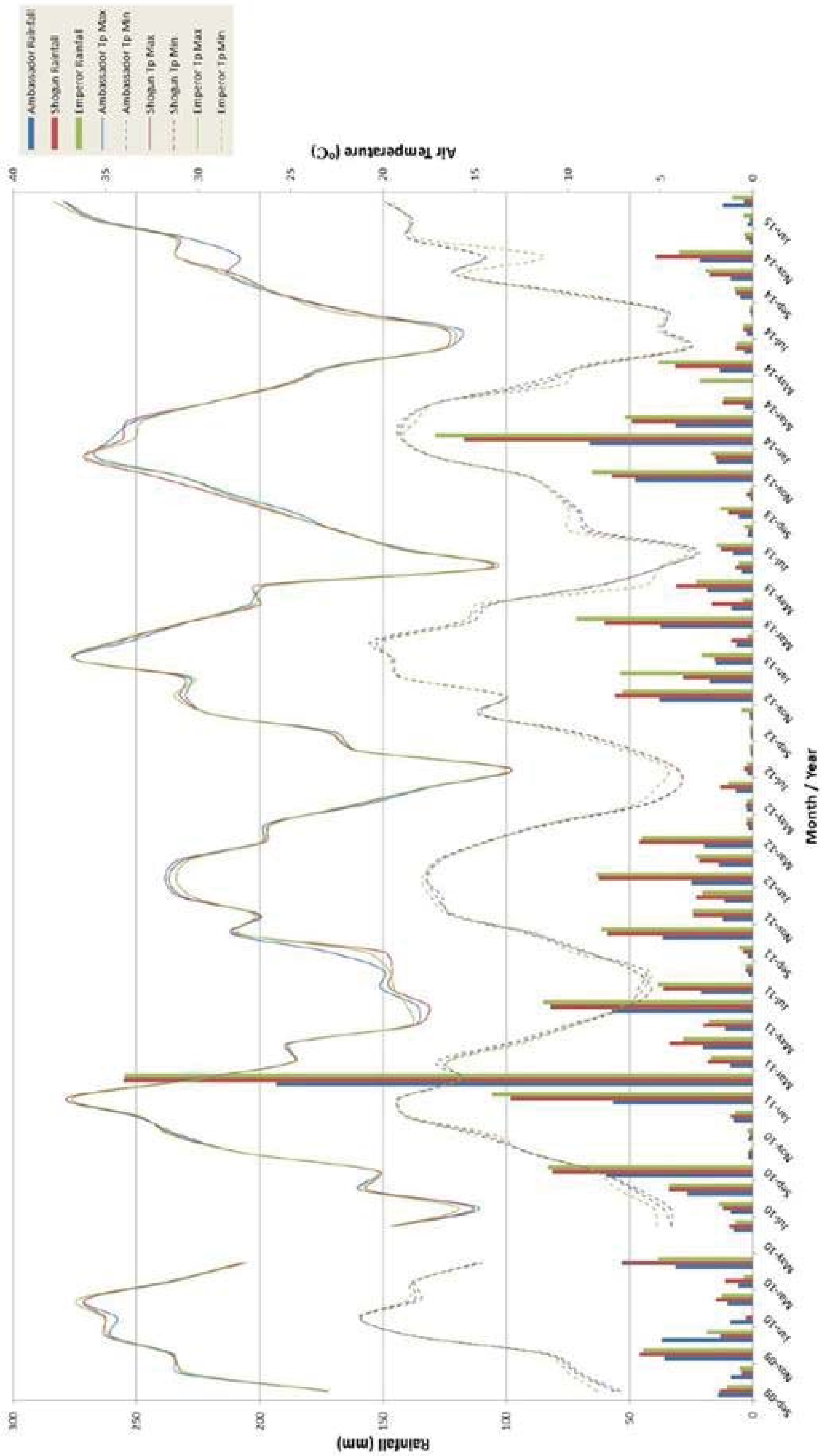
Figure 4



rainfalls & temp.srf

CLIENT: Vimy Resources PROJECT: Mulga Rock Hydrogeology DATE: October 2015 Dwg No: 345.0/15/7-4	MAXIMUM & MINIMUM TEMPERATURES, AND MONTHLY RAINFALLS, MULGA ROCK WEATHER STATIONS Rockwater Pty Ltd

CLIENT: Vimy Resources

PROJECT: Mulga Rock Hydrogeology

DATE: October 2015

Dwg No: 345.0/15/7-5

geological setting.srf

REGIONAL GEOLOGICAL SETTING

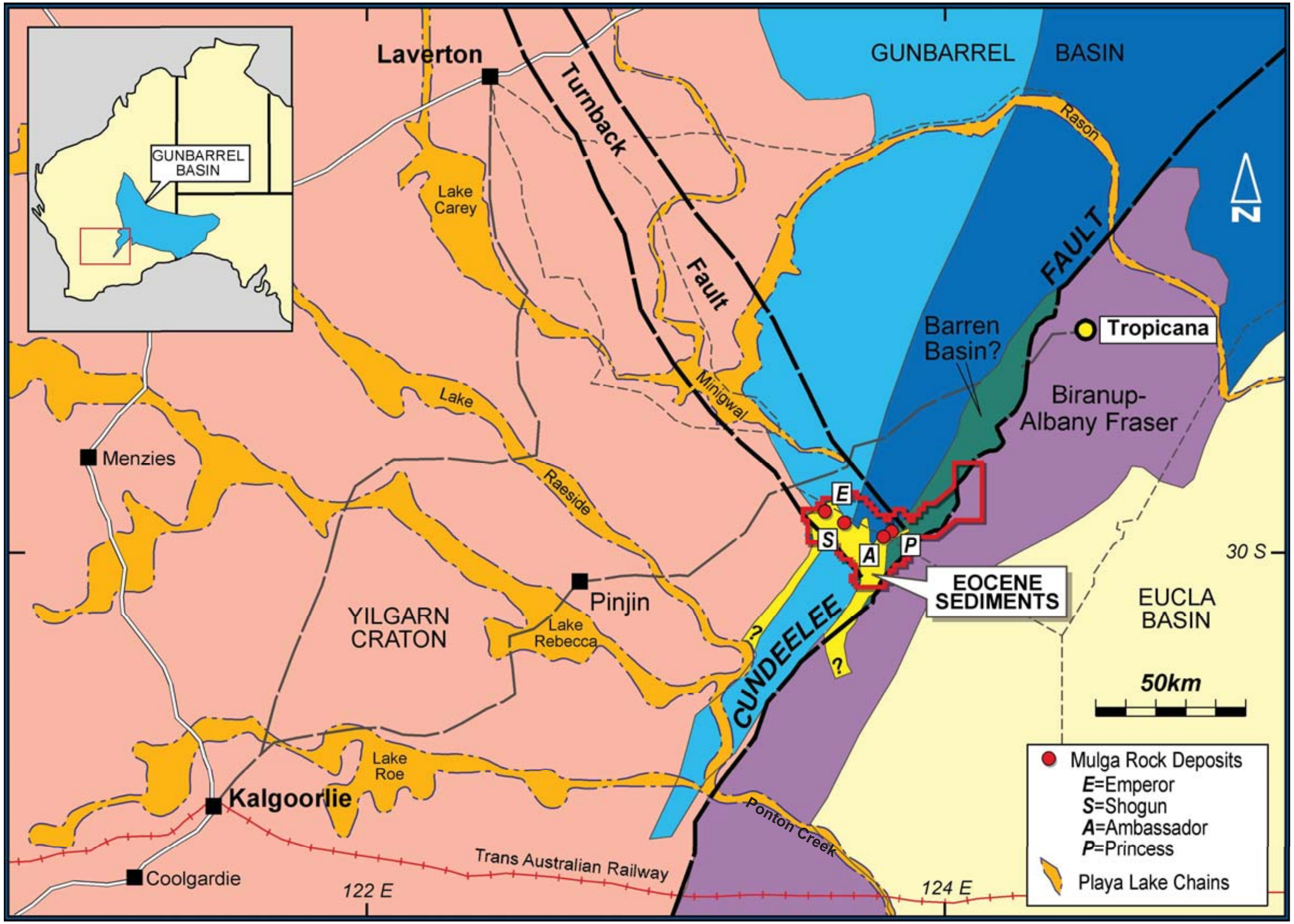


Figure 5

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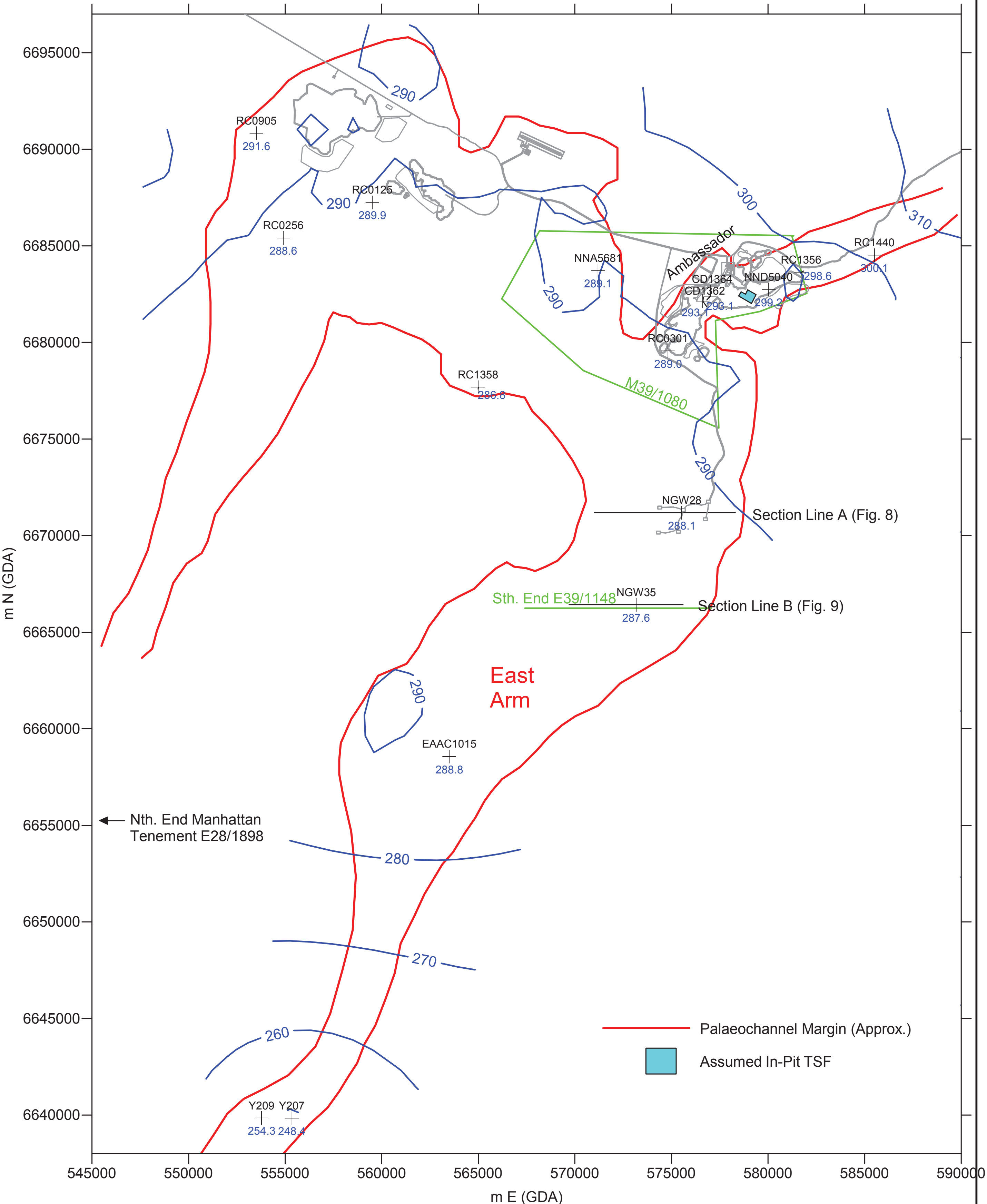
Figure 6



rlwls & calib bores.srf

CLIENT: Vimy Resources

PROJECT: Mulga Rock Hydrogeology

DATE: September 2015

Dwg No: 345.0/15/7-6

REDUCED GROUNDWATER LEVELS (m AHD) MEASURED IN ALL BORES AT VARIOUS TIMES (CONTOURS), AND IN CALIBRATION BORES (POST VALUES)

Rockwater Pty Ltd

CLIENT: Vimy Resources
PROJECT: Mulga Rock Hydrogeology
DATE: October 2015
Dwg No: 345.0/15/7-7

GROUNDWATER LEVELS (m AHD) MEASURED APRIL 2014, AMBASSADOR DEPOSIT

Rockwater Pty Ltd

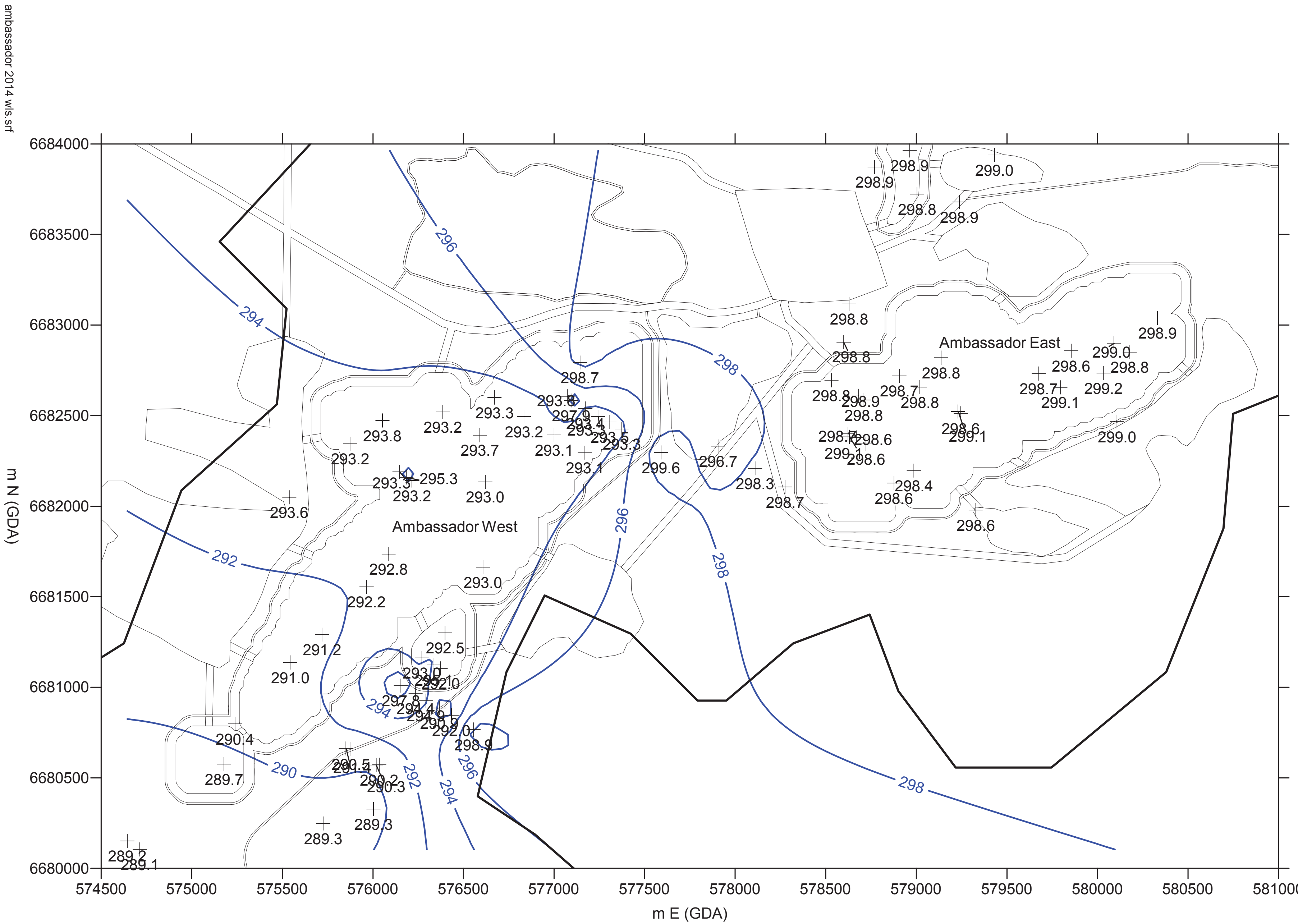
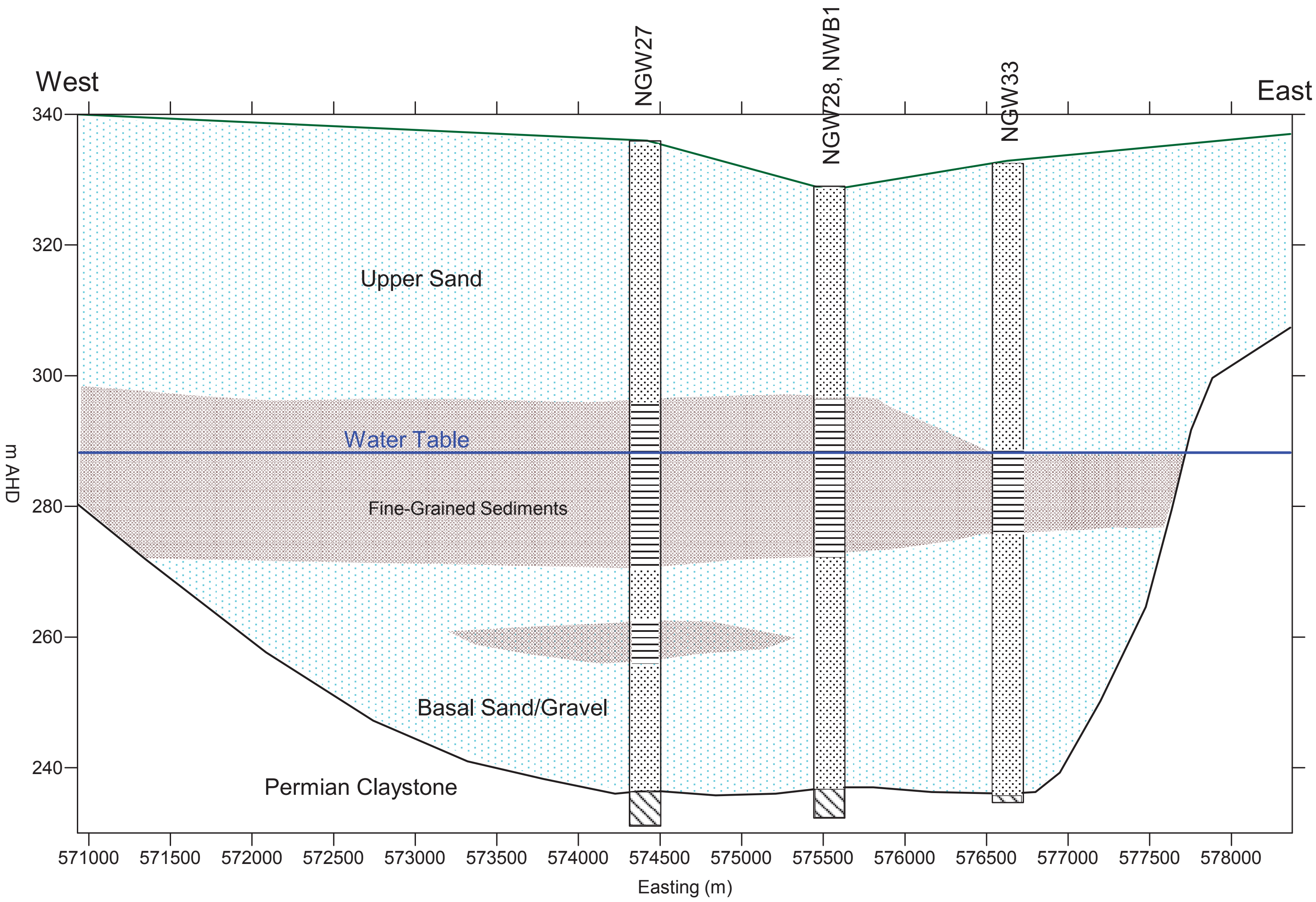


Figure 7



40 X Vertical Exaggeration

Figure 8

section Line A.srf

CLIENT: Vimy Resources

PROJECT: Mulga Rock Hydrogeology

DATE: October 2015

Dwg No: 345.0/15/7-8

HYDROGEOLOGICAL CROSS-SECTION

INJECTION BOREFIELD AT NWB1 (LINE A)

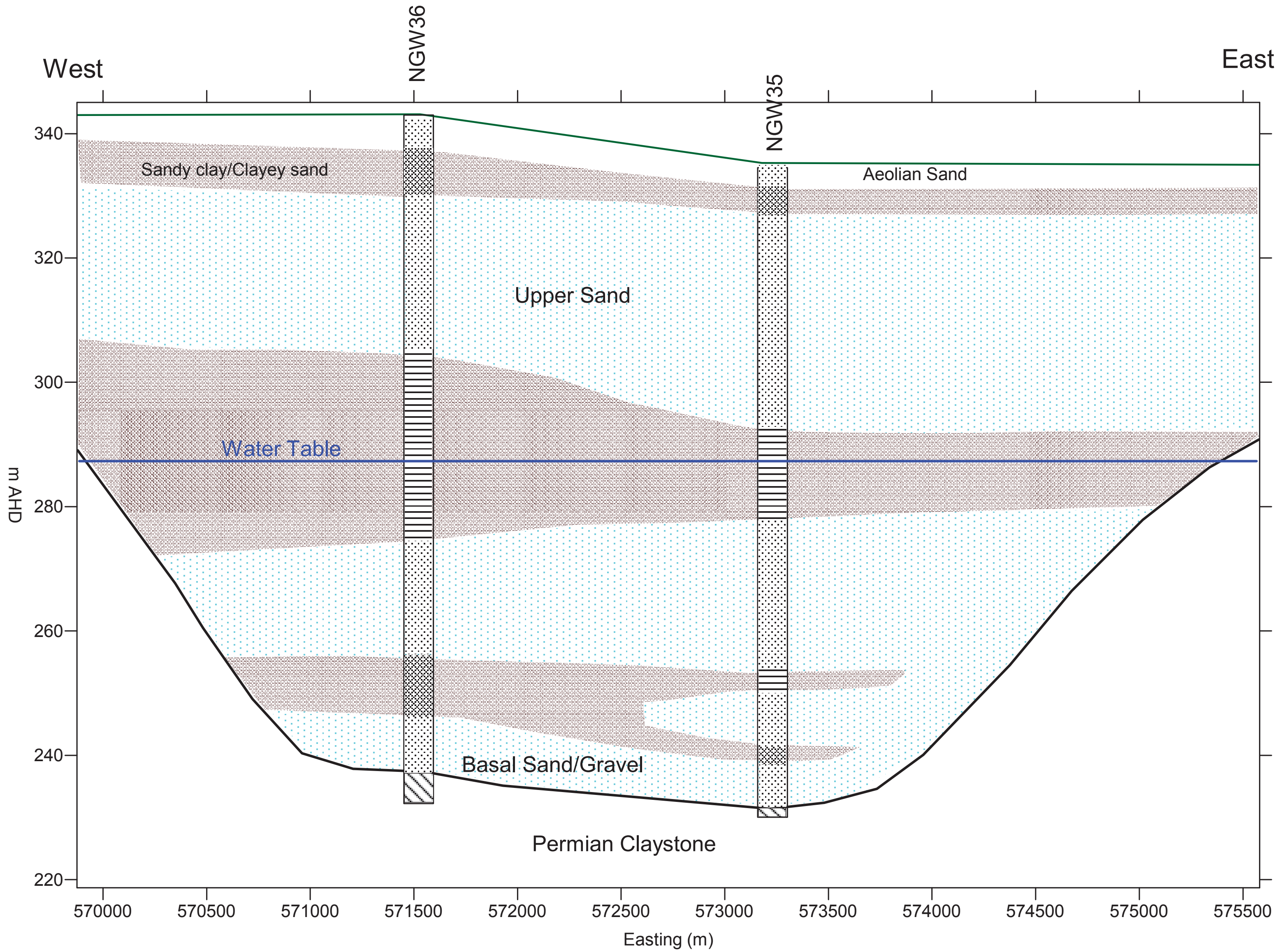
Rockwater Pty Ltd

CLIENT: Vimy Resources
PROJECT: Mulga Rock Hydrogeology
DATE: October 2015
Dwg No: 345.0/15/7-9

section Line B.srf

HYDROGEOLOGICAL CROSS-SECTION
SOUTH OF INJECTION BOREFIELD, LINE B

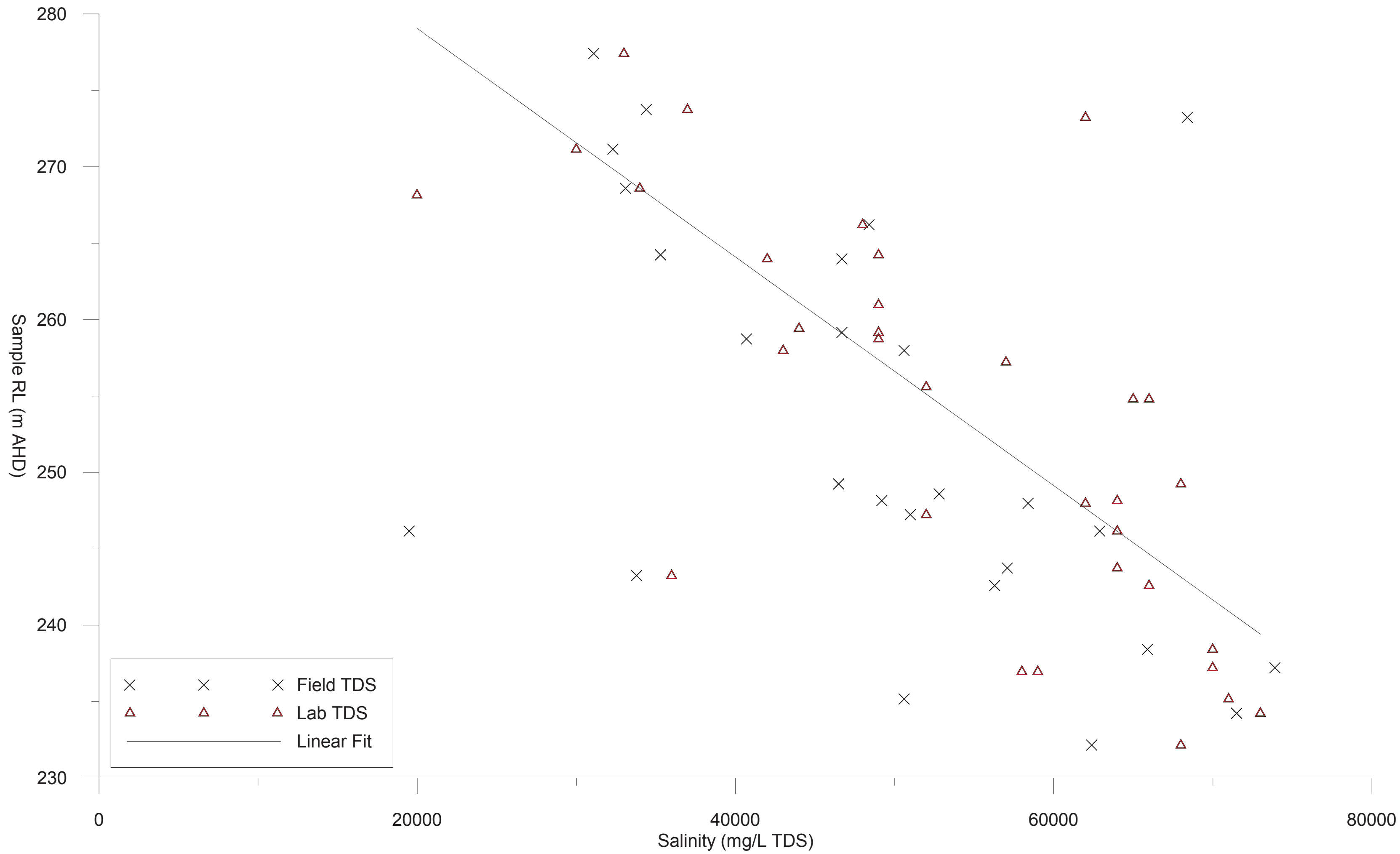
Rockwater Pty Ltd



30 X Vertical Exaggeration

Figure 9

Figure 10



injection tds vs depth.grf

Client: Vimy Resources
Project: Mulga Rock
Date: October 2015
Dwg. No: 345-0/15/7-10

REINJECTION AREA: SALINITY VERSUS SAMPLING DEPTH

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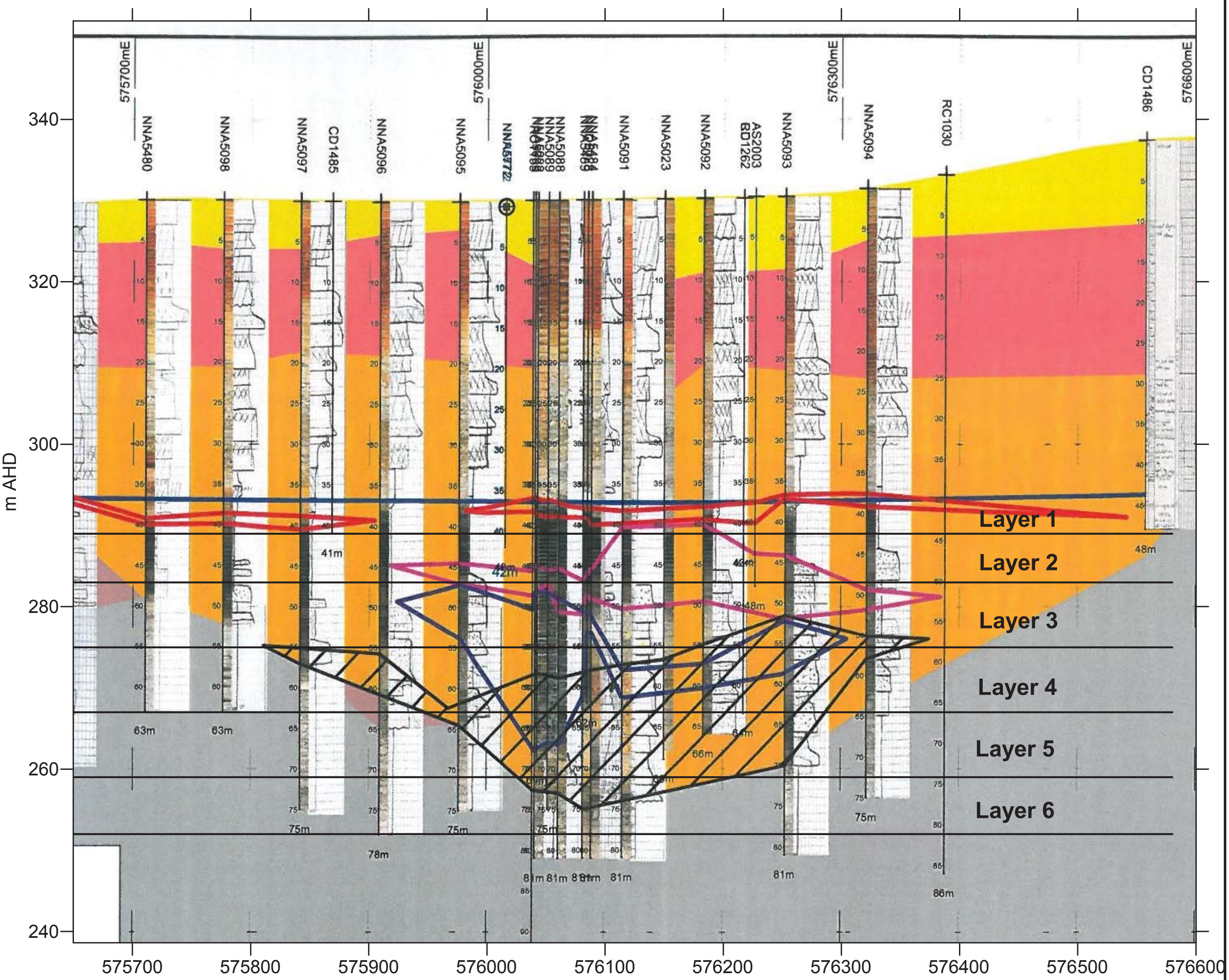
Figure 11



amb w 48760.srf

CLIENT: Vimy Resources

PROJECT: Fate of Tailings Seepage

DATE: October 2015

Dwg No: 345.0/15/7-11

MODEL LAYERS AND GEOLOGY, AMBASSADOR WEST

SECTION 48760N

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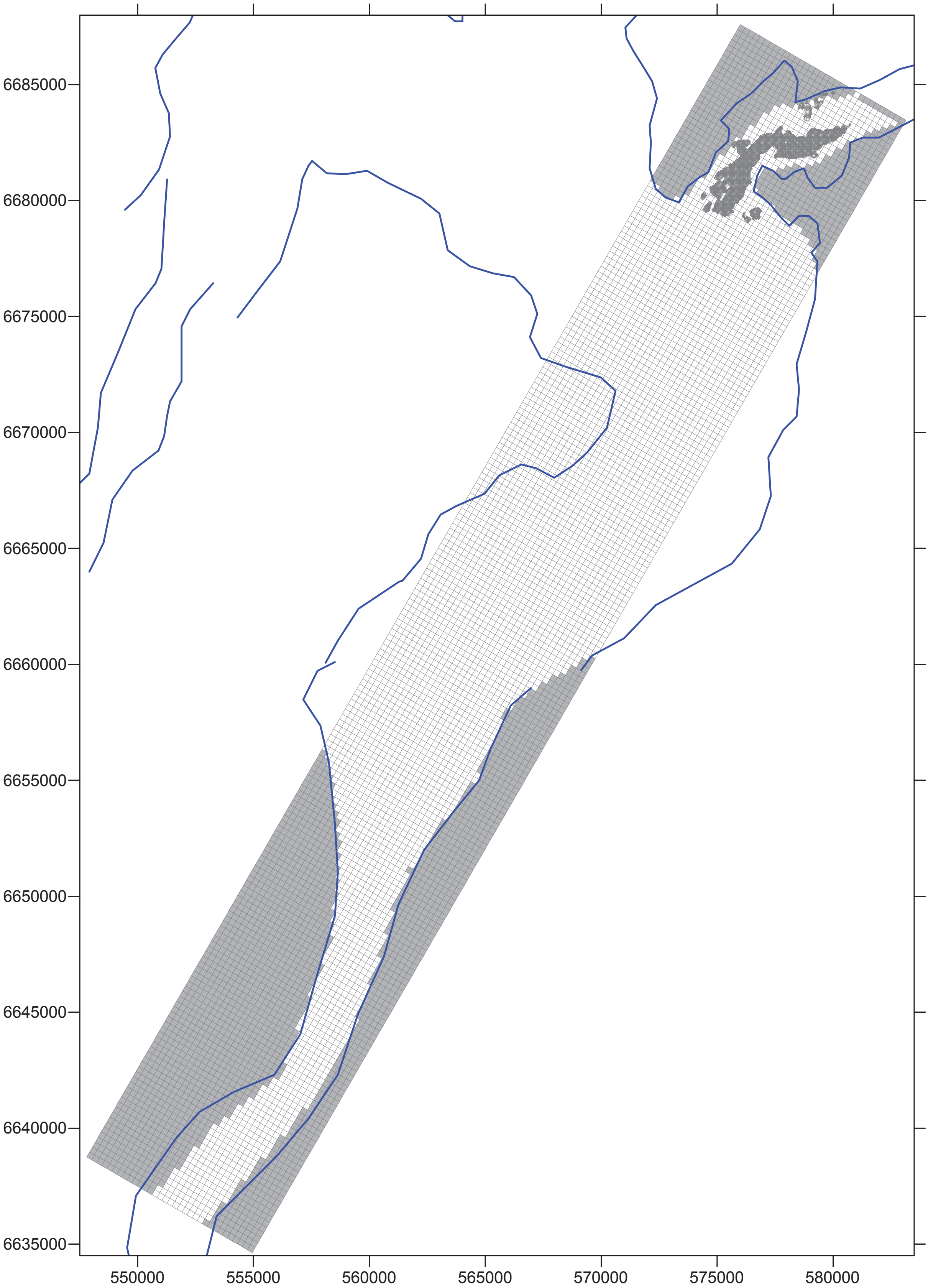
Figure 12



model grid.srf

CLIENT: Vimy Resources

PROJECT: Fate of Tailings Seepage

DATE: October 2015

Dwg No: 345.0/15/7-12

LAYOUT OF MODEL GRID

LAYER 4

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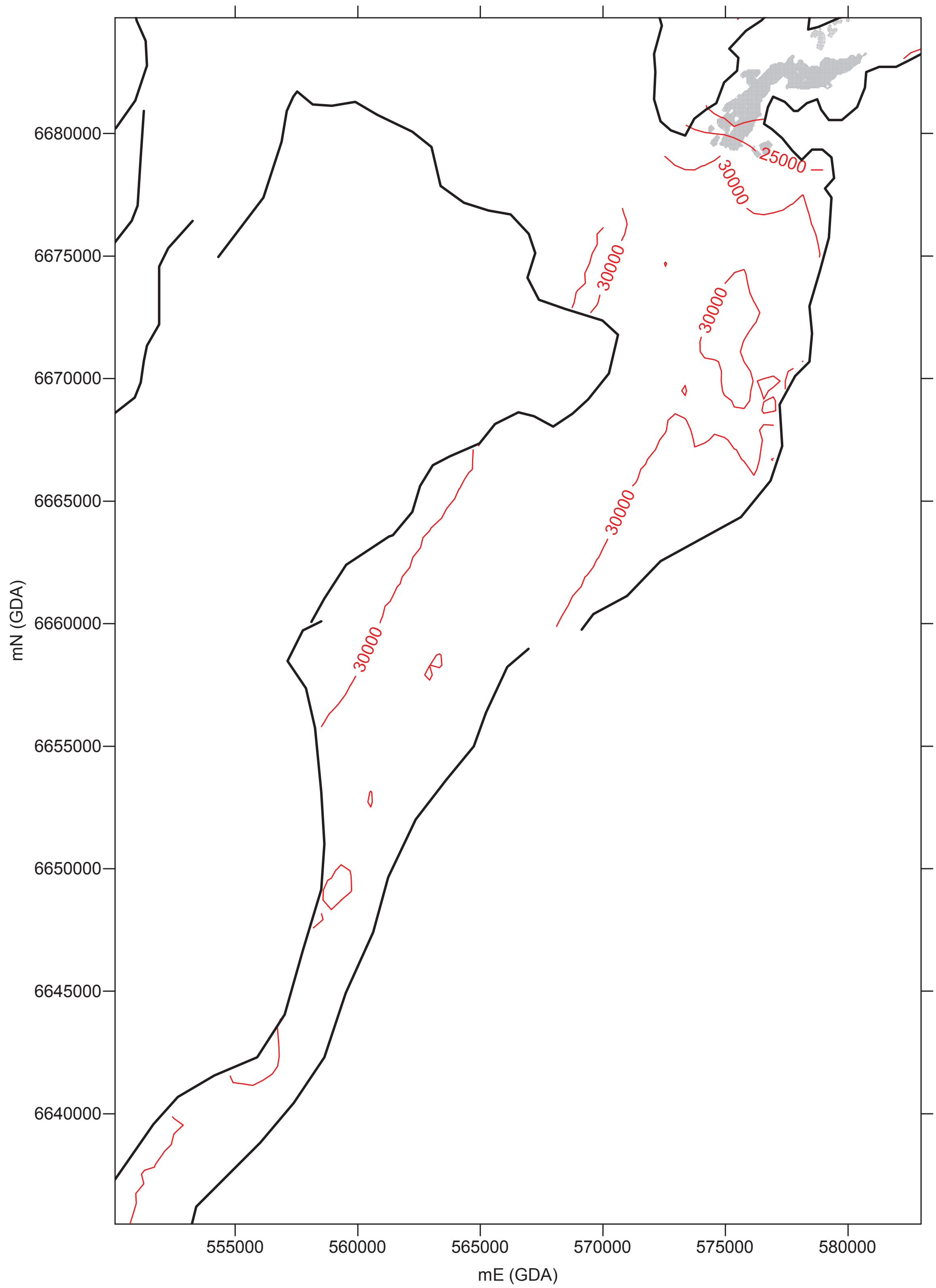
Figure 13



l1itds.srf

CLIENT: Vimy Resources

PROJECT: Fate of Tailings Seepage

DATE: October 2015

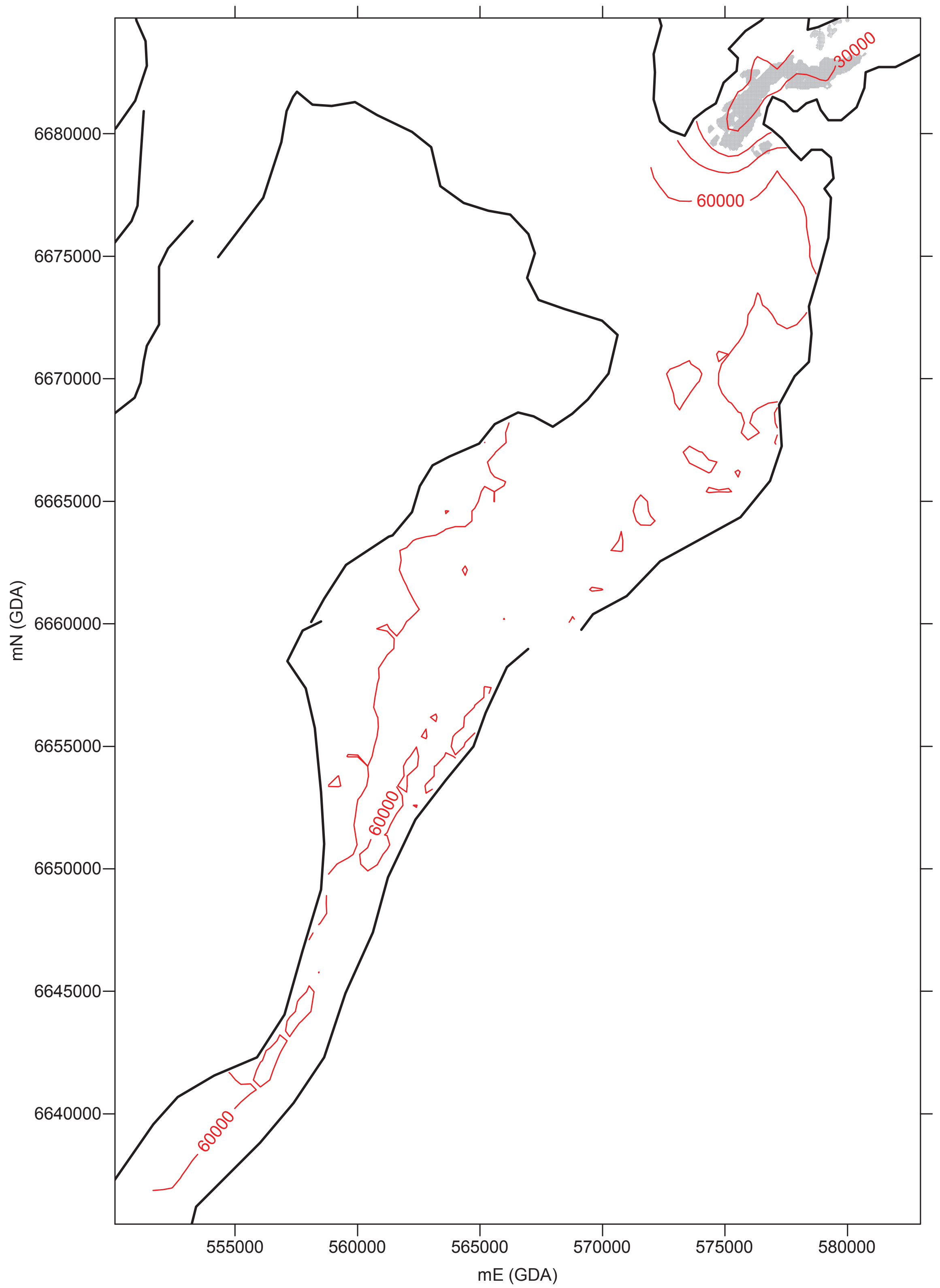
Dwg No: 345.0/15/7-13

INITIAL SALINITY VALUES (mg/L TDS)

ADOPTED FOR LAYER 1 IN MODEL

Rockwater Pty Ltd

Figure 14



l6itds.srf

CLIENT: Vimy Resources

PROJECT: Fate of Tailings Seepage

DATE: October 2015

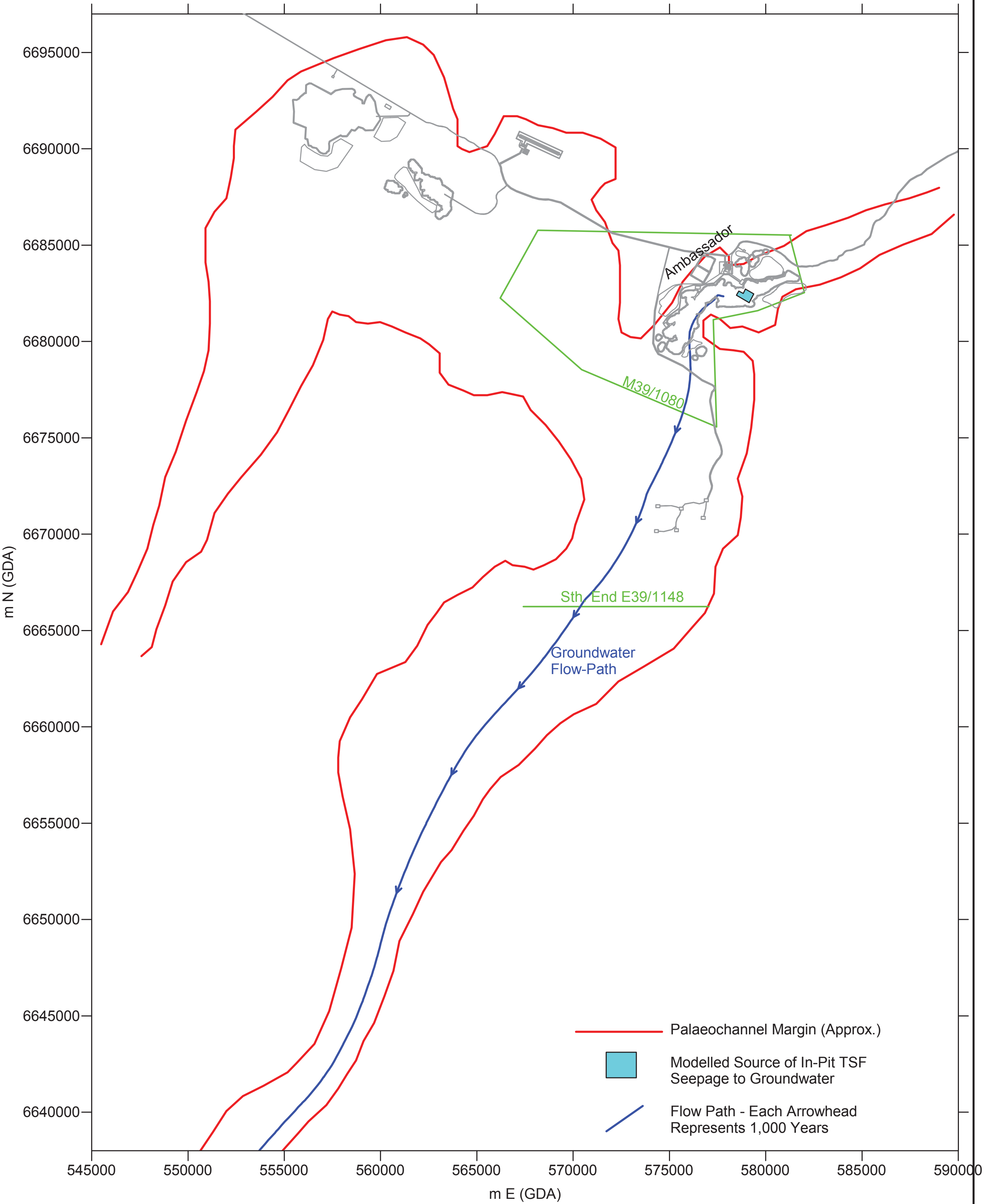
Dwg No: 345.0/15/7-14

INITIAL SALINITY VALUES (mg/L TDS)

ADOPTED FOR LAYER 6 IN MODEL

Rockwater Pty Ltd

Figure 15



l5flowpath.srf

CLIENT: Vimy Resources

PROJECT: Fate of Tailings Seepage

DATE: October 2015

Dwg No: 345.0/15/7-15

MODEL-CALCULATED FLOW-PATH

LAYER 5 (BASAL SAND)

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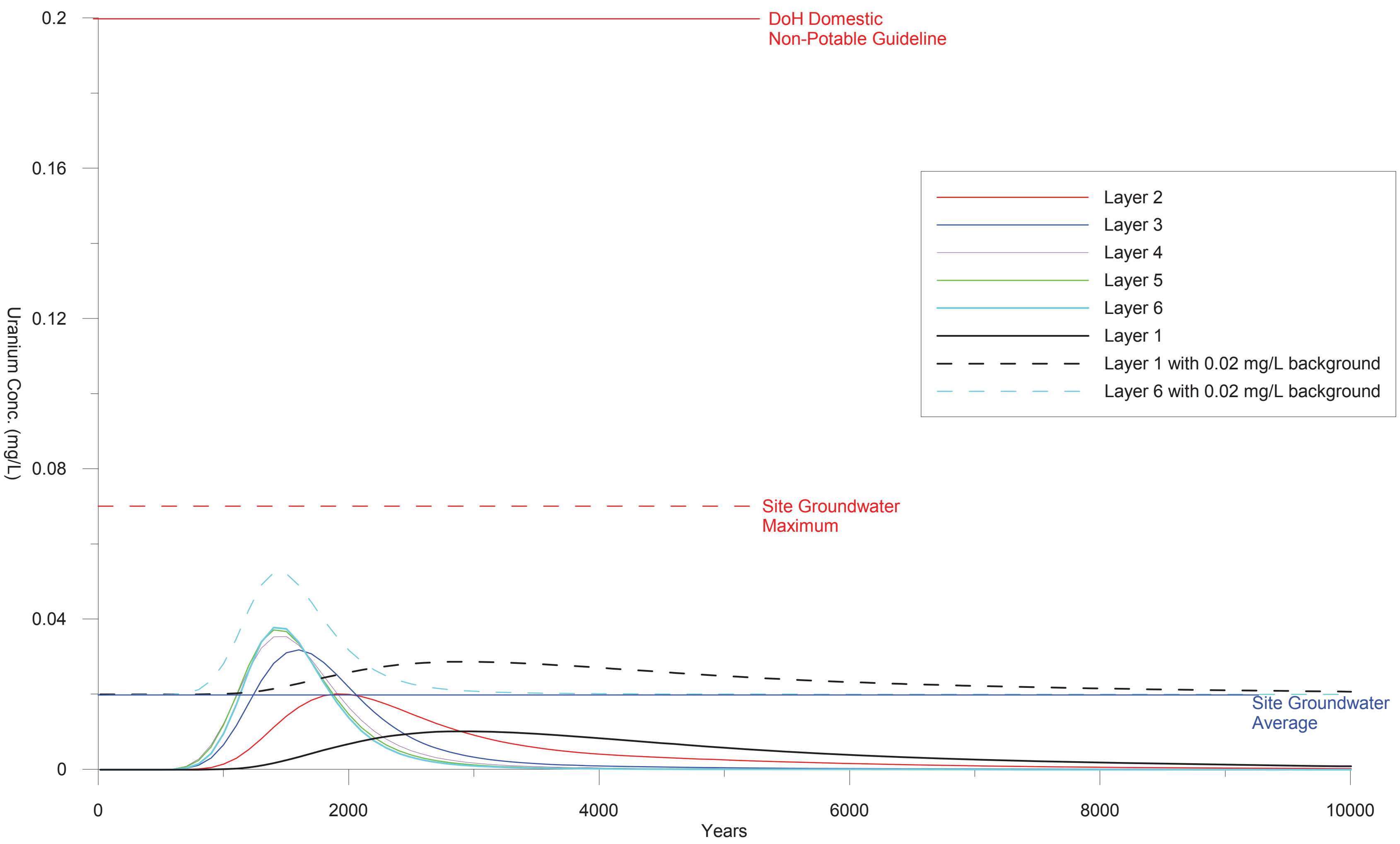


Note: Concentrations are generally above background values

Figure 16

1080u16y.grf

Client: Vimy Resources

Project: Fate of Tailings Seepage

Date: 26 October 2015

Dwg. No: 345-0/15/7-16

URANIUM FRONT CROSSING STH BOUNDARY OF M39/1080, ADOPTED CASE WITH DISPERSION & DENSITY LAYERING, 16 YEAR MINE

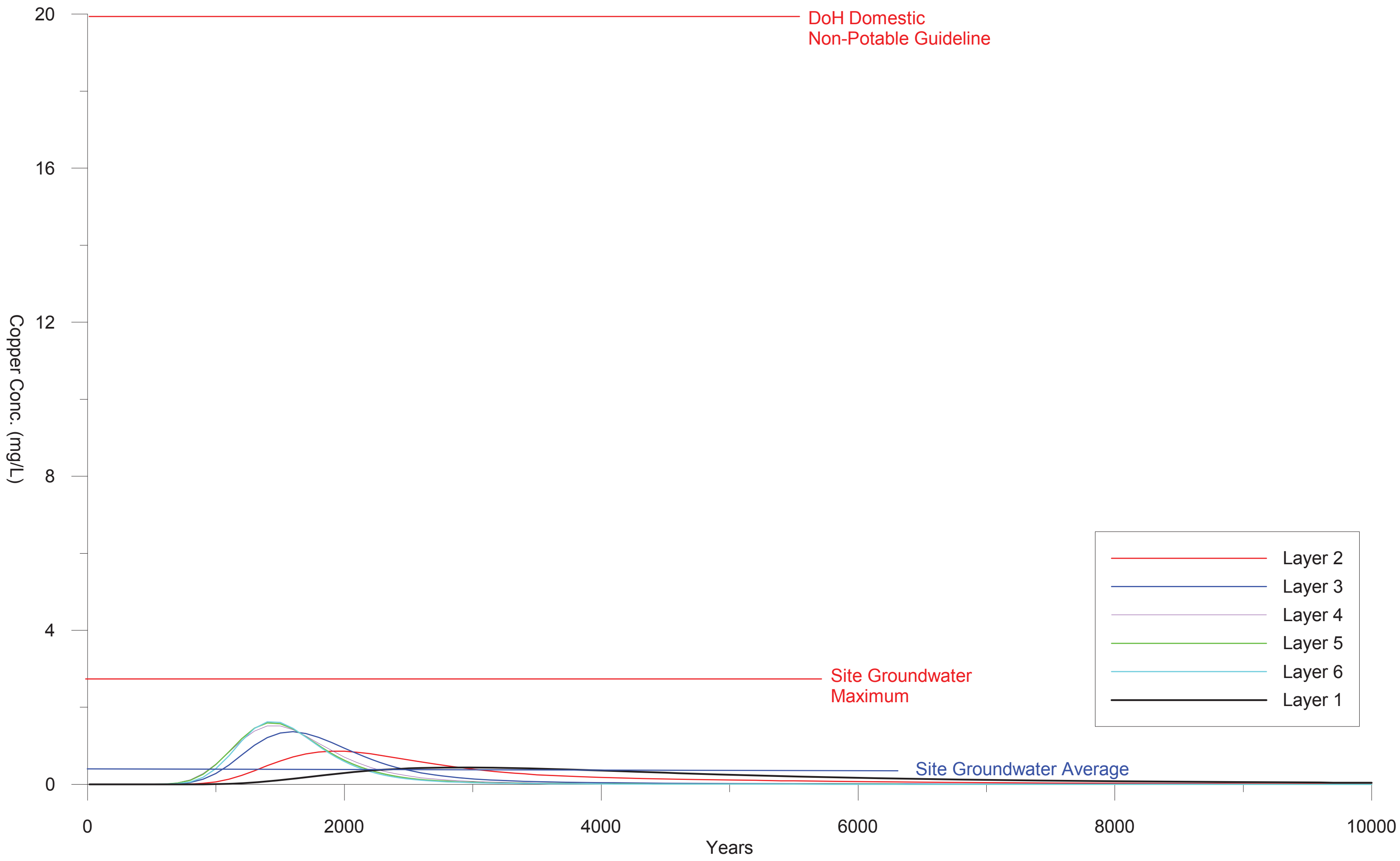
Rockwater Pty Ltd

Client: Vimy Resources
Project: Fate of Tailings Seepage
Date: 26 October 2015
Dwg. No: 345-0/15/7-17

COPPER FRONT CROSSING STH BOUNDARY OF
M39/1080, ADOPTED CASE, WITH DISPERSION
& DENSITY LAYERING, 16 YEAR MINE

Rockwater Pty Ltd

1080cu16y.grf



Note: Concentrations are above background values

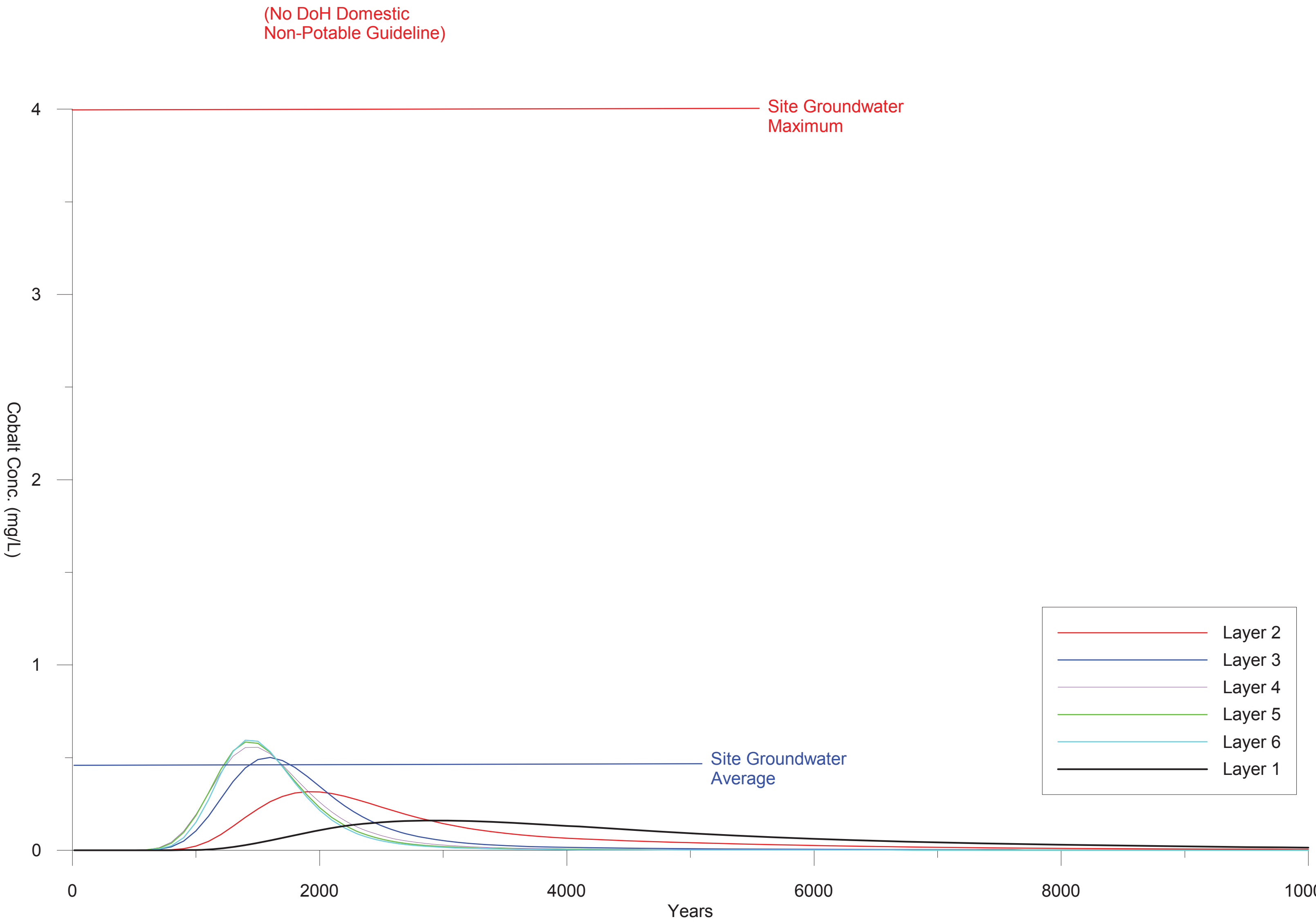
Figure 17

Client: Vimy Resources
Project: Fate of Tailings Seepage
Date: 26 October 2015
Dwg. No: 345-0/15/7-18

COBALT FRONT CROSSING STH BOUNDARY OF M39/1080, ADOPTED CASE, WITH DISPERSION & DENSITY LAYERING, 16 YEAR MINE

Rockwater Pty Ltd

1080co16y.grf



Note: Concentrations are above background values

Figure 18

Client: Vimy Resources

Project: Fate of Tailings Seepage

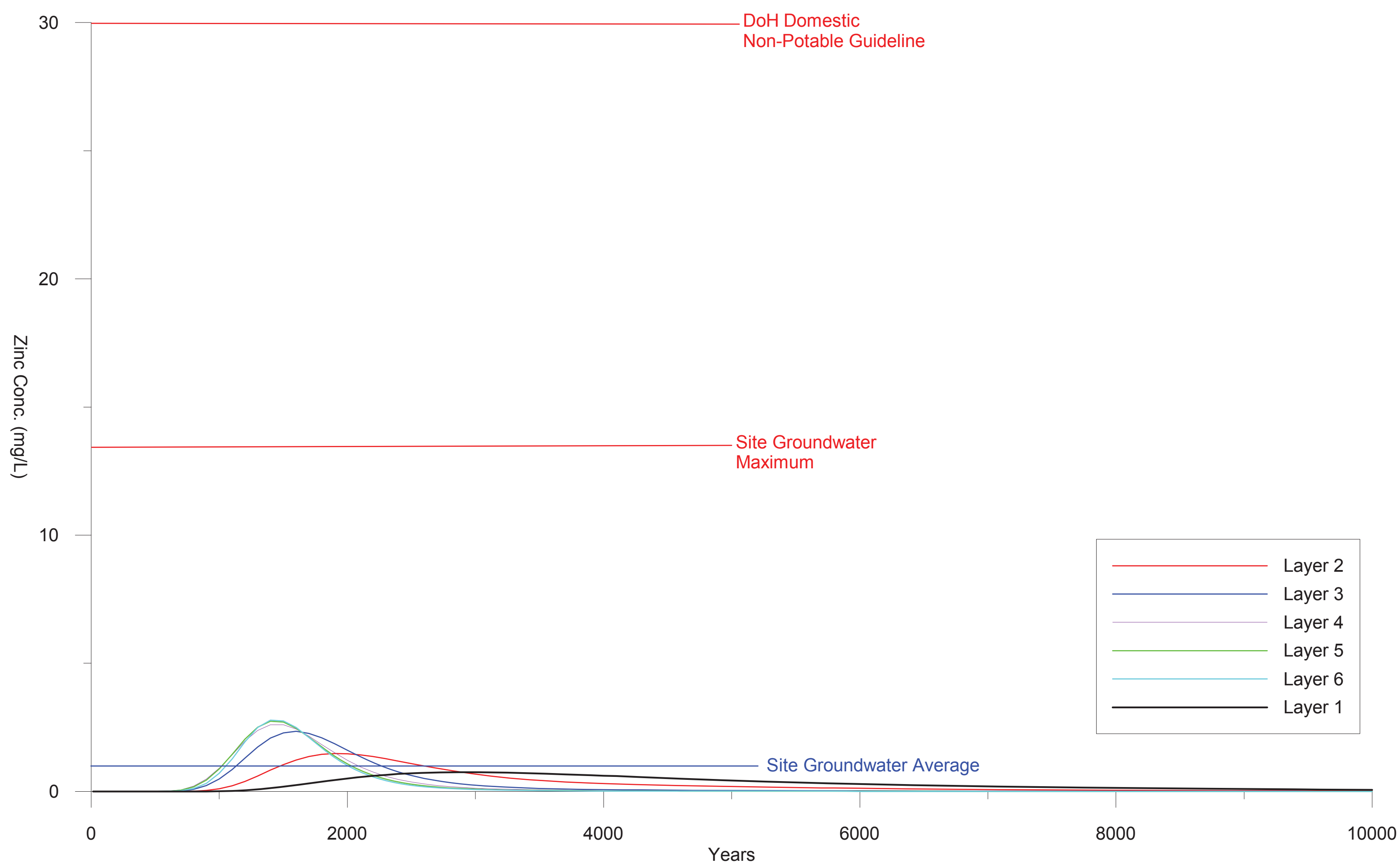
Date: 26 October 2015

Dwg. No: 345-0/15/7-19

ZINC FRONT CROSSING STH BOUNDARY OF M39/1080, ADOPTED CASE, WITH DISPERSION & DENSITY LAYERING, 16 YEAR MINE

Rockwater Pty Ltd

1080zn16y.grf



Note: Concentrations are above background values

Figure 19

Client: Vimy Resources
Project: Fate of Tailings Seepage
Date: 26 October 2015
Dwg. No: 345-0/15/7-20

DISTANCE OF 0.02 mg/L URANIUM FRONT FROM TSF
ADOPTED CASE, 16 YEAR MINE, WITH DISPERSION & DENSITY LAYERING

Rockwater Pty Ltd

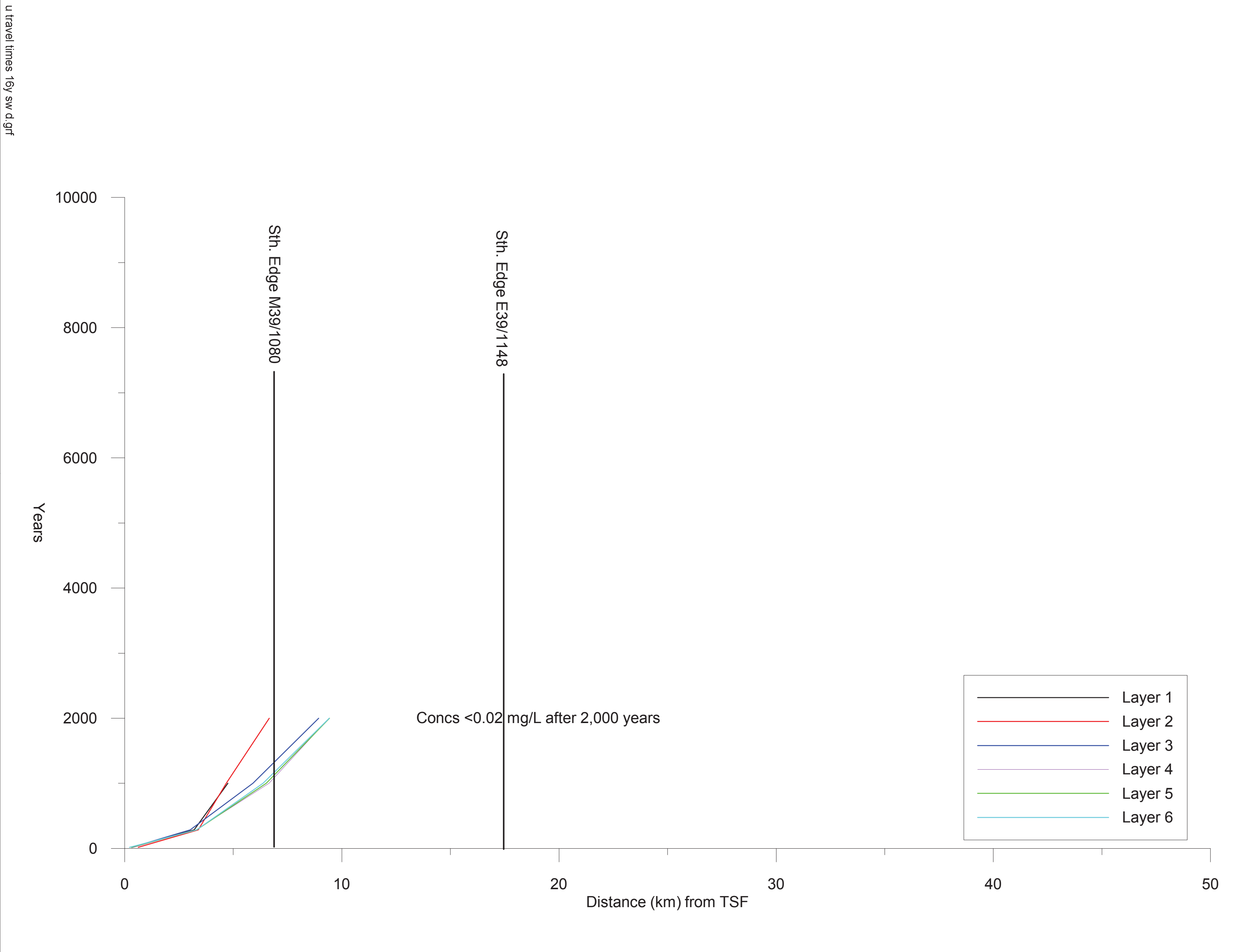
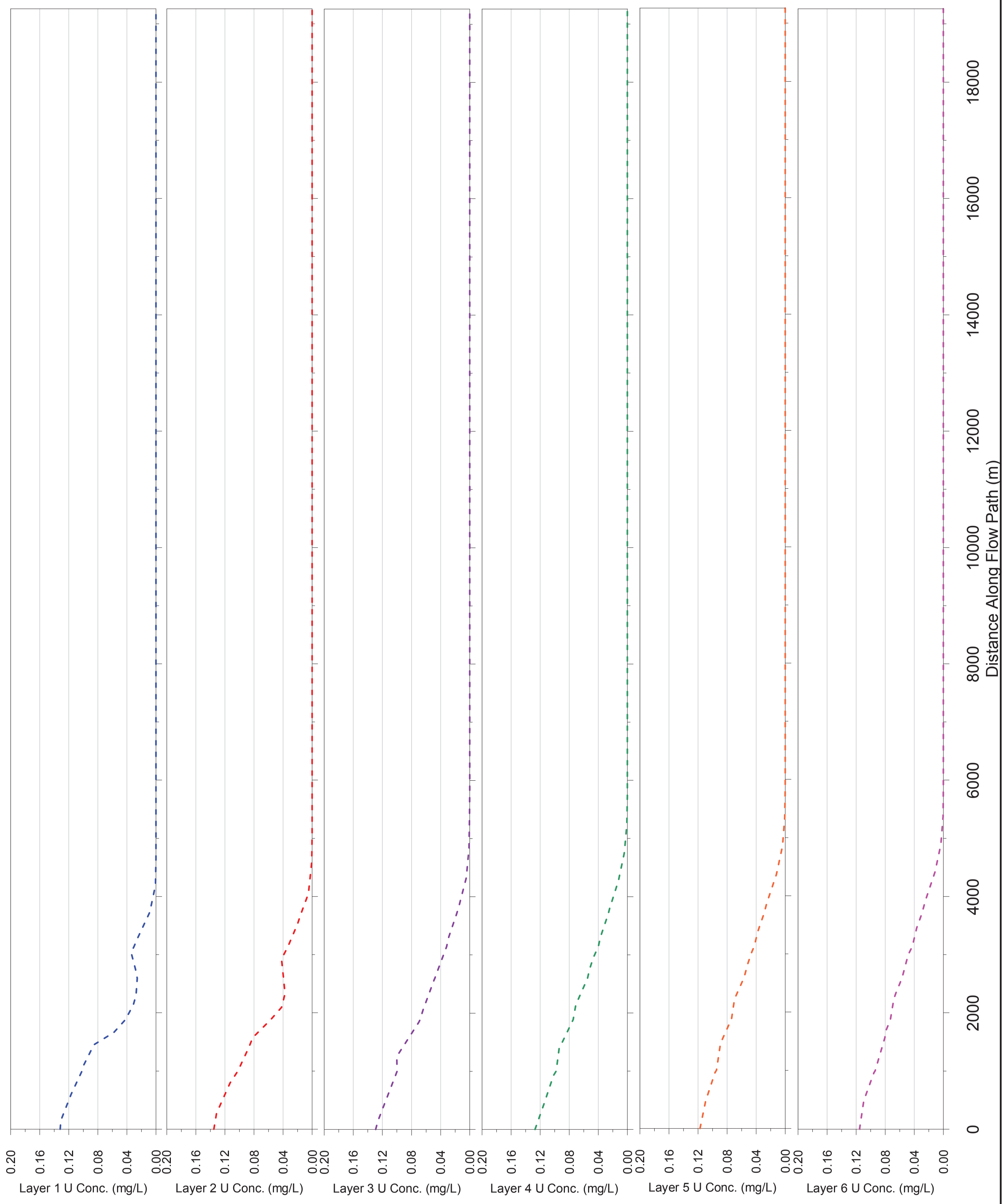


Figure 20

Figure 21



345-0/Grapher/Solute Transport/U conc Slices/284yrUconc.grf

Client: Vimy Resources

Project: Fate of Tailings Seepage

Date: October 2015

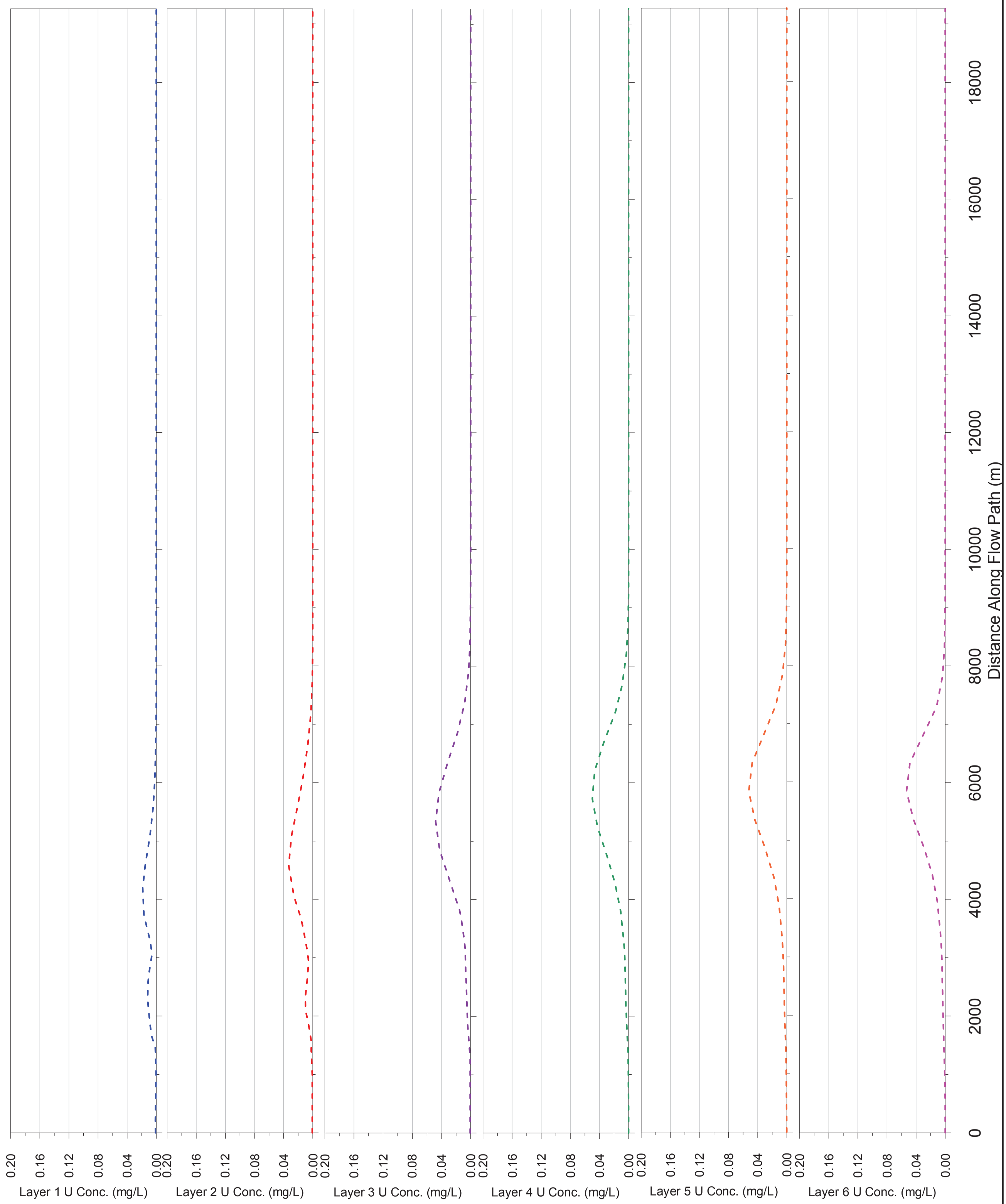
Dwg. No: 345-0/15/7-21

284 YEAR URANIUM CONCENTRATIONS

ALONG FLOWPATH

Rockwater Pty Ltd

Figure 22



345-0/Grapher/Solute Transport/U conc Slices/1000yrUconc.grf

Client: Vimy Resources

Project: Fate of Tailings Seepage

Date: October 2015

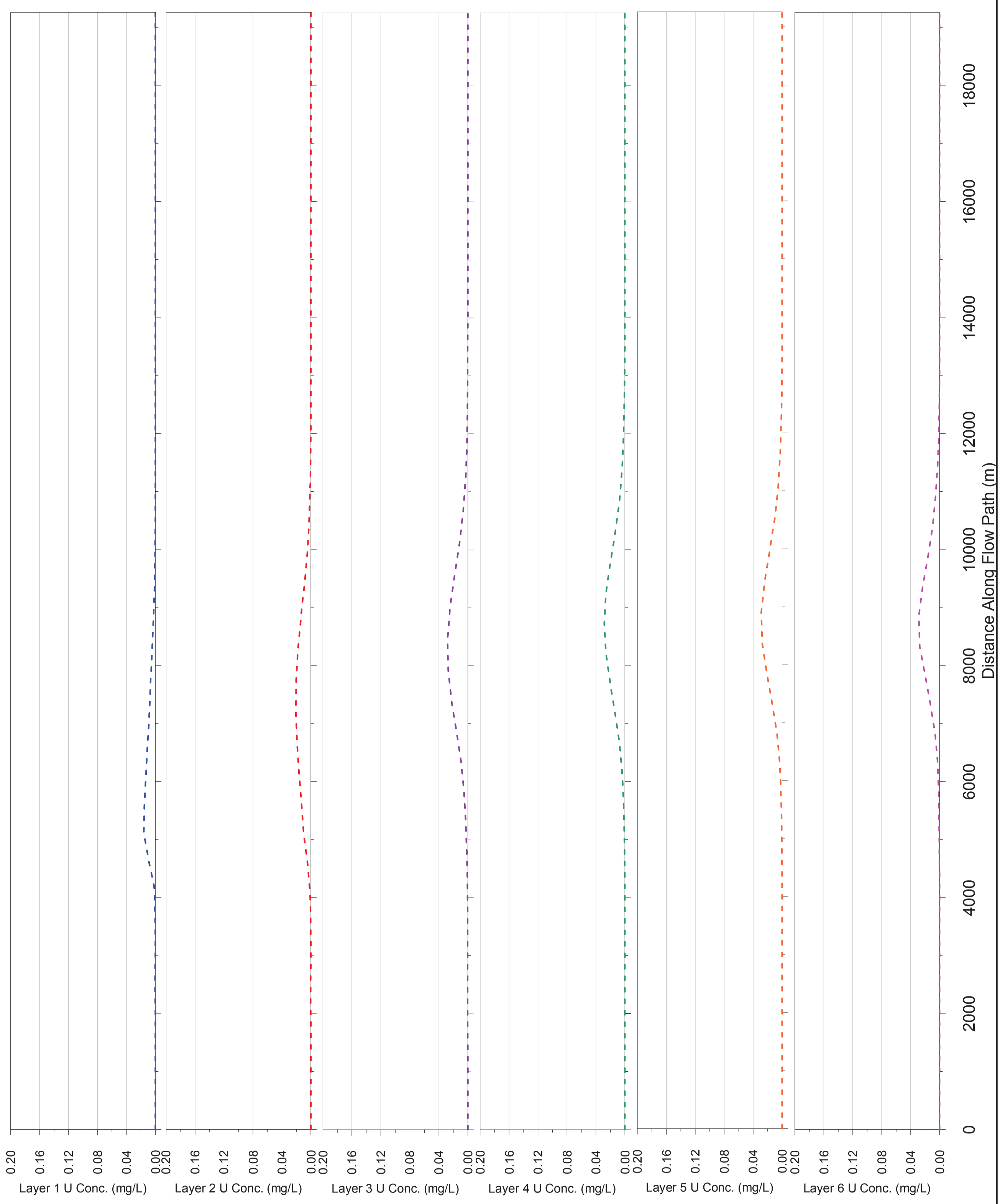
Dwg. No: 345-0/15/7-22

1,000 YEAR URANIUM CONCENTRATIONS

ALONG FLOWPATH

Rockwater Pty Ltd

Figure 23



345-0/Grapher/Solute Transport/U conc Slices/2000yrUconc.grf

Client: Vimy Resources

Project: Fate of Tailings Seepage

Date: October 2015

Dwg. No: 345-0/15/7-23

2,000 YEAR URANIUM CONCENTRATIONS

ALONG FLOWPATH

Rockwater Pty Ltd

Client: Vimy Resources
Project: Fate of Tailings Seepage
Date: 26 October 2015
Dwg. No: 345-0/15/7-24

URANIUM CONCENTRATIONS 100 m SW OF TSF,
WITH DISPERSION, ADSORPTION
& DENSITY LAYERING, 16 YEAR MINE

Rockwater Pty Ltd

1080u16yad.grf

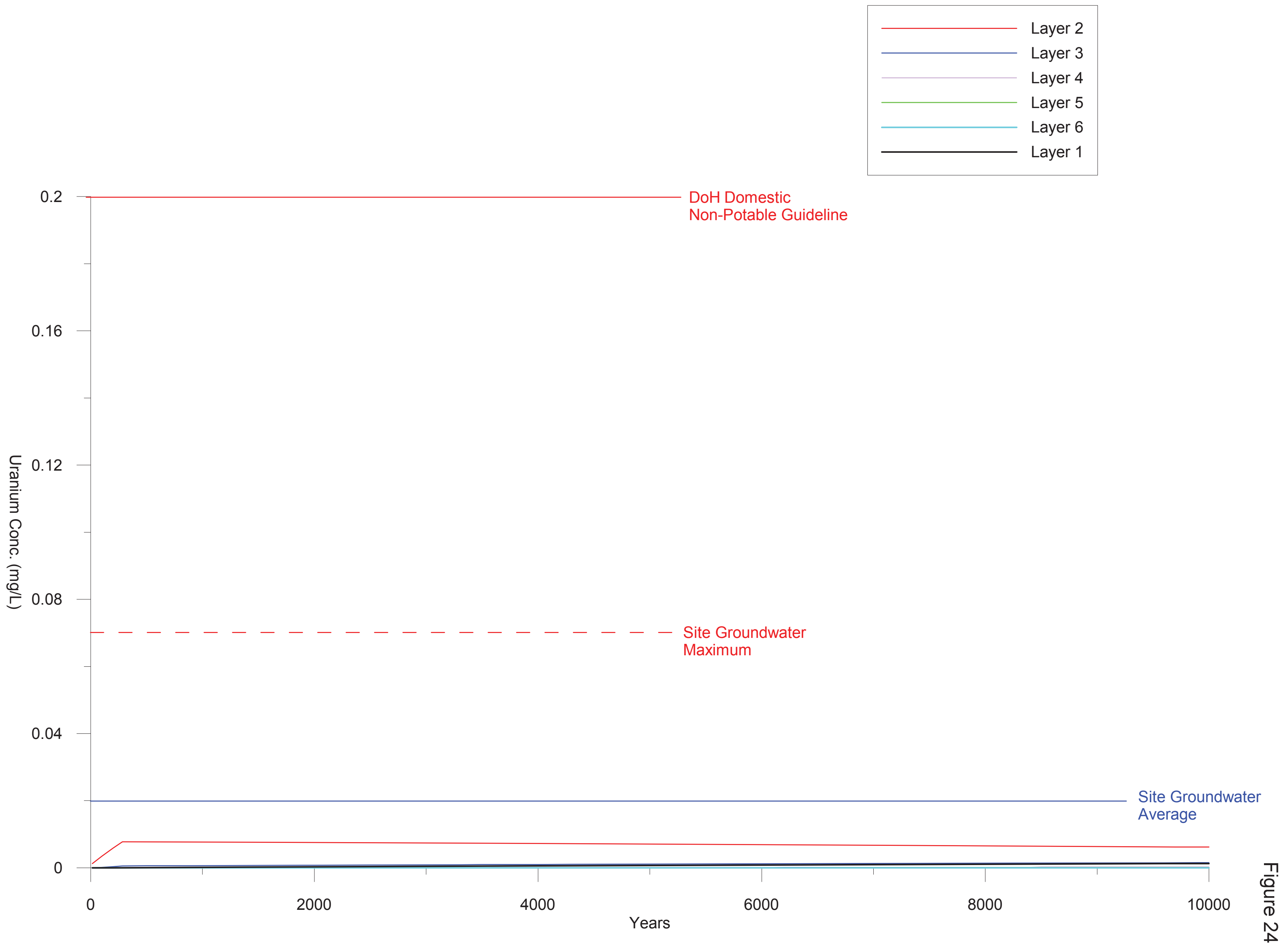


Figure 24

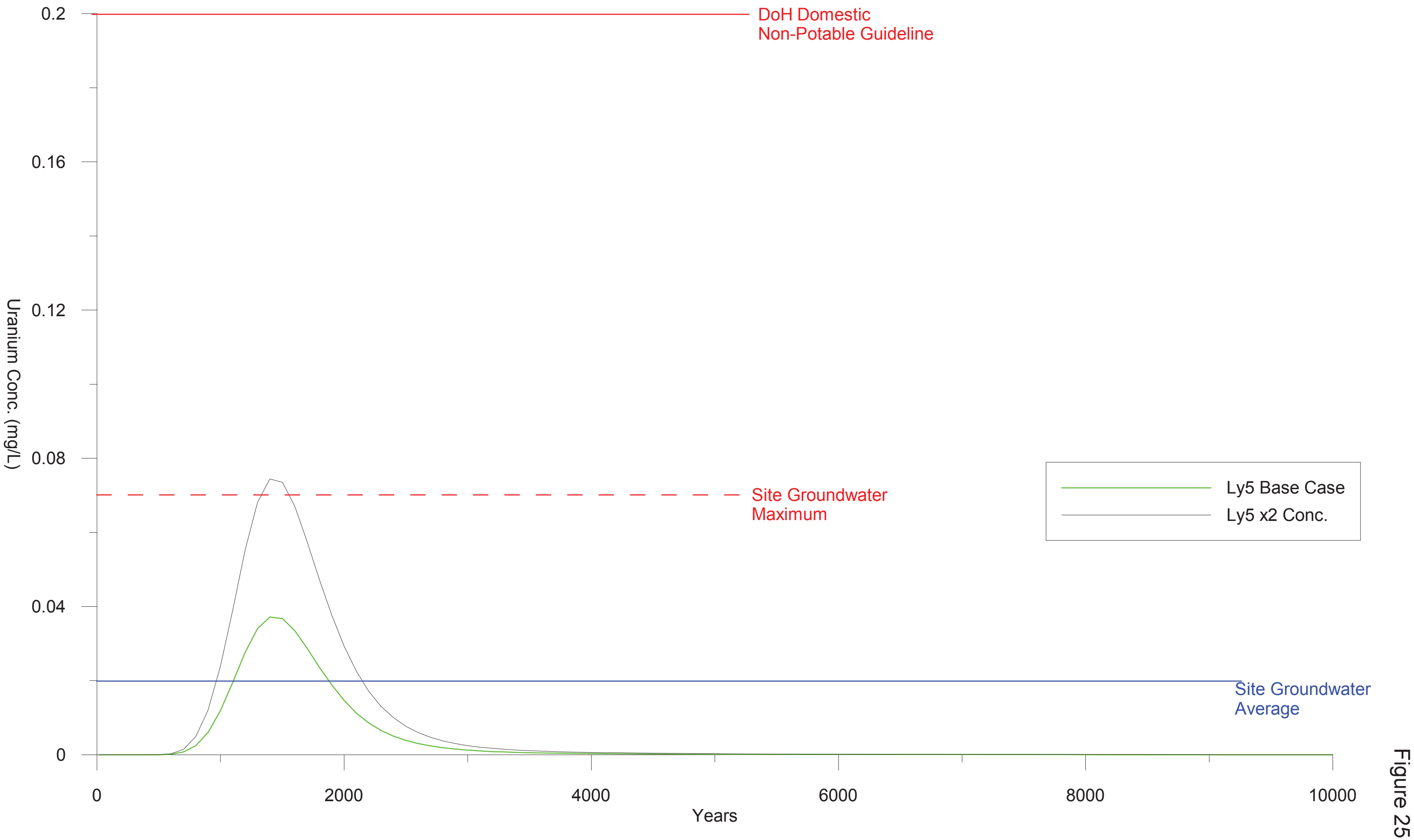
Note: Concentrations are generally above background values

Client: Vimy Resources
Project: Fate of Tailings Seepage
Date: 26 October 2015
Dwg. No: 345-0/15/7-25

SENSITIVITY ANALYSIS
URANIUM FRONT CROSSING STH BOUNDARY
OF M39/1080, ADOPTED BASE CASE
COMPARED WITH 2X SOURCE CONCENTRATIONS

Rockwater Pty Ltd

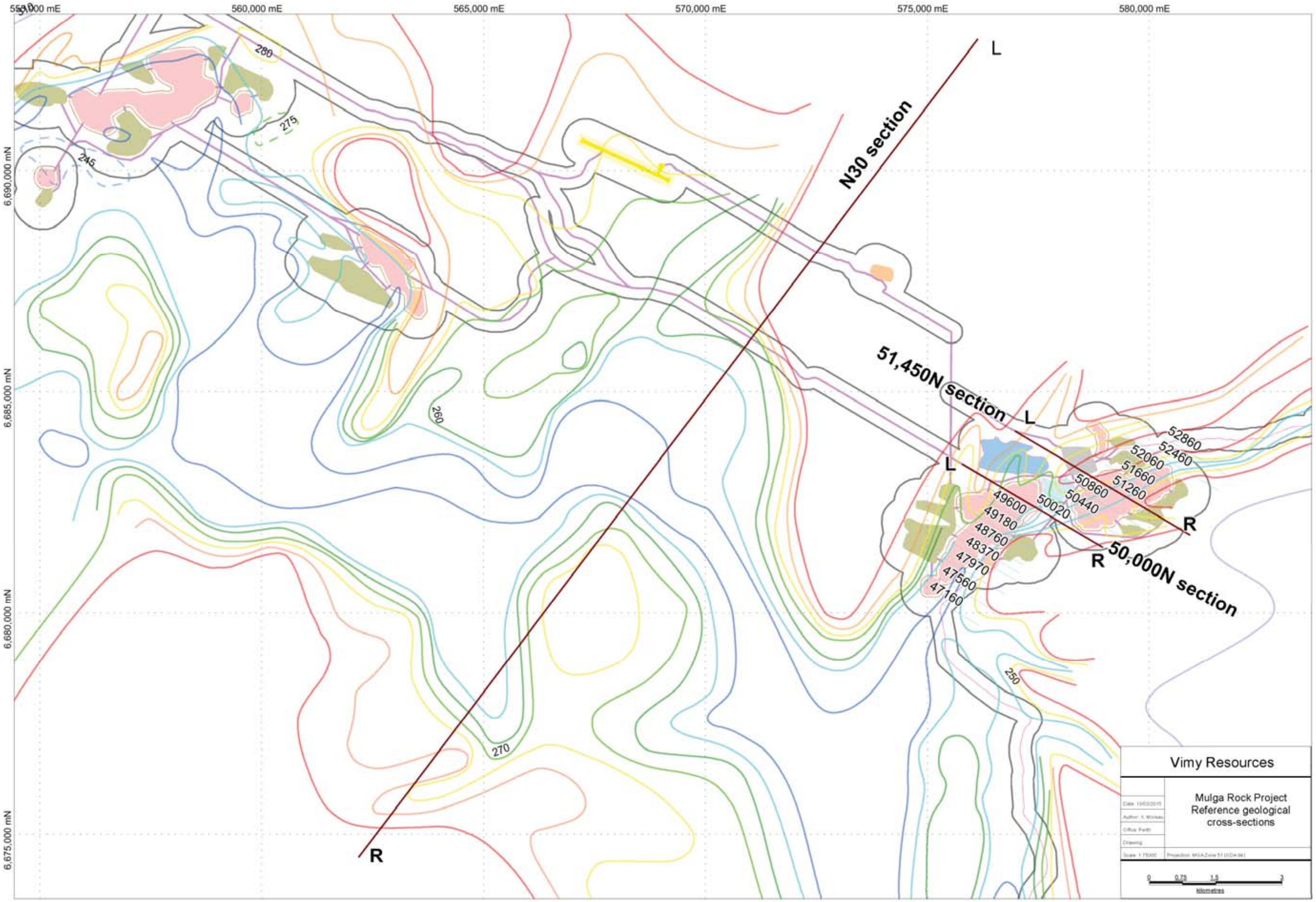
1080u16y uncertainty.grf



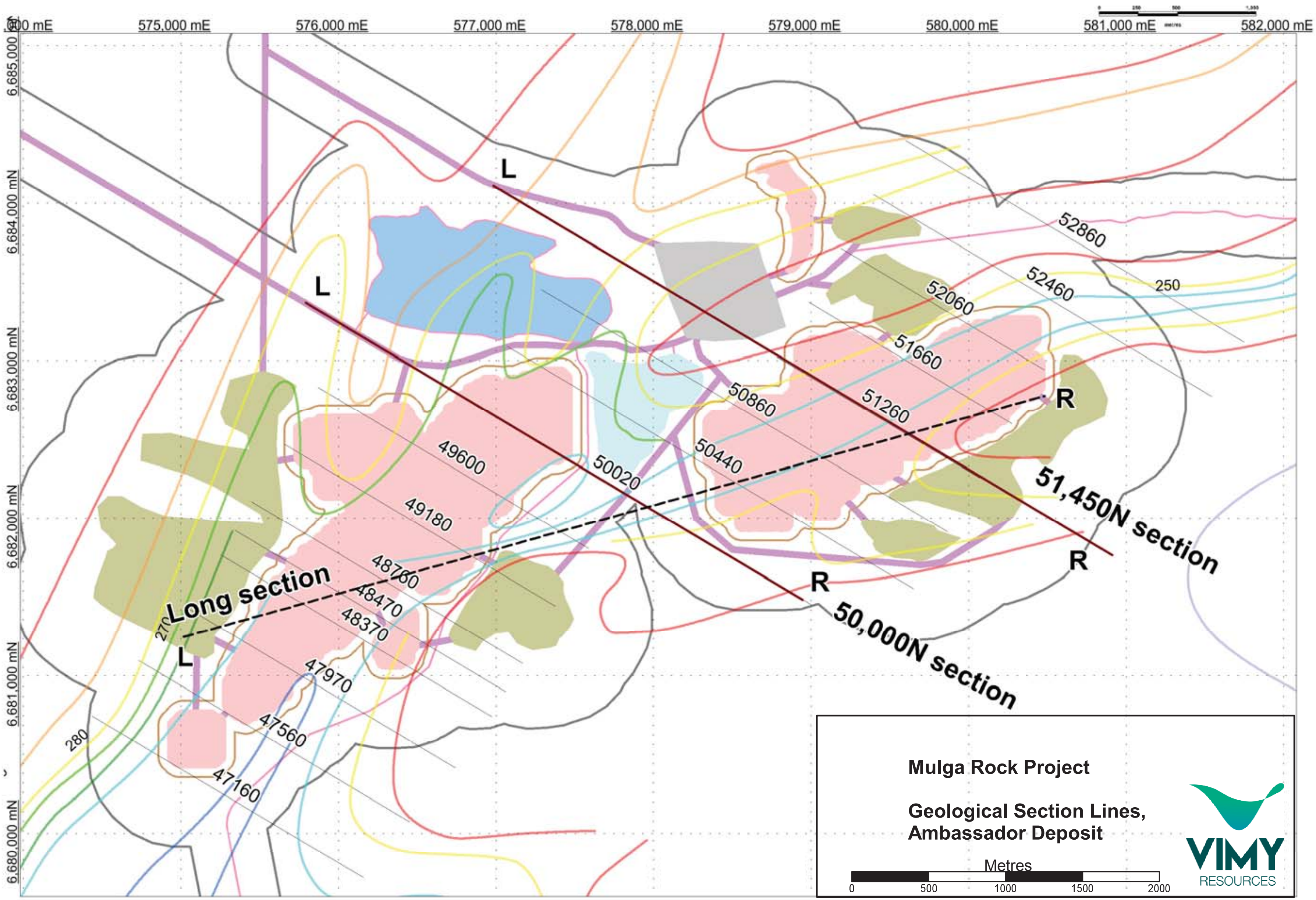
Note: Concentrations are generally above background values

Figure 25

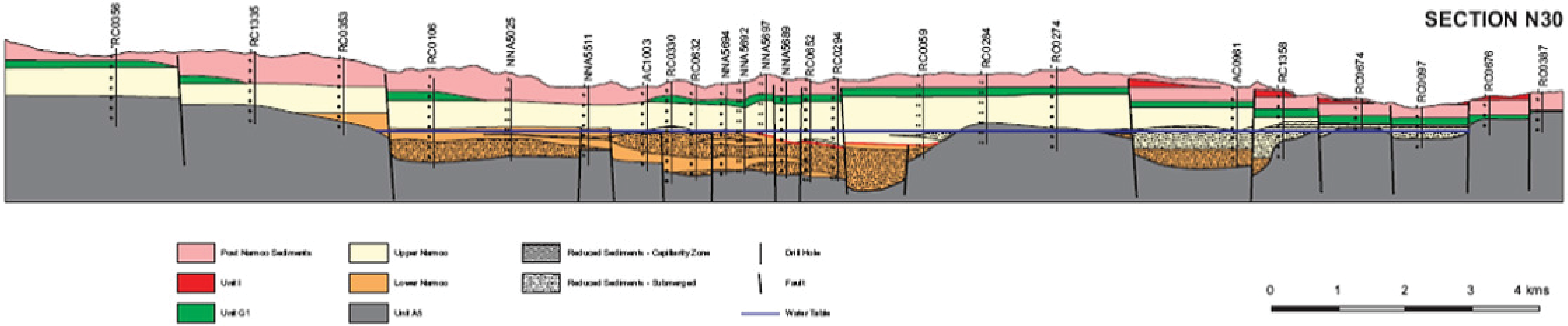
APPENDIX I
GEOLOGICAL SECTIONS

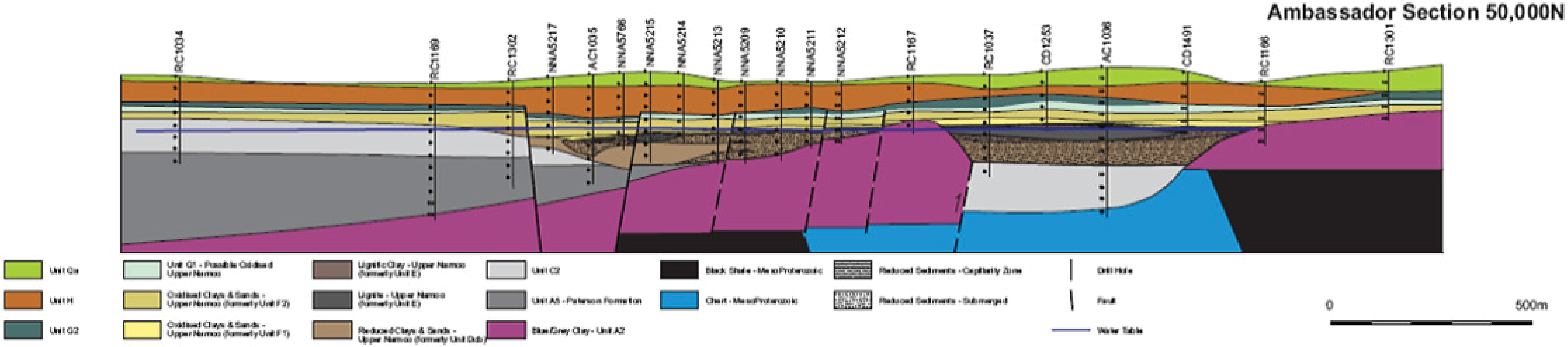


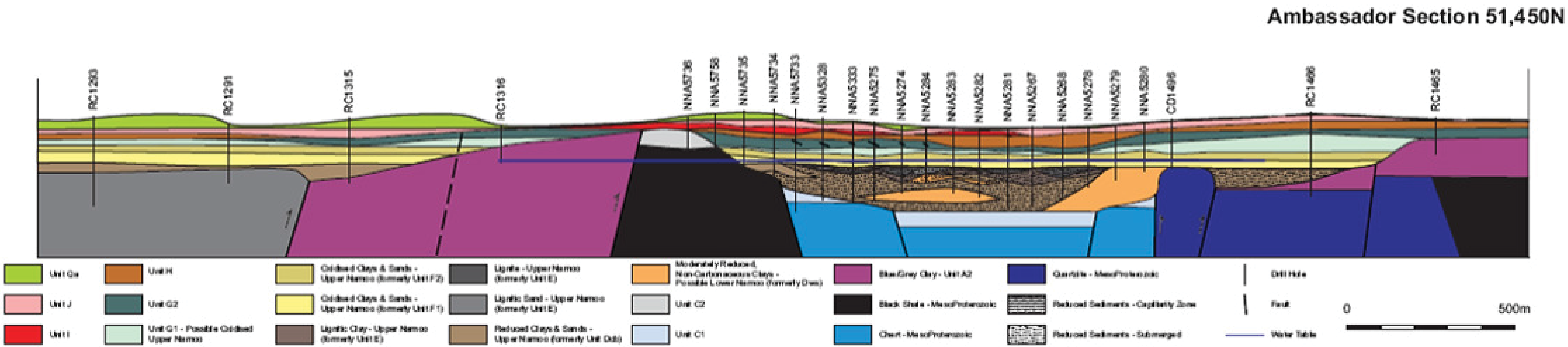
555,000 mE
560,000 mE
565,000 mE
570,000 mE
575,000 mE
580,000 mE
6,690,000 mN
6,685,000 mN
6,680,000 mN
6,675,000 mN
280
275
245
260
270
250
N30 section
L
R
51,450N section
50,000N section
52860
52460
52060
51660
51260
50860
50440
50020
49600
49180
48760
48370
47970
47560
47160
Vimy Resources
Mulga Rock Project
Reference geological
cross-sections
Kilometres

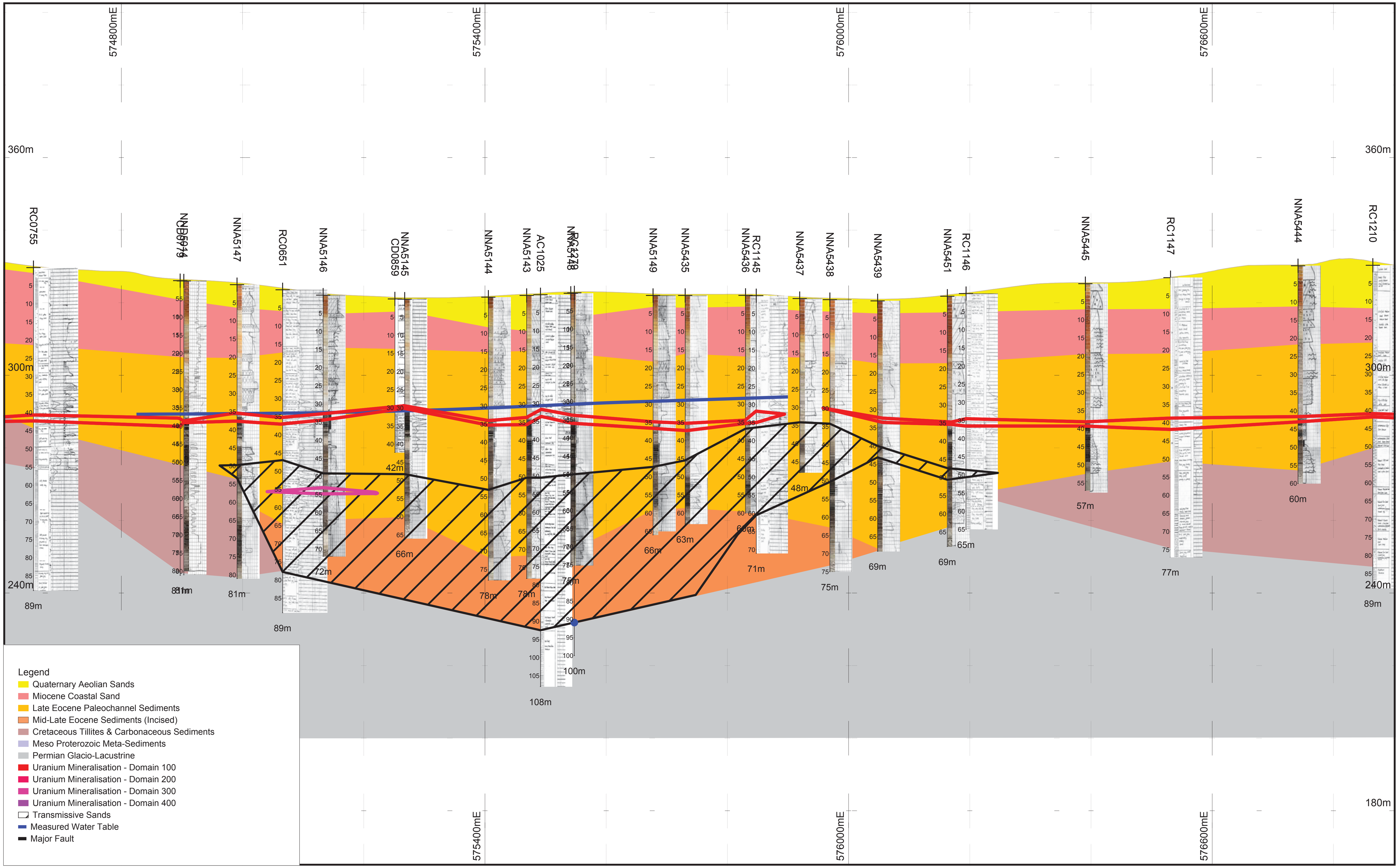


575,000 mE
576,000 mE
577,000 mE
578,000 mE
579,000 mE
580,000 mE
581,000 mE
582,000 mE
6,685,000 mN
6,684,000 mN
6,683,000 mN
6,682,000 mN
6,681,000 mN
6,680,000 mN
L
L
L
R
R
R
52860
52460
52060
51660
51260
50860
50440
50020
49600
49180
48760
48470
48370
47970
47560
47160
250
270
280
Long section
50,000N section
51,450N section
Mulga Rock Project
Geological Section Lines, Ambassador Deposit
Metres
0
500
1000
1500
2000
VIMY
RESOURCES


SECTION N30
Post Namoo Sediments
Unit I
Unit G1
Upper Namoo
Lower Namoo
Unit A5
Reduced Sediments - Capillarity Zone
Reduced Sediments - Submerged
Drill Hole
Fault
Water Table
0 1 2 3 4 kms


Ambassador Section 50,000N
Unit Qa
Unit H
Unit G2
Unit G1 - Possible Oxidised Upper Namoo
Oxidised Clays & Sands - Upper Namoo (formerly Unit F2)
Oxidised Clays & Sands - Upper Namoo (formerly Unit F1)
Lignitic Clay - Upper Namoo (formerly Unit E)
Lignite - Upper Namoo (formerly Unit E)
Reduced Clays & Sands - Upper Namoo (formerly Unit Dcb)
Unit C2
Unit A5 - Paterson Formation
Blue/Grey Clay - Unit A2
Black Shale - MesoProterozoic
Chert - MesoProterozoic
Reduced Sediments - Capillarity Zone
Reduced Sediments - Submerged
Drill Hole
Fault
Water Table
0 500m


Ambassador Section 51,450N
Unit Qa
Unit J
Unit I
Unit H
Unit G2
Unit G1 - Possible Oxidised Upper Namoo
Oxidised Clays & Sands - Upper Namoo (formerly Unit F2)
Oxidised Clays & Sands - Upper Namoo (formerly Unit F1)
Lignitic Clay - Upper Namoo (formerly Unit E)
Lignite - Upper Namoo (formerly Unit E)
Lignitic Sand - Upper Namoo (formerly Unit E)
Reduced Clays & Sands - Upper Namoo (formerly Unit Dcb)
Moderately Reduced, Non-Carbonaceous Clays - Possible Lower Namoo (formerly Dws)
Unit C2
Unit C1
Blue/Grey Clay - Unit A2
Black Shale - MesoProterozoic
Chert - MesoProterozoic
Quartzite - MesoProterozoic
Reduced Sediments - Capillarity Zone
Reduced Sediments - Submerged
Drill Hole
Fault
Water Table
0 500m



VIMY RESOURCES

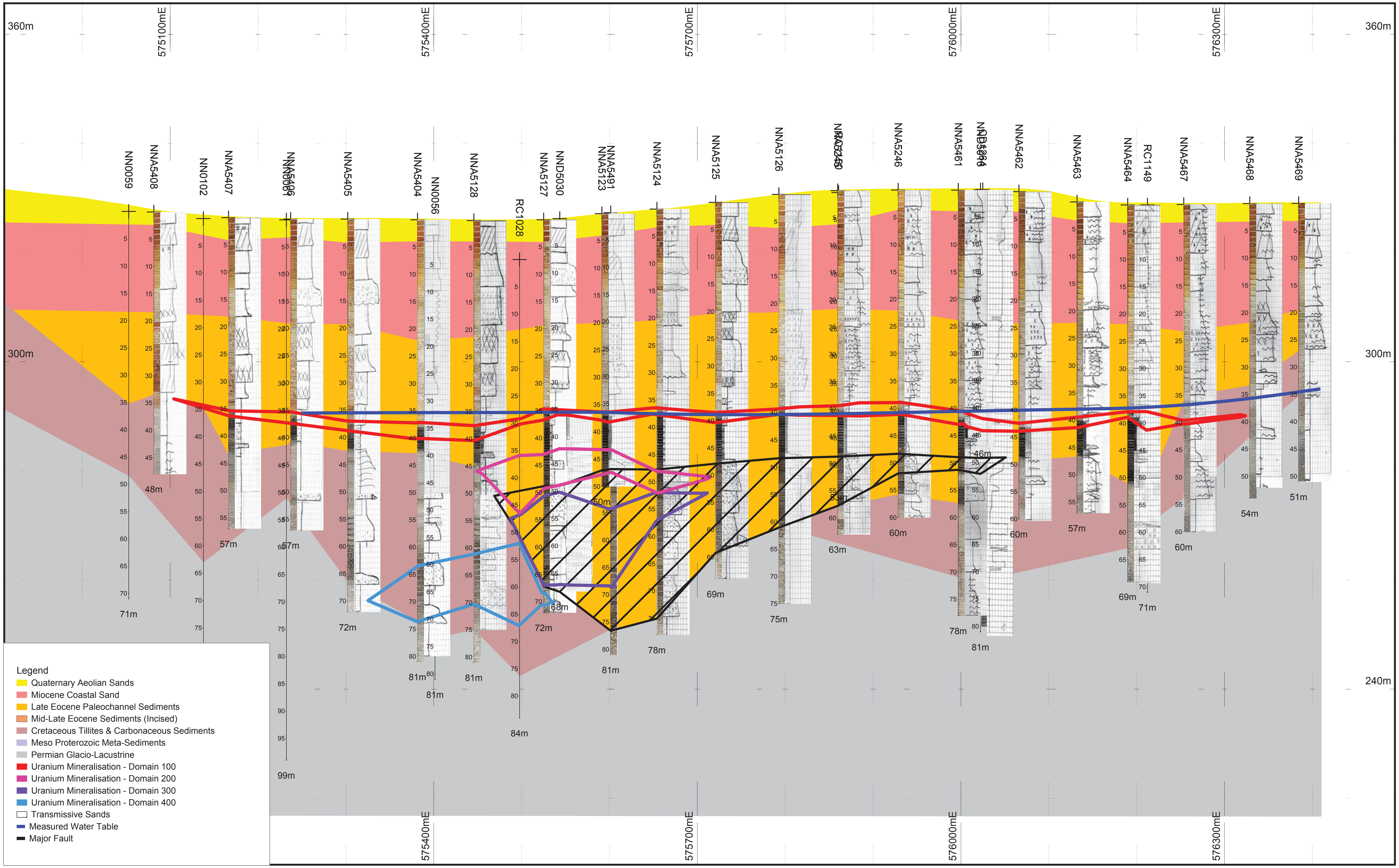
X Scale = 1 : 7047.34
Y Scale = 1 : 1009.47

Plot Date	Sheet
22-Apr-2015	1 of 1

Plot File: 47060N_Hydrology

100 0 100m

Ambassador West
Local Northing - 47060N



VIMY RESOURCES

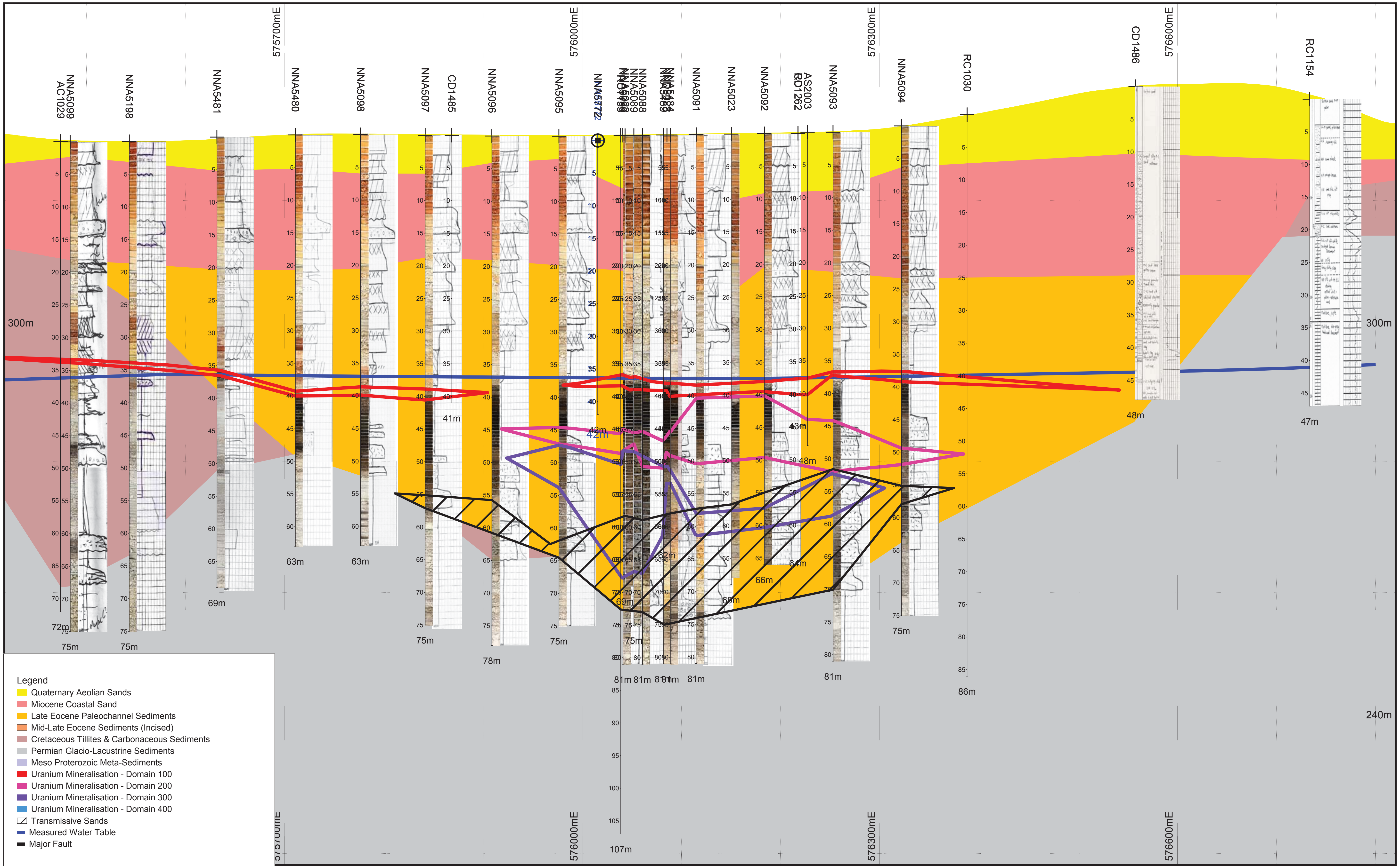
X Scale = 1 : 4856.47
Y Scale = 1 : 671.29

Plot Date	Sheet
22-Apr-2015	1 of 1

Plot File: 47970N_Hydrology

100 0 100m

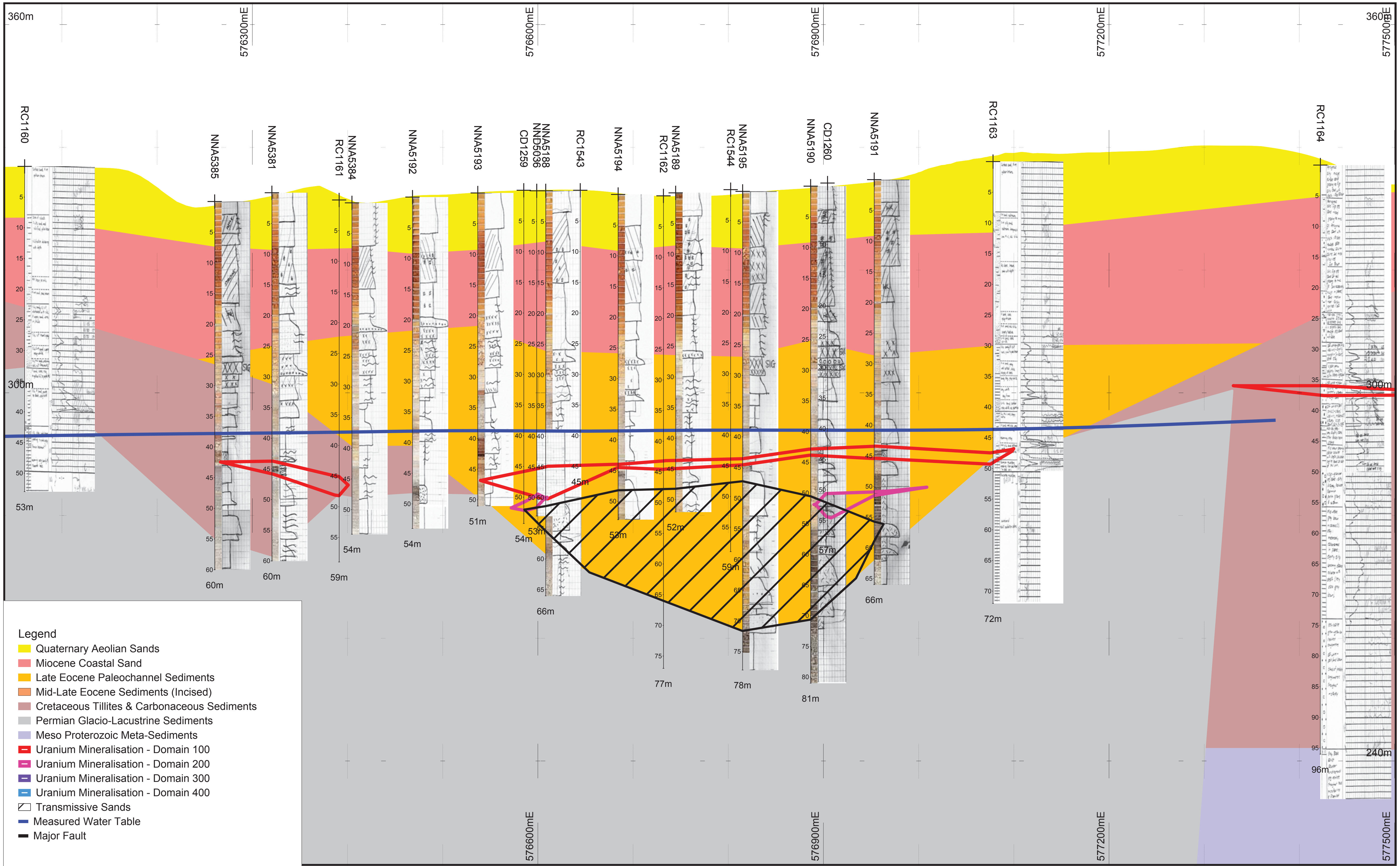
Ambassador West
Local Northing - 47970N



VIMY RESOURCES

X Scale = 1 : 4305.41 Y Scale = 1 : 561.08	Plot Date 22-Apr-2015	Sheet 1 of 1
	Plot File: 48760N_Hydrology	
100 0 100m		

Ambassador West
Local Northing - 48760N



VIMY RESOURCES

X Scale = 1 : 4485.38
Y Scale = 1 : 597.08

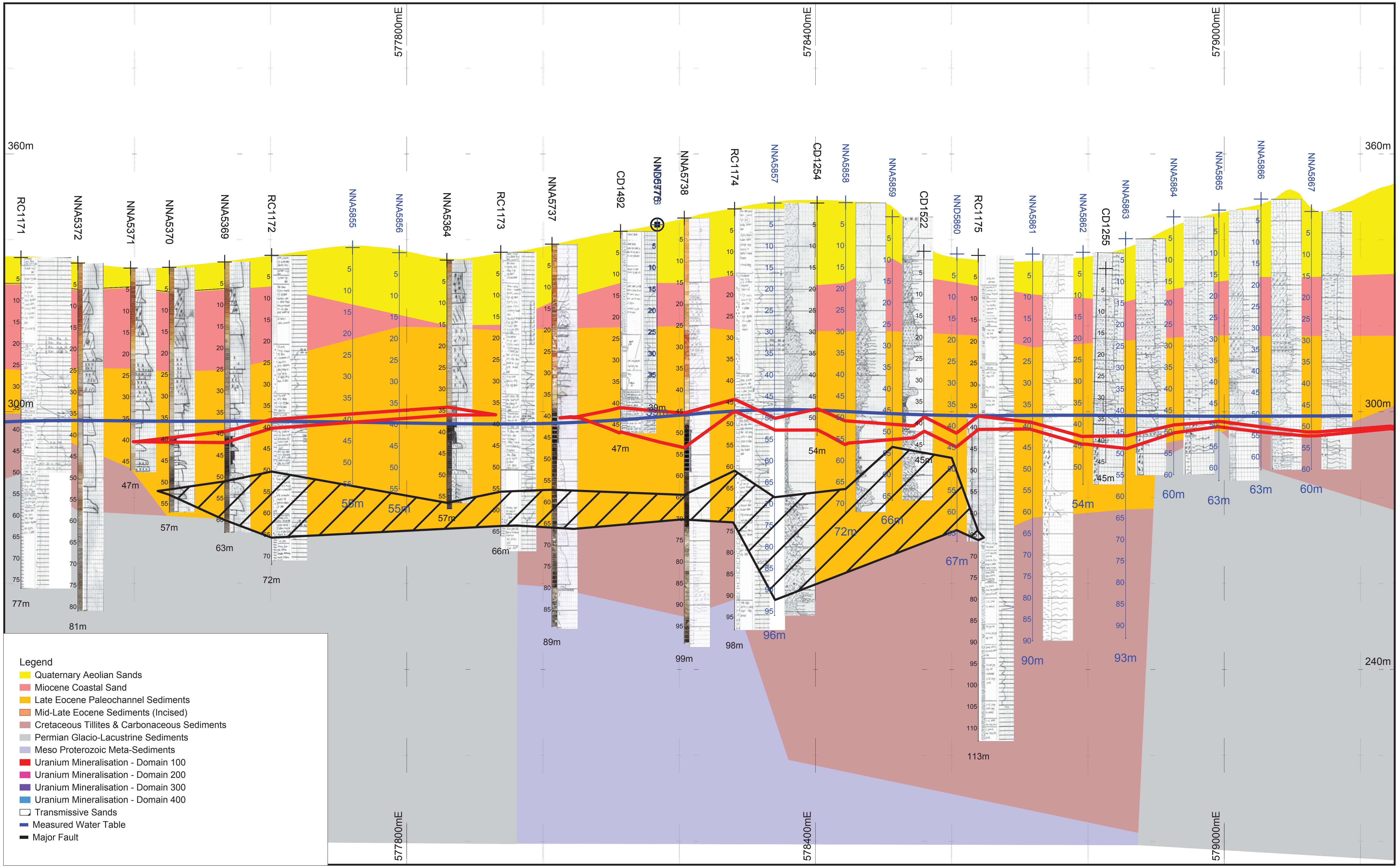
Plot Date 22-Apr-2015

Sheet 1 of 1

Plot File: 49600N_Hydrology

100 0 100m

Ambassador West Local Northing - 49600N



VIMY RESOURCES

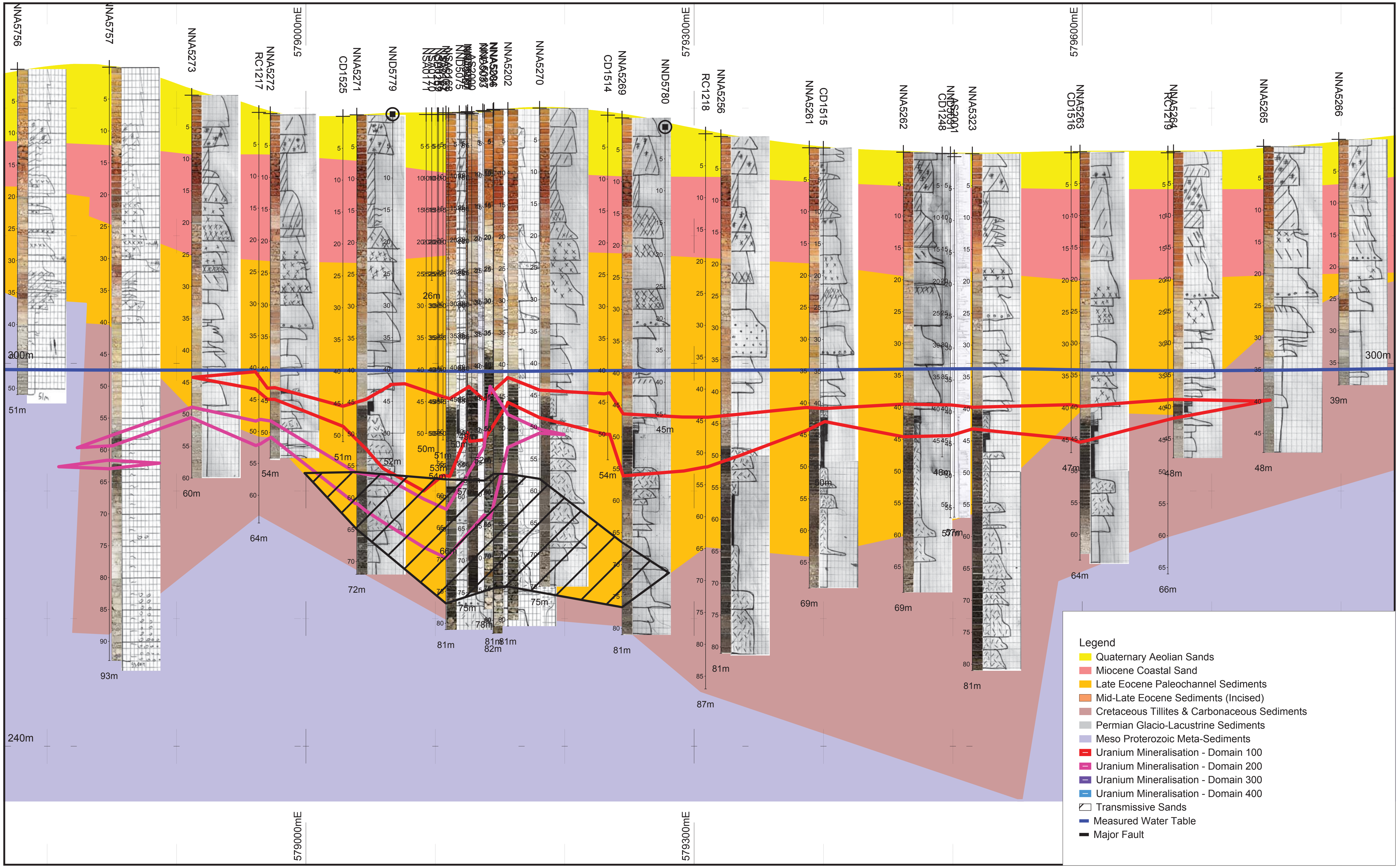
X Scale = 1 : 6262.94
Y Scale = 1 : 852.59

Plot Date	Sheet
22-Apr-2015	1 of 1

Plot File: 50440N_Hydrology

100 0 100m

Ambassador West to East Local Northing - 50440N



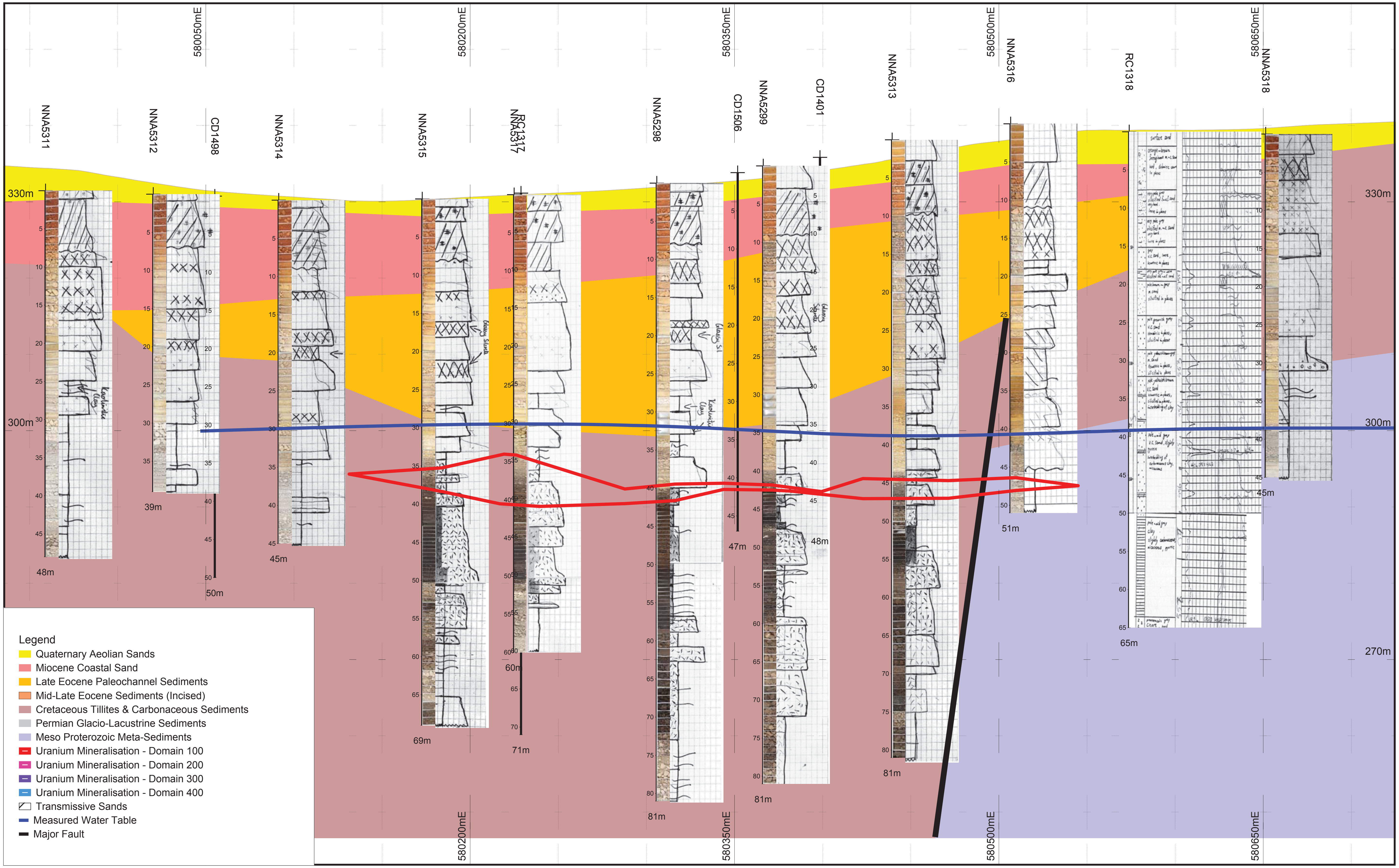
VIMY RESOURCES

X Scale = 1 : 3270.37
Y Scale = 1 : 574.07

Plot Date	Sheet
22-Apr-2015	1 of 1
Plot File: 51250N_Hydrology	

50 0 50m

Ambassador East
Local Northing - 51250N



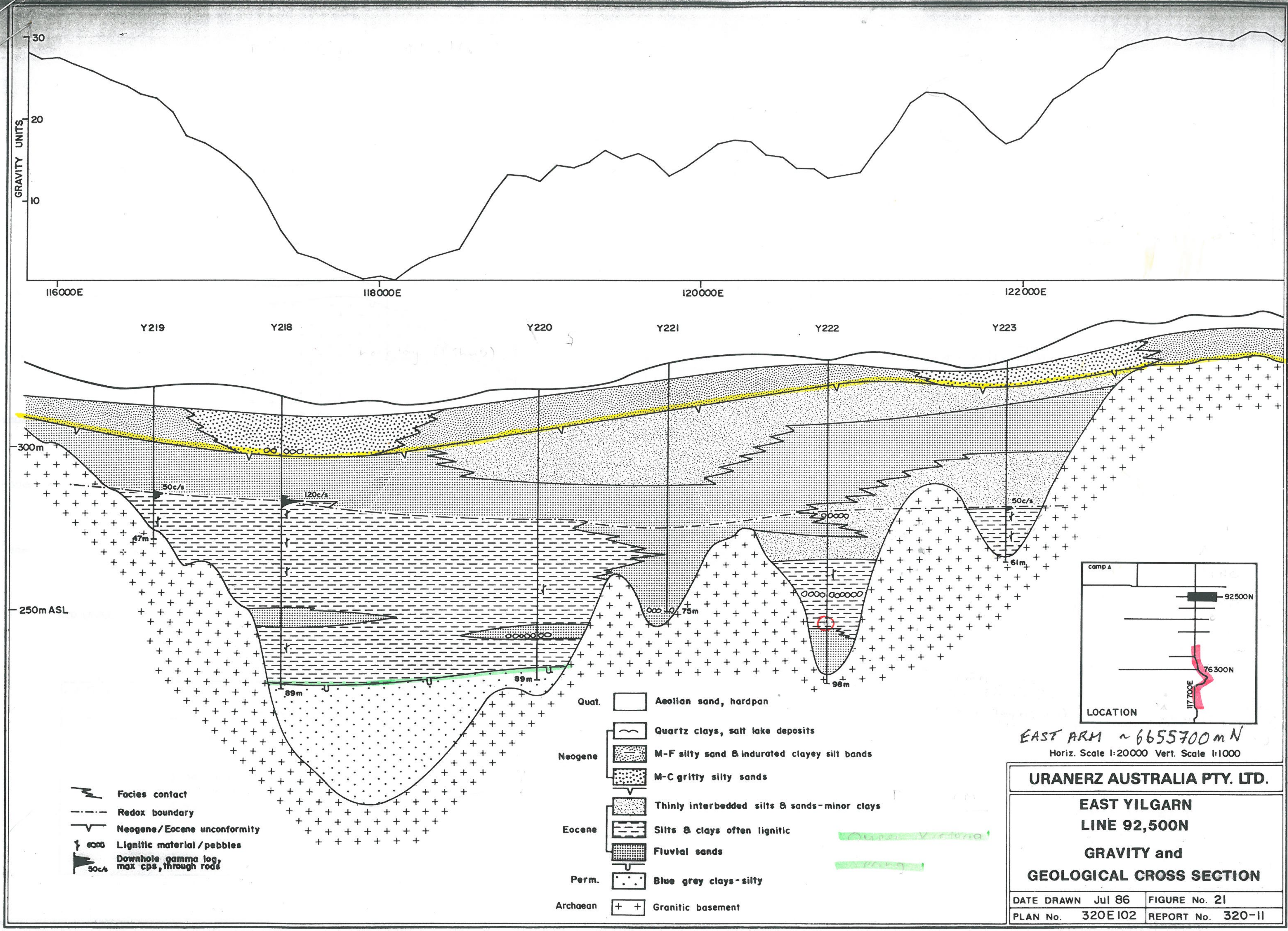
VIMY RESOURCES

X Scale = 1 : 2400.93
Y Scale = 1 : 480.19

Plot Date	Sheet
21-Apr-2015	1 of 1
Plot File: 52060N_Hydrology2	

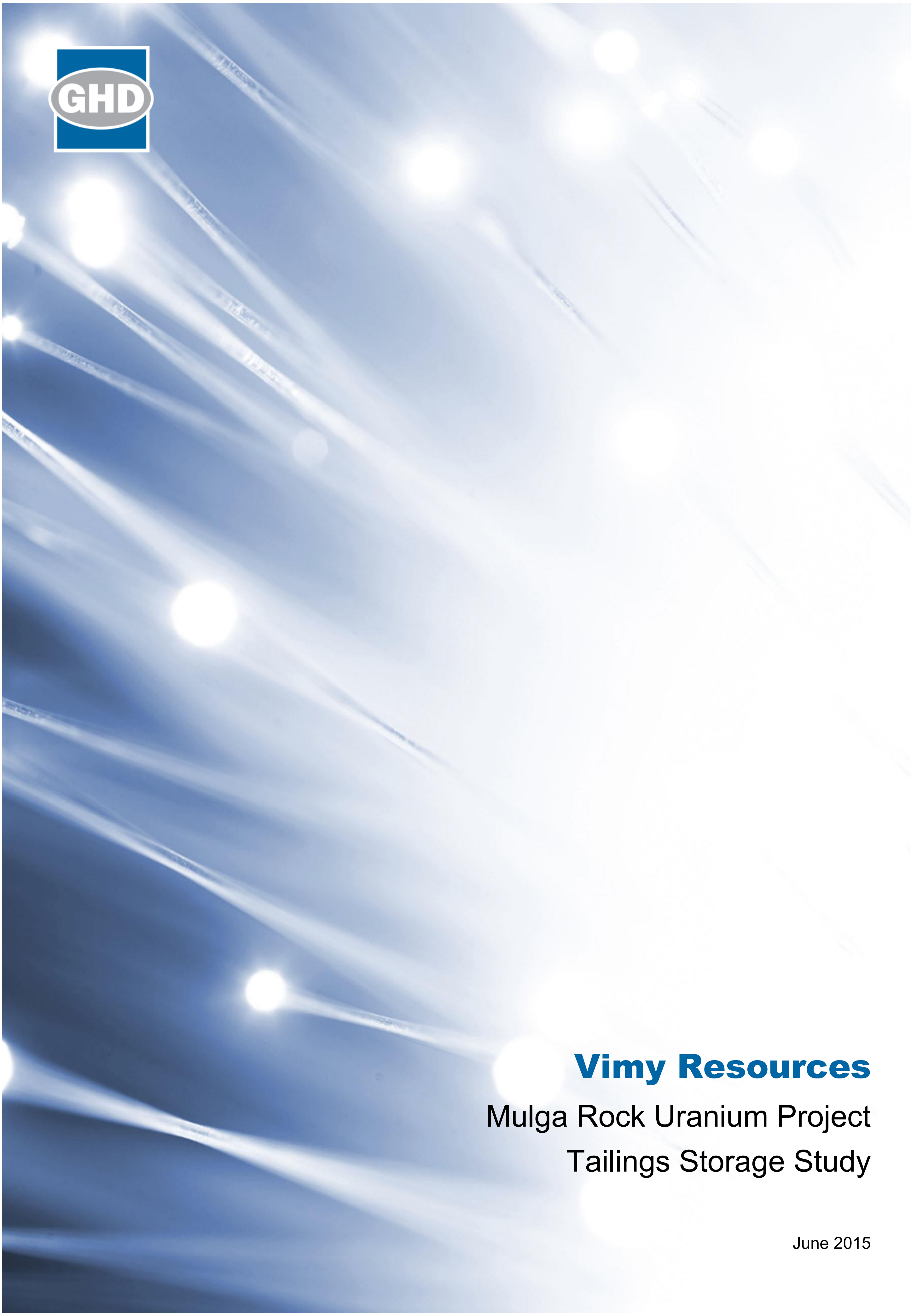
50 0 50m

Ambassador East
Local Northing - 52060N



30
20
10
GRAVITY UNITS
116000E
118000E
120000E
122000E
Y219
Y218
Y220
Y221
Y222
Y223
300m
250m ASL
50c/s
120c/s
50c/s
47m
89m
89m
75m
98m
61m
camp
92500N
76300N
117700E
LOCATION
Facies contact
Redox boundary
Neogene/Eocene unconformity
Lignitic material/pebbles
Downhole gamma log, max cps, through rods
50c/s
Quat.
Aeolian sand, hardpan
Neogene
Quartz clays, salt lake deposits
M-F silty sand & indurated clayey silt bands
M-C gritty silty sands
Eocene
Thinly interbedded silts & sands-minor clays
Silts & clays often lignitic
Fluvial sands
Perm.
Blue grey clays-silty
Archaean
Granitic basement
EAST ARM ~6655700mN
Horiz. Scale 1:20000 Vert. Scale 1:1000
URANERZ AUSTRALIA PTY. LTD.
EAST YILGARN
LINE 92,500N
GRAVITY and
GEOLOGICAL CROSS SECTION
DATE DRAWN Jul 86
FIGURE No. 21
PLAN No. 320E102
REPORT No. 320-11

APPENDIX II
GHD (2015) REPORTS



Vimy Resources

Mulga Rock Uranium Project
Tailings Storage Study

June 2015

Executive summary

This report presents the outcomes from the above ground tailings disposal study for the Mulga Rock Uranium Project (MRUP) prepared by GHD for Vimy Resources Limited (Vimy). The Project is located in an arid region of Western Australia, approximately 240 km east-northeast of Kalgoorlie.

The key objective of this study was to develop a concept design of the above ground Tailings Storage Facility (TSF) for the MRUP, outline the tailings disposal operations and the tailings facility closure. The above ground TSF is planned to be used for the initial 18 months of ore processing, after which the tailings will be directed into an exhausted mine void. As a contingency measure, the above ground TSF will also include capacity to accommodate an additional 18 months of storage capacity beyond that indicated previously for initial ore processing.

The above ground TSF was conceptually designed as a non-release structure, while the in-pit facility is expected to release leachate into the groundwater body.

Based on the geochemical properties of the tailings and the fact that the oxidation process is detrimental with respect to the formation of acid and metalliferous leachates, the intention is to keep deposited tailings fully saturated and submerged at all times. This has the added benefit of controlling radon and protecting the tailings surface from the desiccating effects of high temperatures and the potential for wind induced dust dispersion.

Sub-aqueous tailings deposition will be maintained throughout the entire operational period using discharge spigots fed through a perimeter tailings pipework.

The size of the TSF surface area was selected to ensure that the final height of the TSF is restricted to equal or below the surrounding dunes and it will ensure that the final closure landscape will blend into the natural surroundings.

To allow for a staged construction and simplify the facility operation, the tailings storage area was split into two cells. The first cell would provide sufficient capacity for the initial 18 months of deposition and the second cell could be constructed during the initial operational stages of the mine for reserve storage. The smaller surface area of the operational cell would also reduce the requirements for volume of water needed to provide permanent water cover until the closure stages.

The sides of the TSF have a double liner such as HDPE and clay to prevent seepage in to the adjoining sandier ground. This is further controlled by a leak detector drain at the base of the slope. The floor is covered by a double clay liner. Seepage into the underlying more clayey material is further restricted by including a tailings underdrainage system that will reduce pore pressures on the liner. Any seepage that does migrate through the liner will be neutralised by the underlying calcrete which will reduce mobility of metals and metalloids.

The operation of the above ground TSF will be conventional using a perimeter tailings discharge method. A decant system was not included as the potentially recoverable water would not be useable for processing and also to keep and maintain water pond area for the subaqueous deposition. The floor drainage system is located above the floor liner. It leads to a pump well where the pressure can be lowered whilst recirculating water to the surface to maintain water cover. The pump well has a valved outlet which when open at closure will allow gravity drainage without pumping.

At the initial stage of deposition, the drainage outlet will be closed to allow for control of the water volume and pressure by pump control.

The floor underdrainage system will also enable reduction of pore water pressures at the base of the facility and once is open it will facilitate consolidation of the tailings. During closure earthworks, the floor drainage system will be used to remove excess water from the facility when the closure materials are being placed and thus, accelerate the closure process.

In addition to the floor drainage system, a leak detection system is also design to control a double liner constructed on the upstream slopes of the TSF.

The closure of the above ground TSF will be conventional using a domed landform which will include a capillary break layer between the deposited tailings and top cover. The surface materials and landform will be selected such that the final shape of the closed TSF will be integrated with the existing landscape.

Table of contents

Table index

Figure index

Appendices

1. Introduction

1.1 General

GHD Pty Ltd (GHD) was commissioned by Vimy Resources Limited (Vimy) to undertake a Tailings Storage Study for the proposed Mulga Rock Uranium Project (the Project).The Project is located approximately 240 km east-northeast of Kalgoorlie, Western Australia.

As part of the Project development, Vimy submitted Environmental Scoping documents to the Department of Mines and Petroleum (DMP) in late 2014 and is currently in the process of preparing a Public Environmental Review (PER).

Upon receiving comments from DMP, Vimy identified the above ground tailings storage as one of the key concerns of the regulators. GHD was therefore engaged to prepare a Tailings Storage Study to present a concept design of the above ground tailings storage facility (TSF).

This report presents the outcomes from the Tailings Storage Study prepared for the Mulga Rock Uranium Project.

1.2 Limitations

This report: has been prepared by GHD for Vimy Resources and may only be used and relied on by Vimy Resources for the purpose agreed between GHD and the Vimy Resources as set out in Section 2 of this report.

GHD otherwise disclaims responsibility to any person other than Vimy Resources 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.

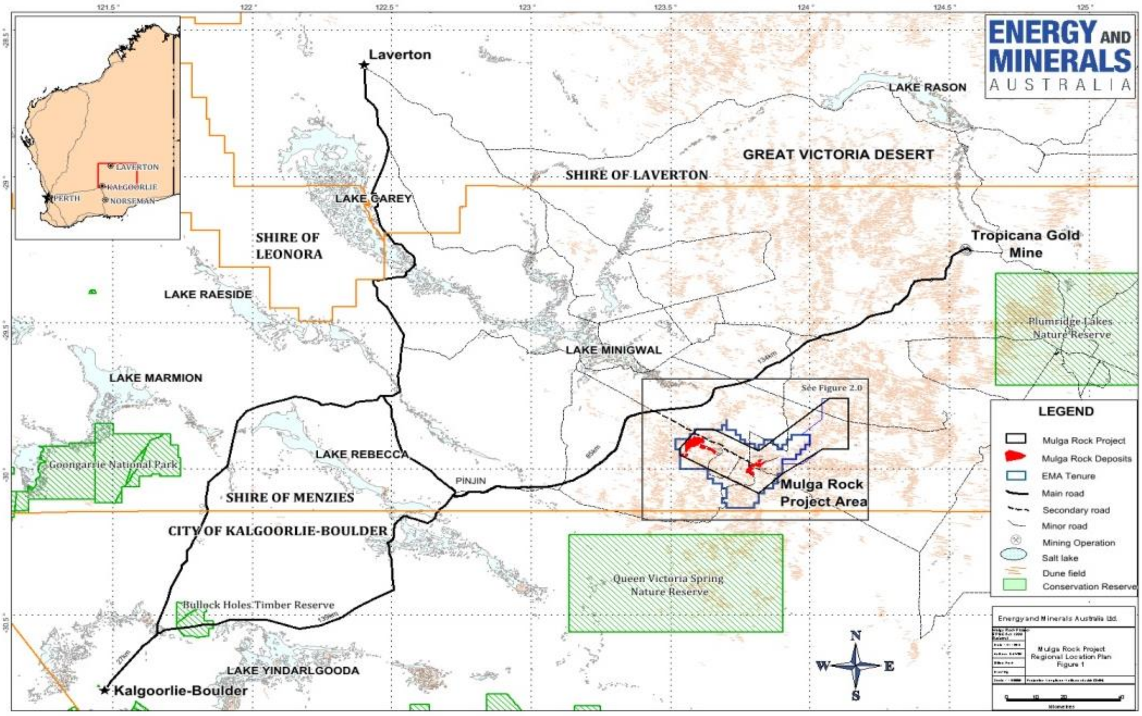
GHD has prepared this report on the basis of information provided by Vimy Resources and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such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

1.3 Project Background

1.3.1 Project Location

The Project is located approximately 240 km east-northeast of Kalgoorlie, Western Australia, on the south western margin of the Great Victoria Desert (refer Figure 1-1). The Great Victoria Desert extends from the Eastern Goldfields area in Western Australia across the southern parts of central Australia to the Stuart and Gawler Ranges in South Australia. It is divided into three subregions, with the western shield subregion covering 54,427 km^2 – the only division relevant to the Project.

Figure 1-1 Mulga Rock location



1.3.2 Mine Layout

The Project is situated on granted Mining Leases ML39/1080 and ML39/1081. It will involve the shallow open pit mining of four poly-metallic deposits with commercial grades of contained uranium hosted in carbonaceous material that extends a shallow depth below the groundwater table.

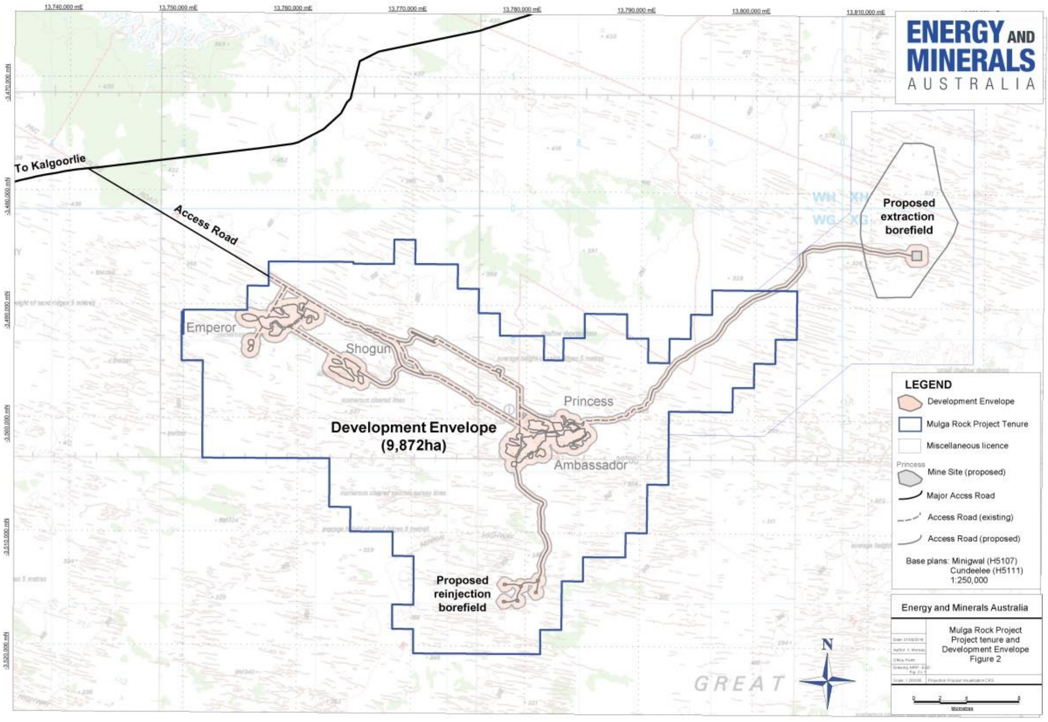
The Project is split into two deposits referred to as Mulga Rock East and Mulga Rock West. The Mulga Rock East deposit is made up of the Princess and Ambassador Resources, and the Mulga Rock West deposit comprises the Shogun and Emperor Resources. The general development area is shown in Figure 1-2

Major built infrastructure will include a processing plant, ore stockpile area, construction of above-ground overburden landforms for un-mineralised mined materials, an initial short term above-ground tailings storage facility and water storage/evaporation facilities.

Required project infrastructure will also include mine administration and workshop facilities, fuel and chemical storage, a diesel-fired power plant, a saline water borefield, mine water reinjection borefield and associated pipelines.

Service infrastructure will include a power supply, accommodation village for a fly-in fly-out workforce, airstrip, laydown areas and other supporting ancillary infrastructure such as communication systems, roads, waste water treatment plant and solid waste landfill facilities.

Figure 1-2 Mulga Rock Project - Project Tenure and Development Envelope

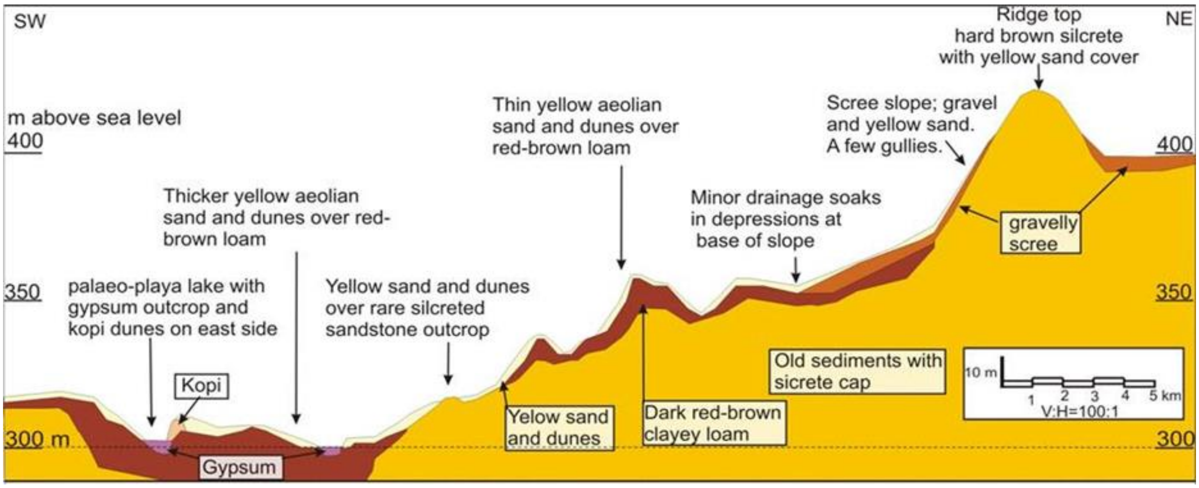


1.3.3 Topography

The Project area is surrounded by an undulating sandy plain at an elevation of between 325 m and 400 m Australian Height Datum (AHD) crossed by east-trending sand dunes that locally can reach up to 15 m high and 10 km long.

The Project area consists of an undulating sandy plain at an elevation of approximately 300 to 400m AHD, crossed by ESE-trading linear sand dunes that locally can reach a height of 10 to 15 m (GRC, 1984). A schematic of a SW-NE cross section profile of the Project is shown in Figure 1-3.

Figure 1-3 Schematic SW – NW Section



1.3.4 Vegetation and Land Use

The bioregion at Mulga Rock comprises yellow sand plain communities with diverse mammalian and reptile fauna and distinctive plant communities. The vegetation consists predominantly of an open spinifex – eucalypt association.

Land has a limited use in the area. From map data and visual inspection it is identified that to the north land was typically unused and comprises some salt lakes. The land to the west is also unused and contains some creeks and salt lakes with a possibility for agriculture. The land to the south is used as nature reserves with some creeks and salt lakes, and land to the east is unused land.

1.3.5 Climate

Vimy has established climate monitoring at the Project area. A summary of the monthly rainfall is provided in Table 1-1 and shown graphically in Figure 1-4.

The climate at Mulga Rock is arid to semi-arid, with mean annual rainfall ranging from below 150 mm to over 300 mm. Rainfall is non-seasonal and shows great variability between years.

Mean daily maximum and minimum temperatures are about 34°C and 18°C, respectively, in January, and 16 C and 6°C in July when overnight minima can commonly fall below 0°C. Annual evaporation for the area, derived from Luke *et al.* (1987), is 3,000 mm.

The intensity – duration – frequency rainfall curves generated for the Project using the Bureau of Meteorology website are shown in Figure 1-5.

Table 1-1 Monthly Rainfall Totals (mm)

Month	Airstrip					Emperor					Shogun				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
January	9.3	58.7	23.6	15.2	65.7	0	108.2	55.4	20.8	128.8	3.0	105.8	62.6	15.2	116.6
February	10.3	191.3	13.7	7.5	31.3	12.6	252.4	23.0	3.8	51.8	15.0	247.4	21.6	10.2	49.2
March	5.9	9.3	20.7	36.6	3.3	3.6	17.0	47.4	70.0	11.8	11.2	18.2	48.8	58.2	12.2
April	31.3	20.3	0.7	8.6	0.9	38.2	28.8	0.2	14.6	21.4	53.0	33.8	0.2	16.6	12.0
May	8.0	11.2	2.6	18.7	17.2	7.3	17.4	2.6	18.2	38.4	9.1	19.8	3.0	31.0	31.6
June	7.8	57.2	6.9	4.5	4.6	7.8	85.2	10.0	5.8	6.6	9.6	82.2	13.2	7.2	7.2
July	8.8	21.0	2.1	8.1	2.5	13.2	38.4	2.4	14.7	4.0	12.0	36.2	3.4	13.0	4.0
August	55.1	1.9	0.6	2.1	0.4	86.8	3.0	1.4	3.4	1.2	79.2	3.0	0.8	1.8	1.2
September	27.4	2.1	0.6	5.8	5.1	36.4	5.6	1.0	13.2	7.6	36.2	4.0	0.8	10.0	6.8
October	1.5	36.7	3.8	0.9	9.0	0.6	61.4	9.4	1.2	19.2	1.8	59.2	6.4	2.8	17.4
November	1.9	12.2	35.1	47.9	21.6	2.0	24.4	48.0	65.4	30.0	1.0	24.2	50.8	57.2	32.0
December	7.7	12.7	17.5	15	N/A	7.4	28.8	53.8	16.8	N/A	9.0	22.8	28.4	16.0	N/A
Annual Total	175	434.6	127.9	170.9	161.6	215.9	670.6	254.6	247.9	320.8	240.1	656.6	240.0	239.2	290.2

Figure 1-4 Annual Rainfall

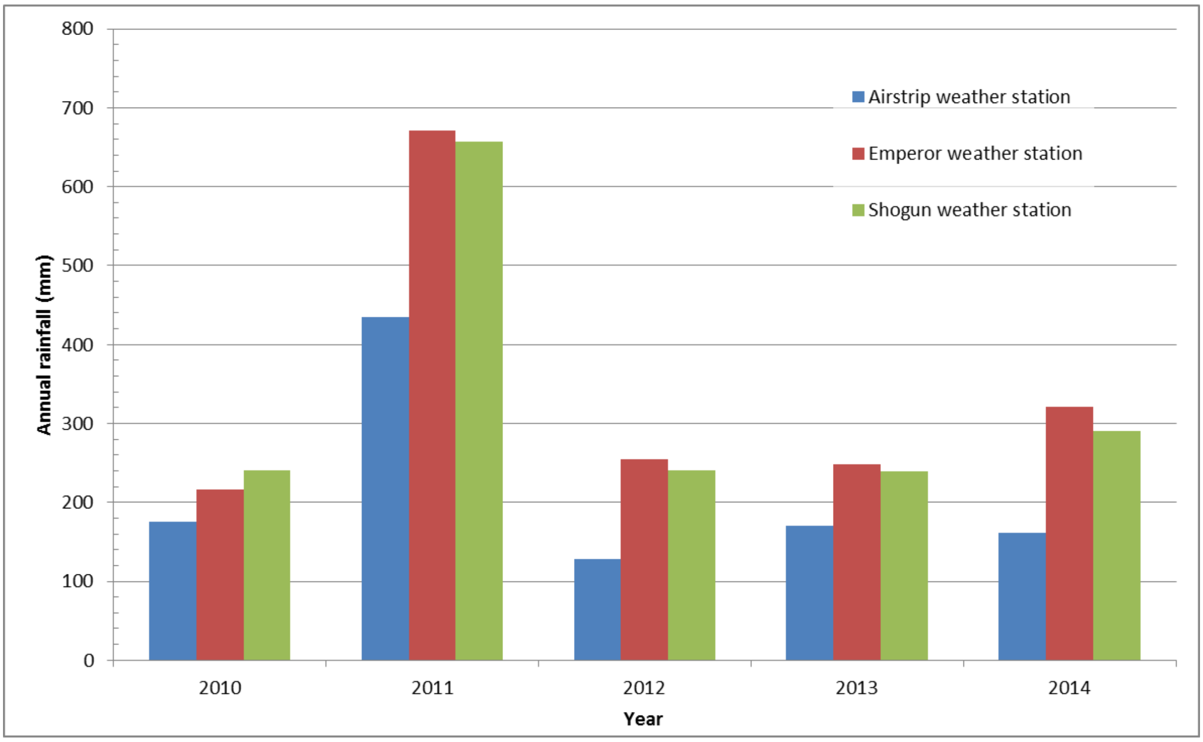
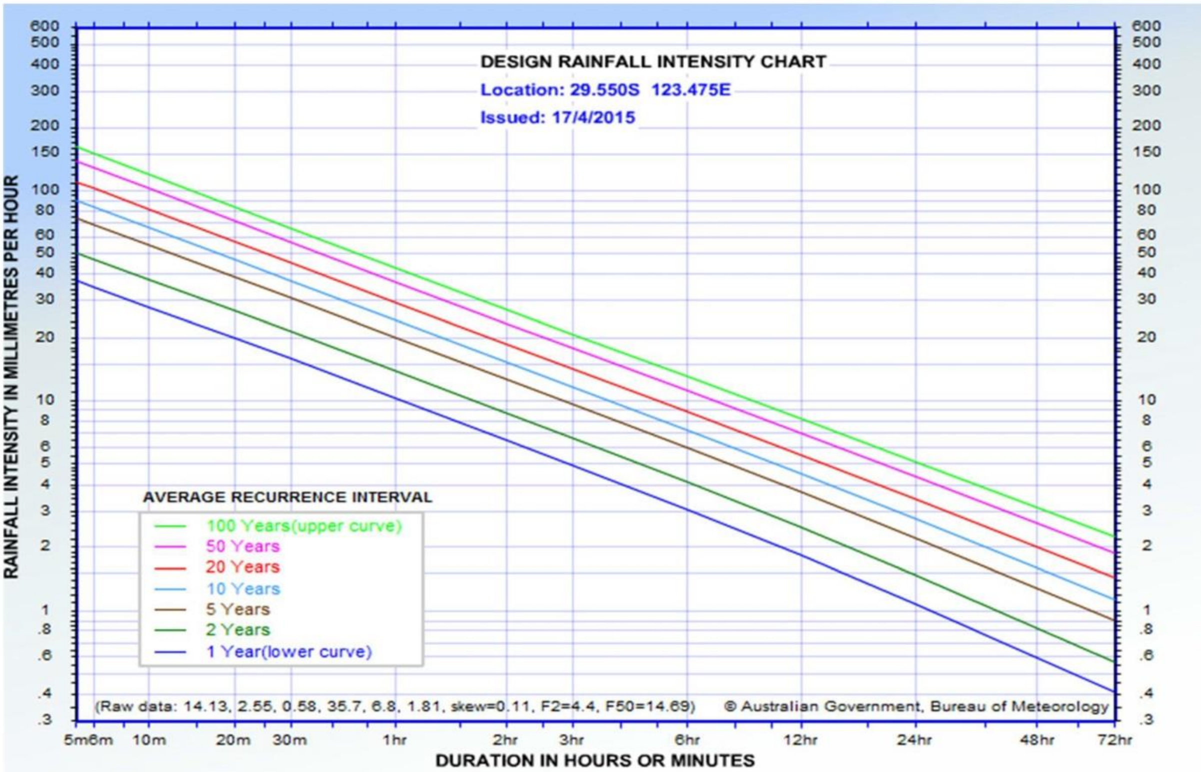


Figure 1-5 Intensity-Duration-Frequency Curves



1.3.6 Surface Water Drainage

Surface drainage occurs via broad shallow creeks that trend south-eastwards in the east to south-westwards into Ponton Creek in the west (GRC, 1984). There are no permanent surface water bodies present.

Lake Minigwal is located approximately 50 km to the northwest (upstream) of the Project.

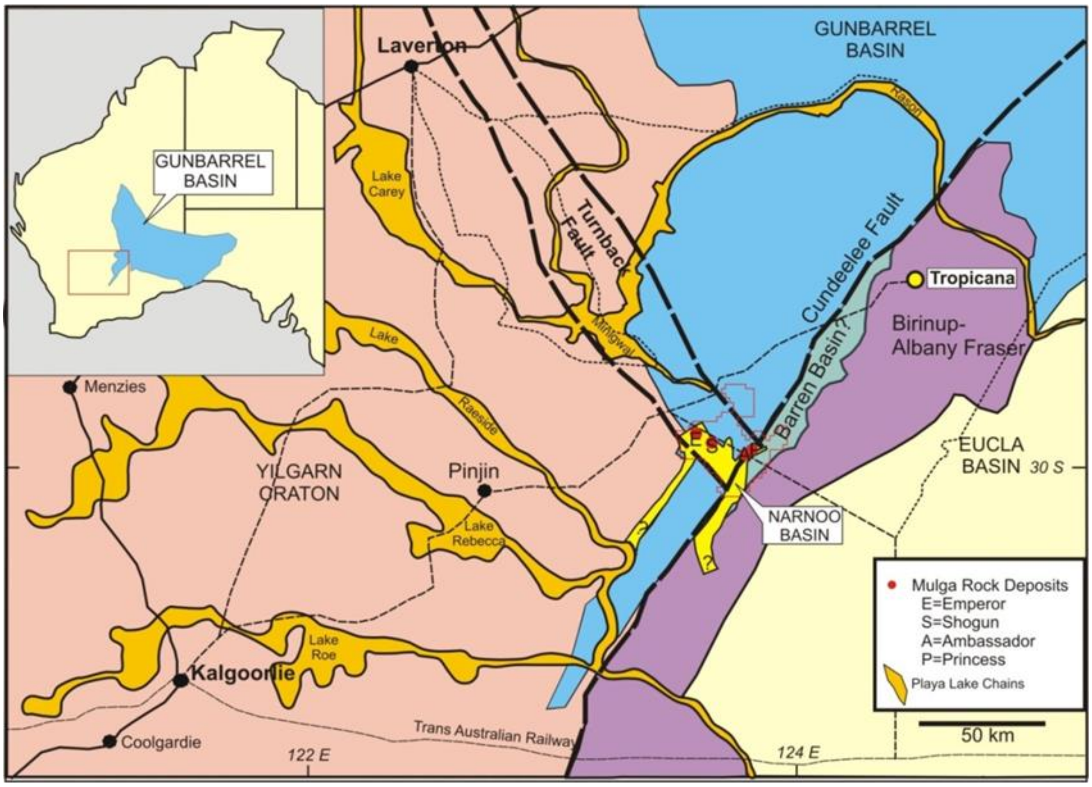
1.3.7 Geological Setting

The Project is located in an embayment in the southwest corner of the Officer Basin, which is a Proterozoic trough containing Phanerozoic sediments.

The Project covers a significant portion of the Narnoo Basin, a small Late Eocene sub-basin within the larger Gunbarrel Basin (mostly filled with Late Carboniferous - Early Permian glacio-fluvial sediments), located at the contact between an Archaean basement of the Yilgarn craton (Burtville Terrane) and a Paleo-Proterozoic metamorphic basement (Northern Foreland, reworked Archean). The position and scale of the basin with respect to surrounding tectonic units is shown in Figure 1-6.

As shown in Figure 1-6, a palaeodrainage system has been mapped regionally which indicates a number of drainage systems trending generally eastwards and southwards e.g. Lake Raeside, Lake Minigwal and Lake Rebecca, before draining to the Eucla Basin / Southern Ocean. It is suspected that the Lake Minigwal drainage flowed into the Narnoo Basin, however, this was disrupted by more recent tectonism.

Figure 1-6 Regional Geological Setting



The Mulga Rock deposits lie in a structurally controlled palaeovalley / palaeochannel which contains fluvial, lacustrine and marine sediments that include sandstone, claystone, lignite and minor conglomerate commonly occurring in graded beds (Rockwater, 2013). As shown in Figure 1-6, the palaeochannel has an east and western ‘arm’, with the latter potentially connected with the Lake Raeside and Lake Rebecca drainage systems.

The paleochannel is incised through Permian age sediments, infilled with Paleogene/Neogene age sediments and covered by Quaternary sediments (GRC, 1984). The palaeochannel is up to 7 km wide and 110 m deep, occupying a graben between the Yilgarn Block to the west and the Albany-Fraser Province to the east. The southern extension of the palaeochannel is bound to the south by an uplifted fault block within the main graben. GRC (1984) described the sides of the palaeochannel to be very abrupt in places and probably fault controlled.

Permian rocks rarely outcrop, but are overlain by a variety of Mesozoic (Lower Cretaceous) and Cenozoic sediments. The region has been subjected to continental conditions since the Cretaceous, and planation and sedimentation have continued under humid (Paleogene/Eocene Epoch) and then arid (Neogene/Miocene Epoch) conditions. The Permian sediments consist mainly of mudstone interbedded siltstone and very fine-grained sandstone.

The sequences of Paleogene/Neogene sediments within the palaeochannel are of fluviatile – lacustrine origin, deposited in a very humid environment, with abundant vegetation (GRC, 1984). The sequence has been further subdivided:

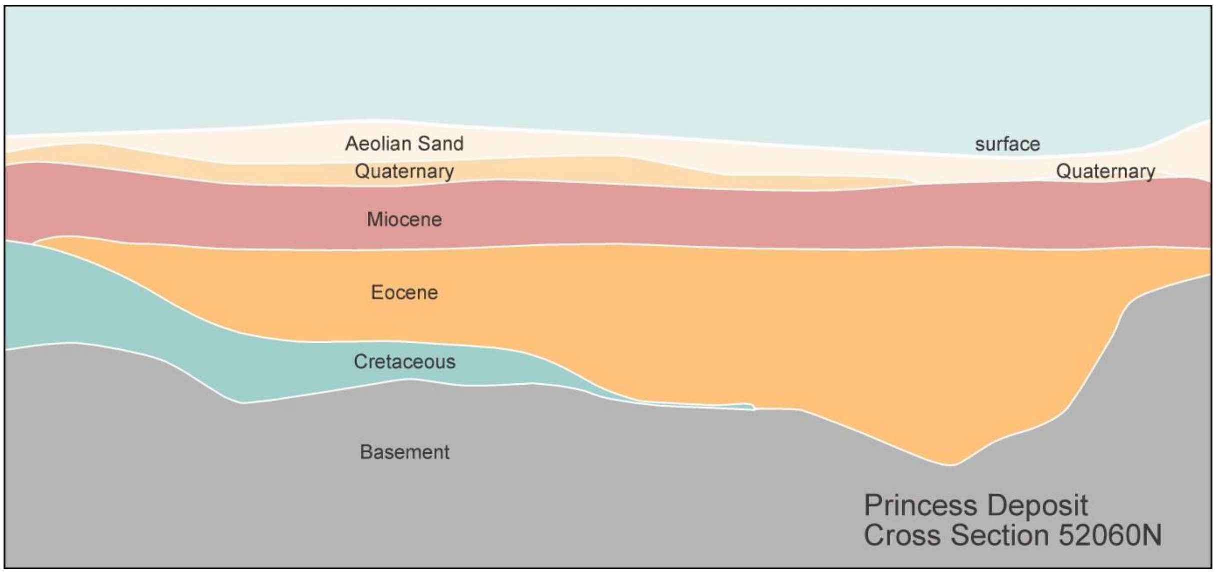
- The upper part of the sequence (Miocene – Late Eocene) comprises sandstone and siltstone, with minor clay with a total thickness of 20 m to 30 m. The upper strata has been oxidised, silcretised and laterised by weathering. Interpreted to be deposited under fluvial conditions, with interbedded lacustrine sediments.
- The middle part of the sequence (Eocene) comprises carbonaceous clay and peat, with minor sandy interbeds, and generally ranges 5 m to 20 m, up to 50 m thick (GRC, 1984). The upper part of the unit is generally oxidised, forming white-light brown kaolinitic clay. Uranium mineralisation occurs mainly at the redox interface within this carbonaceous clay and peat sequence. Interpreted to be deposited under lacustrine to paludal conditions.
- The lower sandy section consists of basal sand and conglomerate approximately 2 m to 3 m thick overlain by approximately 40 m thick sands (commonly carbonaceous and pyritic and generally unconsolidated) interbedded with silt, clay and peaty clay. Interpreted to be deposited under fluviatile conditions.

Overlying the Paleogene/Neogene sequence are Quaternary age superficial aeolian sands of 10 m to 20 m in thickness.

1.3.8 Lithological Units

The selected above ground Tailings Storage Facility (TSF) area is directly north of the Princess Deposit and Figure 1-7 shows the Lithological units found in that area.

Figure 1-7 Princess Pit Geological Section



The basal parts of the Eocene comprise coarse-grained sandstone which has been targeted as part of the injection investigations undertaken at the Project, and historical investigations targeting a process water supply.

The Eocene sediments have variable combinations of clays, sands and silts, but with a tendency to fine up within the sequence. A number of faults have been interpreted based on drilling and geophysics (Rockwater, 2013a).

The Miocene sediments contain silcretes and variable mixtures of fine and coarse grained materials, sandy clays, conglomerate and diamictites (poorly sorted sedimentary rocks, sands within mud matrix). This zone has been extensively oxidised and leached.

The Quaternary sediments comprise Aeolian sands of variable thickness.

The location of the TSF was selected by Vimy due to the comparatively shallow thickness of the Aeolian sands and presence of low permeability clayey materials and calcrete formations near the surface.

1.3.9 Ore Bodies

It is understood that the bulk of the ore targeted by Vimy occurs within the carbonaceous Eocene sediments, however, uranium mineralisation also occurs within other parts of the sequence within carbonaceous sandstones. Tertiary (Eocene) to Late Cretaceous sediments may also be targeted, depending upon grades, otherwise these sequences tend to be either too deep or too poor in grade to be economical.

These lignites comprise organic matter, clay and minor sand with some secondary gypsum and salt. The difference in uranium grades between lignite and sandstone ore is related to the concentration of organic matter.

In addition to the association of uranium with the carbonaceous materials at Mulga Rock, Douglas et al (2010) also suggests that uranium could be associated with sulphide materials, e.g. the adsorption of uranium to galena and pyrite surfaces. Laboratory studies indicated that the uranium was not present within the ore as discrete grains, but was highly correlated in association with sulphur.

The targeted ore deposit thickness varies from 12 m in Emperor to 32 m in Ambassador, which has 26 m to 36 m of overburden. The deposits extend over some 30 km, extending approximately 10 km North-South and 25 km East-West (Coffey, 2015).

1.3.10 Mining Technique

The Project is proposed to be mined using conventional open cut (strip mining) methods using both conventional truck and shovel mining equipment. Strip mining commences with the excavation of an initial slot to expose the ore, with stockpiling of the overburden in a waste rock dump. After the ore has been recovered from the first slot, subsequent stripping of overburden is placed within this void. Mining advances one strip at a time as previously mined areas are backfilled.

It is understood that, in order to reach the maximum depth of the minable resource, dewatering is required to be undertaken in the pits.

1.3.11 Groundwater

A number of hydrogeological investigations of the deposits have been completed since the mid-1980s. Depth to groundwater reportedly varies between 12 m to 64 m, dependent on ground topographic elevation. Regional groundwater resource assessment indicates the groundwater quality is generally acidic (pH 4 to 6), and saline (37,000 mg/L TDS or greater). Subtle variations in water quality occur between each of the pits to be developed.

A detailed hydrogeological setting and groundwater assessment is provided in the Groundwater Impact Assessment of Tailings and Process Water Disposal to Princess Pit (GHD, 2015).

1.3.12 Ore Processing and Tailings Production

Onsite processing includes crushing, beneficiation, leaching and precipitation.

Tailings from ore processing will be stored in an above ground TSF. After depletion of the resource in the Princess Pit, the mine void with an estimated capacity of approximately 20 M m^3 will then be used for the in-pit disposal of the tailings for the life of mine.

Tailings production is estimated to be approximately 1.27 million dry tonnes per annum (Mtpa). The tailings will be pumped into the TSFs as a slurry using conventional pumping techniques.

2. Project Objectives and Scope of Work

2.1 Project Objectives

2.1.1 General

The key objective of this project was to develop a concept design of the above ground TSF for the Mulga Rock Project.

The above ground TSF is planned to be used for the initial 18 months of ore processing after which the tailings will be directed into the mine void (Princess Pit). However, the above ground TSF will be provided with an additional 18 months of a storage capacity as a contingency measure.

The above ground TSF was designed as a lined storage, while the in pit TSF does not have a specific liner. The impact of the in-pit TSF on the groundwater body is discussed in a separate report (GHD, 2015).

The concept TSF design included selection of the construction materials, construction techniques, sizing of the TSF structure, drainage system and leakage detection system, deposition strategy and a conceptual closure plan.

2.1.2 DMP and DER compliance criteria

The regulators have requested that the proponents demonstrate that environmental objectives associated with preliminary known environmental factors (PKEFs) be met and that agreed compliance criteria be addressed. Appropriate measures need to be implemented to confirm that the TSF will be stable, safe and environmentally non-polluting in the short and long term.

The compliance criteria and associated control measures are summarised as follows:

- Stability of the embankment walls
  - Selected typical cross section
  - Slope angles
  - Slope protection
  - Freeboard
  - Crest level and crest width
  - Details to confirmed based on ANCOLD guidelines once construction materials were finally selected and their physical characteristics obtained.
- Chemistry of Tailings
- Construction and operational matters
  - Tailings delivery
  - Odour
  - Dust and gas emissions
- Decommissioning and post-closure issues
  - Potential for ground water contamination and downstream metals and metalloids plume, due to moderate to high transmissivities of the pit floor material
  - Isolation from potential environmental receptors

The above ground TSF concept is designed taking into account the criteria set out above and appropriate implemented measures are presented in this report.

2.2 Scope of Work

In order to achieve the Project objectives, the scope of works was defined as follows:

- Review of the production data
- Review of the tailings characteristics
- Select tailings deposition method
- Develop the tailings storage facility concept
- Define construction materials
- Define measures to prevent/control seepage and reduce/control dust emission
- Define operational principles and emergency procedures
- Outline a closure plan

3. Tailings Production and Characteristics

3.1 Tailings Production

Design of the TSF was based on input data obtained from, and confirmed, by VIMY as follows:

Production of dry tailings:	161 t/hr
Plant operation:	7,900 hr/year (90% efficiency)
Annual production of dry tailings:	1,273,000 t/year
Design capacity of the above ground TSF:	36 months (18 months of initial deposition + 18 months of contingency storage).

3.2 Tailings Characteristics

3.2.1 Geochemical Assessment

The geochemical characteristics of the tailings materials, likely to be generated following processing, was tested by ANSTO (2015), and is summarised in a report completed by Soilwater Consultants (SWC) titled *"Physiochemical characterisation of ore and tailings from the Mulga Rock Uranium Project*" (SWC, 2015). In general the tailings are expected to have the following geochemical properties:

- pH between 4 – 4.5, in response to neutralisation in the Base Metals Plant;
- Classified as highly saline (electrical conductivity around 300 mS/m), although tailings liquor (or seepage) is expected to have a salinity lower than the groundwater in the paleodrainage channel;
- Classified as Potential Acid Forming (PAF), with Net Acid Producing Potentials (NAPP; equivalent to the corresponding Maximum Potential Acidity - MPA) ranging from 7 to 114 kg H2SO4/t. Block modelling of Total Sulphur across the four deposits identified that it averaged 1.64% and as there is negligible loss of sulphides during processing the tailings is likely to contain a similar Total S average of 1.64%. This equates to a MPA of 50.2 kg H2SO4/t and given the tailings contains no readily available Acid Neutralizing Capacity (ANC) this value will equate to the NAPP.
- The multi-element composition is similar to the orebody, albeit with lower concentrations of U, Co, Cu, Ni and Zn;
- ASLP testwork showed that the tailings exhibited enhanced mobility of Co, Cu, Mn, Ni, Pb and Zn, likely due to the increased solubility of these solutes in the presence of chloride (Cl^-) dominant water. The overall composition of the expected tailings seepage (as determined by Australian Standard Leach Procedure – ASLP) is similar to that of the groundwater within the paleodrainage channel, although appreciably lower salinity;

Although the tailings are classified as PAF, there are several controls that will limit the extent to which the sulphides will oxidise and generate Acid and Metalliferous Drainage (AMD). These controls include:

- High Carbon content of the tailings –the tailings will likely contain around 40% Total Carbon, with the majority of this, given the acidic of the tailings, to be organic C. Microbial decomposition of the organic material will result in a continual consumption of available oxygen favouring reducing (Eh) conditions below the approximate 660 mV (SHE) needed to oxidise Ferrous (Fe^{2+}) to Ferric (Fe^{3+}), which has the potential to oxidise sulphides.

- Inherent buffering capacity – although the pH of the tailings suggests no readily available acid neutralisation capacity (ANC) is present (i.e. no carbonates present), microbial decomposition of the organic matter, under depleted oxygen and sulphur reducing conditions, will produce biogenic alkalinity which will assist in neutralising the released acidity.
- Limited oxygen diffusion into clayey tailings at field capacity –oxygen diffusion rates at field capacity are expected to be low (< 8.0 × 10-7 m/s) and are likely to limit sulphide oxidation (i.e. to completely oxidise the 1.64% Total S, assuming it is all sulphidic, approximately 30 g of oxygen/kg of soil is needed). Based on the very low oxygen diffusion rates at field capacity in the clayey tailings, insufficient oxygen will be available to fully oxidise the sulphides.
- Low permeability of the tailings following draining –Hydraulic Conductivity Function (HCF) for the tailings (SWC, 2015) shows that the permeability of the tailings is expected to decrease sharply as the tailings consolidated and drains. At field capacity the permeability of the tailings is expected to be around 1.0 × 10-1 cm/d (equivalent to 1.1 × 10-8 m/s; Note: the DoW Clay Liner criteria is 1.0 × 10-9 m/s). Consequently, the transport and seepage of any oxidation reaction products (i.e. AMD) from the base of the TSF, once it is at field capacity, will be limited.
- Given the lower salinity of the tailings seepage, compared to the paleoaquifer, any potentially AMD seepage will be confined to the upper portion of the aquifer, which contains abundant carbonaceous material. This carbonaceous layer is effectively a Passive or Permeable Reactive Barrier (PRB) stripping solutes out of the water quality.

Based on the above information, the risks of the tailings material, and the associated seepage, adversely impacting on the surrounding environment is considered small.

3.2.2 Geotechnical Assessment

Preliminary geotechnical testing on representative tailings materials was undertaken as part of the ANSTO (2015) testwork and is summarised in the SWC report titled *"Physiochemical characterisation of ore and tailings from the Mulga Rock Uranium Project*" (SWC, 2015). Geotechnical parameters assessed included particle size distribution (PSD), Atterberg Limits, Proctor testing (Maximum Bulk Dry Density – MBDD and associated Optimal Moisture Content – OMC) and undrained settling tests.

The beneficiated tailings material, which has a target particle size distribution of P80 < 150 µm, has a high fine fraction, with 80% of the material classified as silt + clay (i.e. < 75 µm) and 25% clay (i.e. < 2 µm). The overall texture of the tailings, according to the Unified Soil Classification System, is an Organic Sandy Clay. Given this PSD the tailings has a high Liquid Limit (LL) of around 53% and Plastic Limit (PL) of 45%, and a relatively small Plasticity Index (PI) of 8%; hence the material is classified as Slightly Plastic and Non-Reactive, with an Activity (=PI/Clay %) between 0.53 and 0.62.

The tailings slurry, under undrained conditions, exhibits poor settling characteristics, due principally to the low density of the tailings, which approaches the density of the surrounding liquor; hence it is relatively buoyant. This testing showed, with no raking, that the final slurry density of the tailings will likely be between 50 – 54% (after a minimum time period of 7 days), from an initial solids content of 40%. Photos showing the settling behaviour of the tailings at 2.5 hours and 7 days after tailings placement are shown in Figure 3-1 and Figure 3-2 respectively. The settling test time plots are provided in Figure 3-3.

The settling behaviour of beneficiated tailings was not tested as part of the preliminary ANSTO (2015) program.

For the purpose of the TSF concept design, the tailings slurry was assumed to settle to an average solid content of 60% after 18 months. This may be considered a conservative assumption, but it is adopted as being on safe side at this stage of design given the absence of settling data of the modified tailings. However, it is essential that additional tests using the modified tailings be carried out to establish operational parameters and refine design criteria.

Figure 3-1 Tailings settling test at 2.5 hours

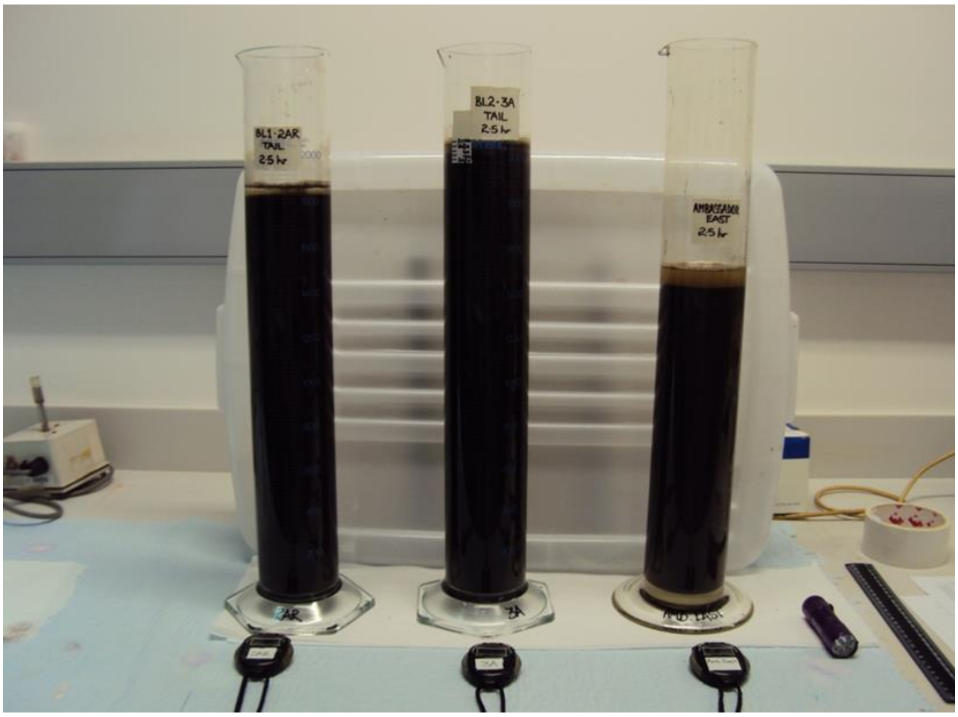


Figure 3-2 Tailings settling test at 7 days

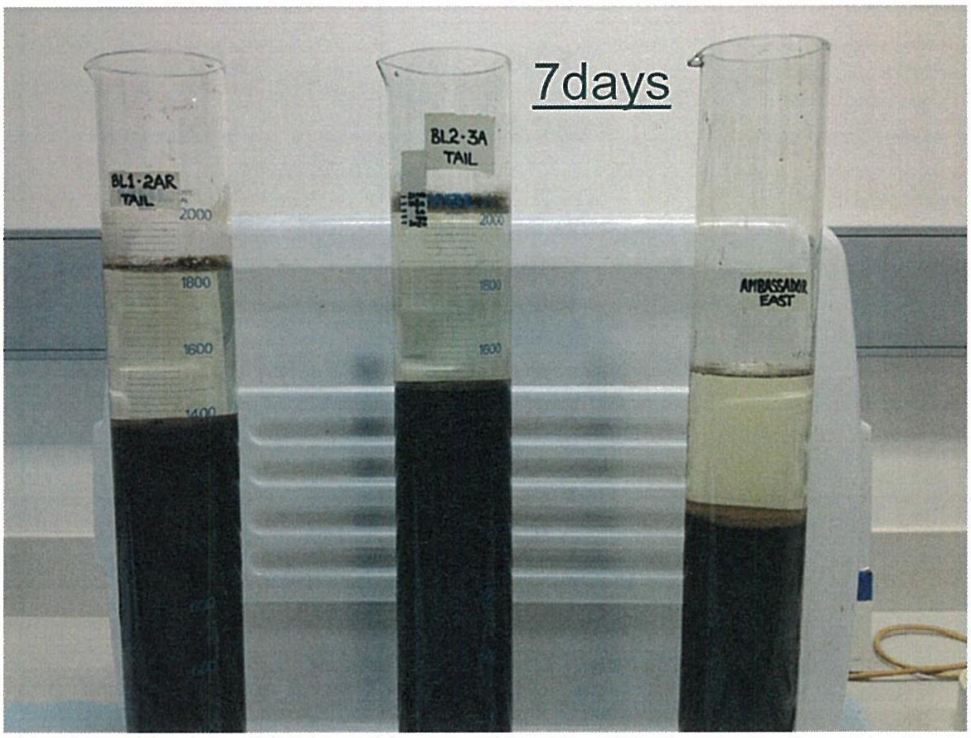
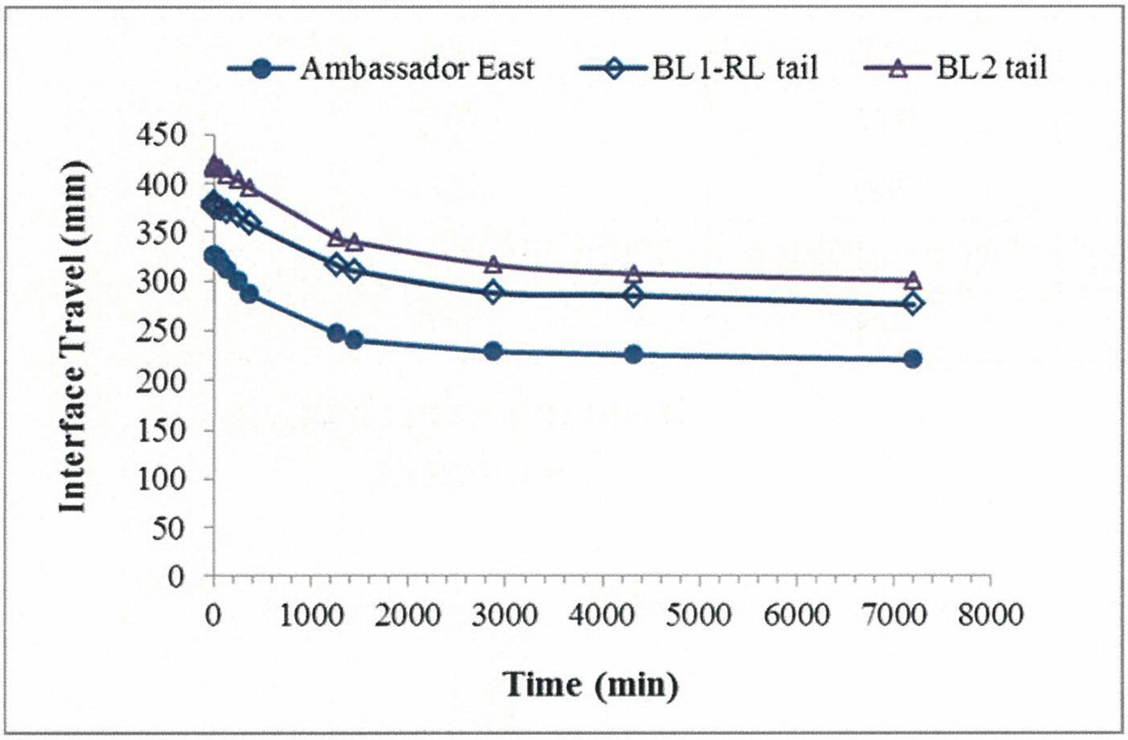


Figure 3-3 Settling test plots



Based on the settling test results, it can be noted that the settling rates were high within the first two days and after that the settlement slow down. The solid content achieved after 7 days was approximately 60%.

The tailings modification and reduction of their solid content impacts the settling behaviour of the tailings slurry. No tailings settling data for the modified tailings were available at the time of this report.

For the purpose of the TSF concept design, the tailing slurry was assumed to settle to an average solid content of 60% after 18 months. This may be considered a conservative assumption, but it is adopted as being on safe side at this stage of design given the absence of settling data of the modified tailings. However, it is recommended to carry out additional testing using the modified tailings.

4. Basis of Design

4.1 TSF Location

The results presented in this report were derived from a desktop study using available data, reports and information provided by Vimy.

The location of the TSF was selected by Vimy for the following reasons:

- TSF proximity to the process plant
- Comparatively small thickness of the Aeolian Sands
- Location in a topographic low for efficient storage whilst remaining below surrounding sand dunes

The TSF location with respect to the other mining infrastructure is shown on drawing 61522-G001 provided in Appendix A.

4.2 General Design Principles

The TSF was conceptually designed as a lined storage facility to prevent seepage from the facility impacting on the surrounding area. The TSF was, therefore, designed as a double-lined facility with underdrainage and leak detection system.

The sides are located in sandy material in places and will have a double lining such as HDPE over clay. The floor liner consists of two separate layers of imported clay materials sourced from selected mine overburden.

The underdrainage system will comprise filters, free draining materials and drain pipes placed above the floor liner.

The leak detection system will include filters, free draining materials and drain pipes placed in between the primary and secondary liners at the toe of the side slopes..

Details of the lining, underdrainage and leakage detection systems are discussed further in the report and are shown on Drawings in Appendix A.

The concept design was developed in accordance with the Tailings Guidelines issued by the Australian National Committee on Large Dams (ANCOLD 2012) and 2012 Code of Practice for Tailings Storage in WA.

4.3 Specific Basis of Design

Different TSF options were considered during the preliminary stage of this study and, based on discussion with Vimy, the following key principles were adopted for incorporation into the concept design:

- Tailings deposition will be subaqueous – achieving dust control during mine operation;
- TSF will be designed as an above ground structure as follows:
  - TSF perimeter crest level will be at RL 342 m
  - TSF will be split into two cells (each cell for 18 months of deposition)
  - The TSF floor will be formed by a double layer of compacted clayey materials from selected mine overburden
  - The side slopes will have a double liner such as HDPE liner over clay
  - Leakage monitoring and recovery system between the two liners (at the side slopes) will be included

  - An underdrainage system comprising drain pipes, filter sand and protection layer will be installed above the floor liner
  - The underdrainage system will be connected to drainage collection pipes (within the TSF perimeter) and drain to a sump where the underdrains can be de-pressured by controlled pumping with water recirculating onto the water cover
- Concept closure design

  The selection of closure design will be influenced by ongoing testing and observations during operation. Possible method of stabilising the tailings while still saturated include ongoing de-pressuring of the underdrains to accelerate consolidation, chemical/or sand addition during deposition, or incremental loading of the surface by the following method.

  - Filter sand will be sprayed onto the TSF water surface to gradually form a thin sand layer (to separate solids from water and accelerate consolidation) using a geotextile separator if necessary
  - The underdrainage system (above TSF floor) will be used to drain the tailings while the sand is being applied to further accelerate tailings consolidation
  - When sufficient layer of sand is formed, closure layers will be gradually constructed as follows:
    - 1 m cover of a capillary break
    - 2-3 m cover of mine overburden on top of the TSF with shaping of the surface and walls to shed rainfall without erosion
    - Layer of Quaternary sand to protect the overburden materials from erosion and hard setting

  The underdrainage system (above TSF floor) will be modified at the collection pit to gravity drain to the mine void whilst maintaining a minimum water level in the pit to keep the drains full of water at minimum pressure.

  Seepage modelling to identify potential environmental impacts on groundwater quality and surrounding native vegetation has been undertaken for the proposed in pit and above ground TSFs by SWC. The results are presented in a report completed by SWC titled *"Mulga Rock Uranium Project Tailings Storage Facility Seepage Analysis"* (SWC, 2015).

  Appropriate testing will have to be carried out to demonstrate an adequate understanding of;

  - Tailings settlement
  - Tailings consolidation rates
  - Means of accelerating the above
  - Practical cover placement

5. Tailings Storage

5.1 General Principles

Developments of the tailings deposition and principles adopted for TSF design included the following main aspects considering the tailings characteristics and the project requirements:

- Provide sufficient storage volume to accommodate tailings deposition for initial 18 months of the mine operation with contingency for additional 18 months
- Utilise subaqueous deposition method which will control dust and lower radon emanation and gamma radiation levels
- Maintain stability of the embankment walls and side slopes of the TSF
- Provide a sustainable system of water management which will allow for internal circulation of water within the TSF
- Develop methods which will provide solid and safe surface for closure concept
- Develop a closure concept to safely encapsulate the tailings for nominal 1000 years

5.2 Tailings Deposition Methods

Subaqueous deposition of tailings will be used as a means of controlling dust and radon. The tailings will be kept saturated by using subaqueous deposition, with multiple discharge spigots on a perimeter ring main. At all times during operation, the tailings surface will be covered with free standing water.

5.3 TSF Design

5.3.1 TSF Arrangement

TSF was designed as a combination of excavation and raised perimeter walls and was configured to blend into the surrounding dunal landscape; located within a natural topographic depression, so that the embankment walls utilise as far as practicable the surrounding dunal systems. This arrangement provides a cost effective solution, as it minimises cut and fill. Within the proposed topographic depression, the floor of the TSF storage will correspond to the RL 334 m, with the perimeter crest of the TSF at RL 342 m, which is below the height of the surrounding dunes.

To allow for a staged construction and simplify the TSF operation, the TSF area was split into two cells (Cell 1 and Cell 2). The first cell would provide sufficient capacity for the initial 18 months of deposition and the second cell could be constructed during the initial operational stages of the mine. Operating in one cell will reduce evaporation and the volume of water required to provide permanent water cover.

The general layout and cross sections of the TSF are shown on the drawings in Appendix A.

5.3.2 TSF Storage Volume

The size of the TSF was defined to provide the following:

- Storage volume to accommodate initial 18 months of production
- Storage volume for another 18 months of production as contingency
- Allowance for water cover
- Freeboard requirements

- Underdrainage system to recover excess consolidation water
- Allowance for closure

The tailings volume in each cell of the TSF was calculated from the annual tailings production and the average solid content of the settled tailings.

Each cell of the TSF was designed to provide sufficient storage capacity for 18 months of production. Based on a dried tailings production of 1.27 Mtpa (Section 3.1), each cell was designed to contain 1.91 Mt of dry tailings, which is equivalent to 18 months of deposition at an average of 0.106 Mt per month. At 60% settled solids content and an average SG of 1.05, the bulk solids density in storage will be 0.62 t/m^3. Hence the volume required for each cell is 3.09 Mm^3.

The storage capacity of each cell was further increased to include an allowance for one metre of water cover and one metre of freeboard as described in Section 5.3.3.

5.3.3 TSF Consequence Category and Freeboard Requirements

The consequence category of a TSF is defined by ANCOLD Guidelines (ANCOLD, 2012) as a measure of potential risk to life, damage, environmental impact and community impact that would be caused if there was a failure of the storage.

The above ground TSF at the MULGA Rock Project will be partly formed by excavation. A breach of the TSF embankments would be trapped within the sand dunes but would have environmental impact, community reaction and potential loss of life of 1-10 persons on the nearby road and pit.

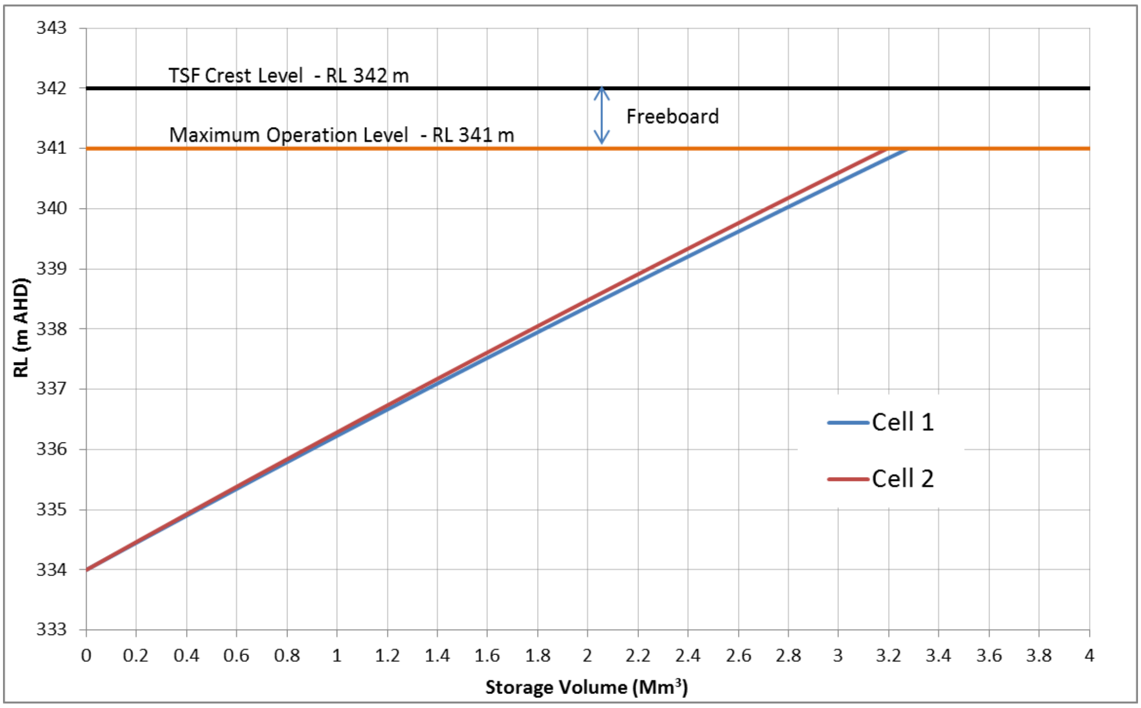
In accordance with the ANCOLD Tailings Guidelines (ANCOLD, 2012), the consequence category of the above ground TSF at Mulga Rock was preliminarily assessed as High C and the following allowance were included in sizing of the TSF cells:

- Rainfall allowance for a 1:100 Annual Exceedance Probability, 72 h duration rainfall event (162 mm based on the BOM data , Section 1.3.5)
- Operational and wave run-up freeboard of 800 mm

The TSF cells were, therefore, designed to keep the maximum water level (including the water cover) below RL 341 m, which is 1 m below the TSF crest. The storage below RL 341 m will only gradually fill such that the design freeboard is easily achieved for the major part of the operation life.

The TSF storage curves along with the freeboard allowance are shown in Figure 5-1.

Figure 5-1 TSF Storage Curves and Freeboard



5.3.4 TSF Components

General

The TSF will comprise two cells, which could be operated independently. Each cell will have the following key components:

- Perimeter crest at RL 342 m
- Perimeter embankment, excavated batters and floor at RL 334 m
- Double liner system
- Underdrainage and leak detection system
- Main ring perimeter discharge
- Instrumentation

Embankment

The main characteristics of the embankment are as follows:

- Crest level at RL 342 m
- Crest width of 6.5 m
- Maximal height : 6 m
- Upstream slop at angle of 1V in 3H
- Downstream slope at angle of 1V in 2.75H
- Downstream slope protection - selected coarse materials
- Upstream – double liner
- Storage floor at RL 334 m

The perimeter embankment will be constructed of compacted clayey loam sourced from either internal excavations or from the nearby Princess pit..

The crest will be 6.5 m wide to allow safely vehicle access and placement of the perimeter tailings distribution pipe line.

The perimeter crest will be covered with a road base to protect against erosion and to accommodate vehicular access in all conditions.

Excavated Batters and Floor

All internal batters will be built to a 1V in 3H slope. This slope will enable installation of the liners and it will also moderate undesirable tensile forces in the liners. The TSF floor will be excavated to RL 334 m.

The floor will be compacted in situ and then covered with two separate layers of compacted clay sourced from selected materials from internal excavation or mine overburden. These layers will be conditioned and compacted to Australian Standard to achieve a permeability of $1x10^{-9}$m/s or better.

Targeted geotechnical investigations in the next phase of the Project will confirm the characteristics of the materials to be used for the floor liner.

Primary and Secondary Liners

The entire internal surface area of the TSF will be double lined. For the batters this could be a primary plastic liner and a secondary clay liner. The TSF floor will be lined with double clay liner.

A plastic liner such as HDPE would be appropriate on the batters since it will not shrink or crack, and because of its chemical resistance, durability and proven performance on similar projects.

The liner types may be refined in the next stage of the project, when the detailed geotechnical conditions and tailings properties will be determined in detail.

Underdrainage and Leakage Detection Systems

The underdrainage system will comprise sand filters, free drainage sand and seepage collection and recovery pipes as shown in Appendix A. The system will be installed across the TSF floor. The sand filter will collect water from tailings and the separated water will be conveyed through the pipes to the collection sumps.

Pumps will recirculate the water into the pond on the tailings, initially at a slow rate until a consolidated bed of tailings forms on top on the sand filter.

The leakage detection system will be installed between the primary and secondary liners along the batters at the internal toes of the TSF cells. It will comprise drainage sands and gravels and drainage pipework. These will pass through an observation well before draining by gravity. If leakage is detected, pumps will be installed into the well to recirculate the water.

Tailings Deposition System

The tailings deposition system will be a conventional perimeter discharge system with tailings delivery pipe from the process plant, perimeter tailings pipe along the TSF crest, spigots and droppers. Tailings will be discharged through the spigots into slotted sacrificial pipes (droppers) running down the TSF batters as shown on drawings in Appendix A. The dropper pipes will dissipate energy of the discharged tailings and thus minimise erosion of the primary liner and underdrainage system.

Any additional water required for the tailings cover may either be delivered through the tailings pipework or through a standalone system. It is important this water requirement is considered during the operations when planning the dewater schedules, as there will be a continual need to keep a water cover over the tailings.

Instrumentation

The instrumentation at the TSF will include a water level indicator, piezometers, surface movement monitoring pins and monitoring bores around the facility.

The monitoring bores could be converted into recovery bores should any contamination beyond agreed threshold limits be detected.

5.4 TSF Operation and Monitoring

The TSF will be operated via the perimeter tailings deposition system, while maintaining the water cover. Tailings deposition will be via the spigots which will be operated in a cyclic pattern in order to gradually fill and maximise the storage volume of the facility.

The concept design assumes that subaqueous beach slope will be 0.5%. It is expected that this value is too high and the beach slope may be significantly flatter. This needs to be confirmed by additional testing. TSF monitoring will include daily routine inspections, monthly inspections, annual inspections and data recording from the TSF instrumentation (Section 5.3.4) in accordance with the ANCOLD Guidelines on Tailings Dams (ANCOLD, 2012).

An Operations Manuel will set out operation procedures, maintenance, monitoring and emergency procedures.

5.5 TSF Closure

Closure concept was considered as part of the concept design for the above ground TSF. The closure concept was developed in accordance with the Guidelines for Preparing Mine Closure Plans (DMP & EPA, 2015) with the intention of providing a safe and stable structure for a considerable period of time (over 1000 years; as required in the ESD document) and to ensure that the rehabilitation materials are retained in such a way as to avoid any potential for loss and contamination of environment.

Based on the tailings characteristics, the closure objectives are as follows:

- Reduce the risk for leachate (if any) to contaminate the surrounding hydrologic environment
- Avoid the dispersion of any rehabilitation material as wind-blown dust
- Ensure the long term integrity of the TSF structure against collapse, movement, displacement, sliding, erosion and any other natural climatic or geologic
- Control seepage such that there are no measurable impacts at tenement boundaries
- Integrate the final shape of closed TSF in the existing landscape

Most of the objectives mentioned above will be achieved by the design measures and ongoing monitoring.

The seepage monitoring will confirm the operation of the liner system and indicate if some additional measures are required.

The cap comprises of the following layers:

- Gradually form a sand layer (to separate solids from water and accelerate consolidation) and to allow further construction of the capping, as indicated in Section 4.3
- The underdrainage system will be utilised (by draining the tailings while the sand is being applied) to further accelerate tailings consolidation

- When a sufficient layer of sand is formed to support heavy equipment, closure layers will be gradually constructed as follows:
  - A capillary break such as one metre of calcrete or silcrete gravel
  - Mine overburden on top of the TSF and shaping of the batter walls
  - A thin layer of local materials capable of supporting growth
- The final cover will have the shape of the dome with gentle gradients of about 0.3% which will connect to the natural ground surface with a gradient of 10%
- Finally the surface will be vegetated with local native flora

The conceptual closure plan will be subject to further evaluation once the tailings properties are fully understood and the final selection of the construction materials and dimensions of the capping layers will be confirmed in the next phases of the project.

Adopted dome capping is shown in Appendix A.

6. References

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Appendices

Appendix A – Drawings

NOTES

1. FOR TSF GENERAL ARRANGEMENT REFER 61-31522-C001
2. FOR TYPICAL SECTIONS REFER 61-31522-C002
3. FOR DRAINAGE SYSTEM DETAILS REFER 61-31522-C002

LEGEND

AMB PITS
PRINCESS PITS

PRELIMINARY

No	Revision	Drawn	Job Manager	Project Director	Date
	Note: * indicates signatures on original issue of drawing or last revision of drawing				

N

0 250 500 750 1000 1250m
SCALE 1:25,000 AT ORIGINAL SIZE

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E permail@ghd.com.au W www.ghd.com

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Drawn M.HELM | Designer N.PETROVIC
Drafting Check | Design Check
Approved (Project Director)
Date
Scale AS SHOWN
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Client **VIMY RESOURCES**
Project **MULGA ROCK URANIUM PROJECT**
Title **TAILINGS STORAGE FACILITY SITE LOCALITY PLAN**

Original Size **A1** Drawing No: **61-31522-G001** Rev: **A**

Plot Date: 11 June 2015 - 5:00 PM Plotted by: Martin Helm Cad File No: G:\61\31522\CADD\Drawings\61-31522-G001.dwg

NOTES

1. FOR LOCALITY PLAN REFER 61-31522-G001
2. FOR TYPICAL SECTIONS REFER 61-31522-C002
3. FOR DRAINAGE SYSTEM DETAILS REFER 61-31522-C002
4. ALL CHAINAGES ARE IN METRES
5. ALL EXCAVATION SLOPES ARE 1:3
6. ALL FILL SLOPES ARE 1:2.75

LEGEND

SURFACE WATER DRAINAGE
UNDER DRAINAGE COLLECTION SYSTEM
UPPER DRAIINAGE COLLECTION SYSTEM

PRELIMINARY

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0 25 50 75 100 125m

SCALE 1:2500 AT ORIGINAL SIZE

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Design Check
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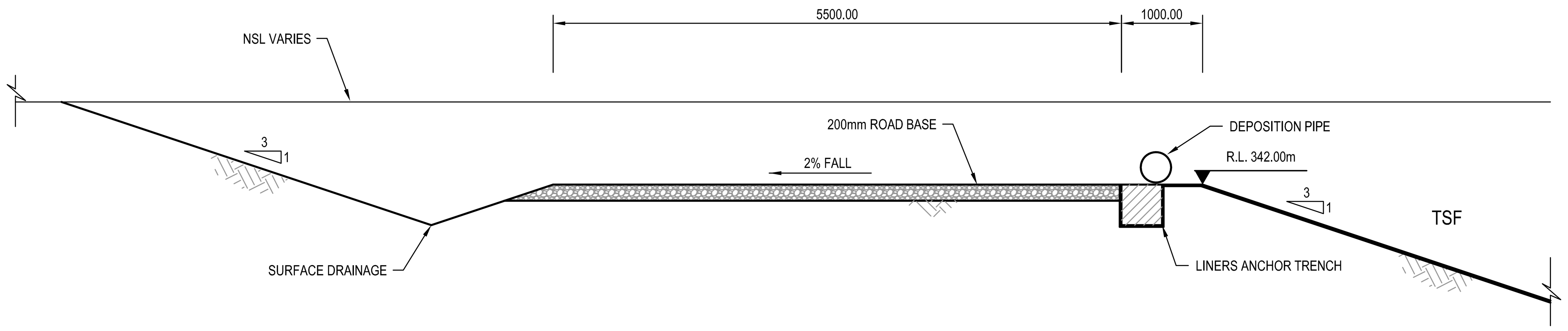
Client **VIMY RESOURCES**
Project **MULGA ROCK URANIUM PROJECT**
Title **TAILINGS STORAGE FACILITY GENERAL ARRANGEMENT AND DRAINAGE SYSTEM**

Original Size **A1**
Drawing No: **61-31522-C001**
Rev: **A**

Plot Date: 11 June 2015 - 5:05 PM Plotted by: Martin Helm Cad File No: G:\61\31522\CADD\Drawings\61-31522-C001.dwg

NOTES

1. FOR SITE LOCALITY REFER 61-31522-G001
2. FOR GENERAL ARRANGEMENT REFER 61-31522-C001
3. ALL DIMENSIONS ARE IN MILLIMETRES (mm) UNO.
4. ALL ELEVATIONS ARE IN METERS, AHD (m) UNO.
5. MINIMUM 2 x 175mm THICK LAYER OF COMPACTED CLAYEY MATERIAL.



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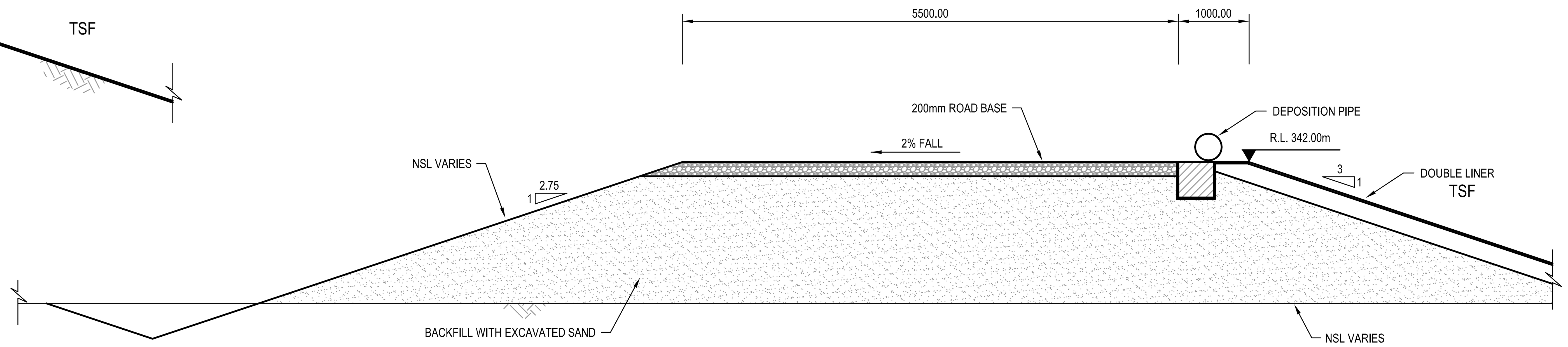
1:50



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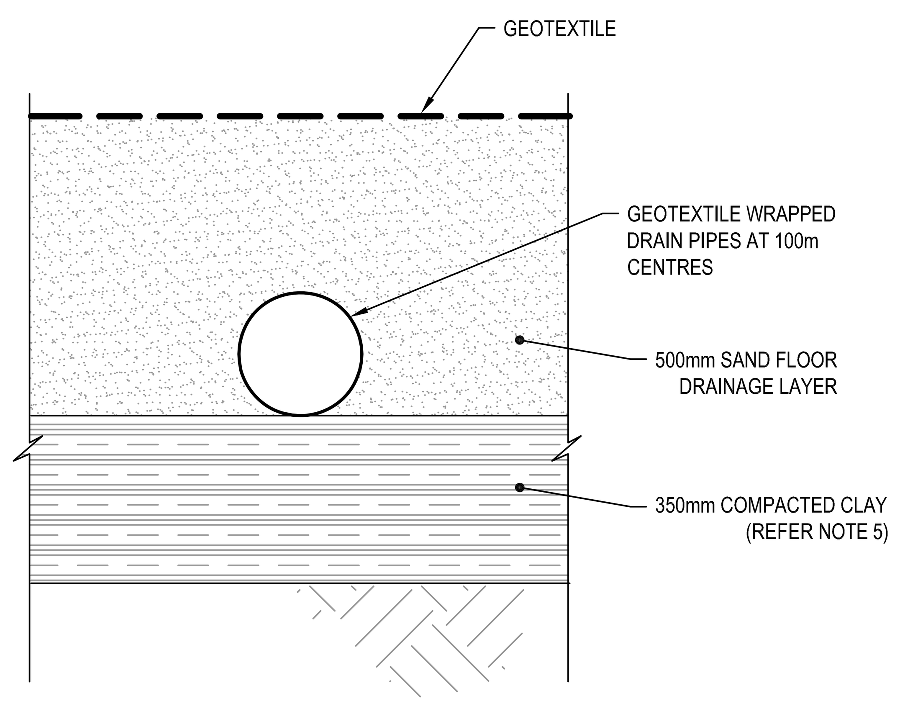
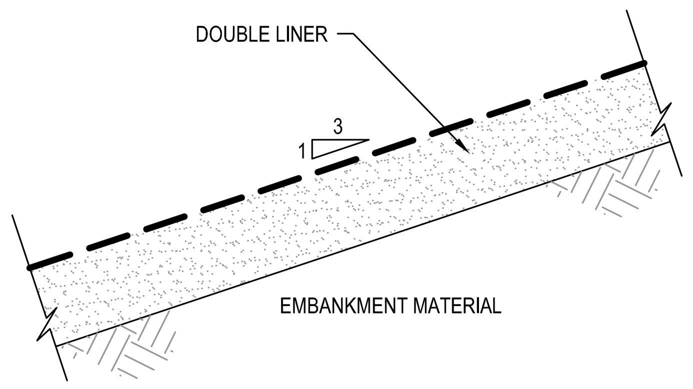


TYPICAL FLOOR LINER AND DRAINAGE
N.T.S



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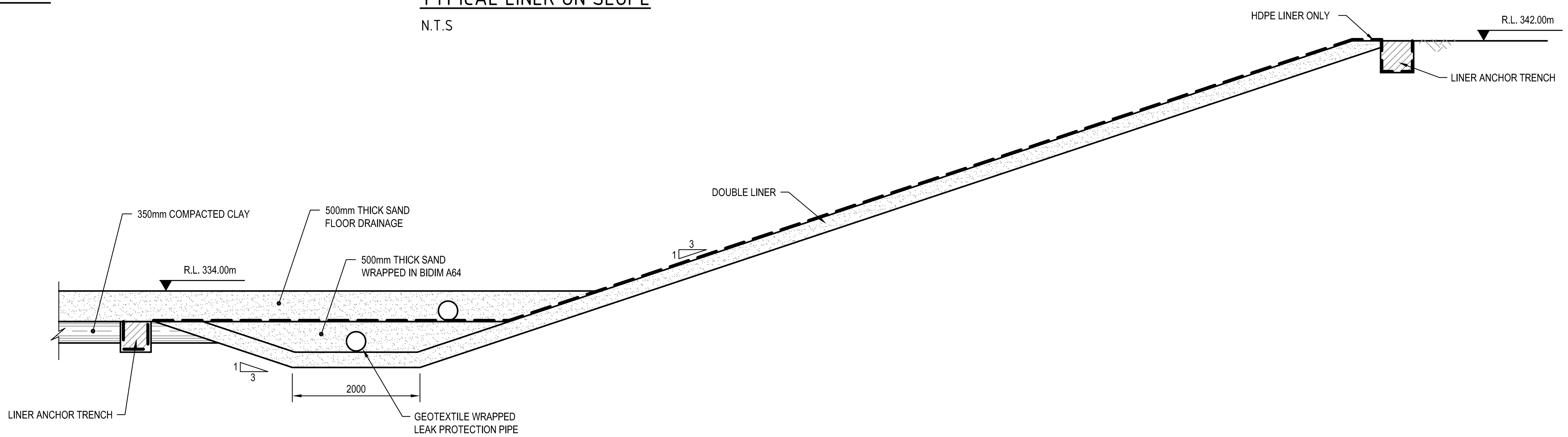

A
C001
SECTION
SCALE 1 : 50

PRELIMINARY

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SCALE 1:25 AT ORIGINAL SIZE

0 500 1000 1500 2000 2500mm
SCALE 1:50 AT ORIGINAL SIZE

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Date	
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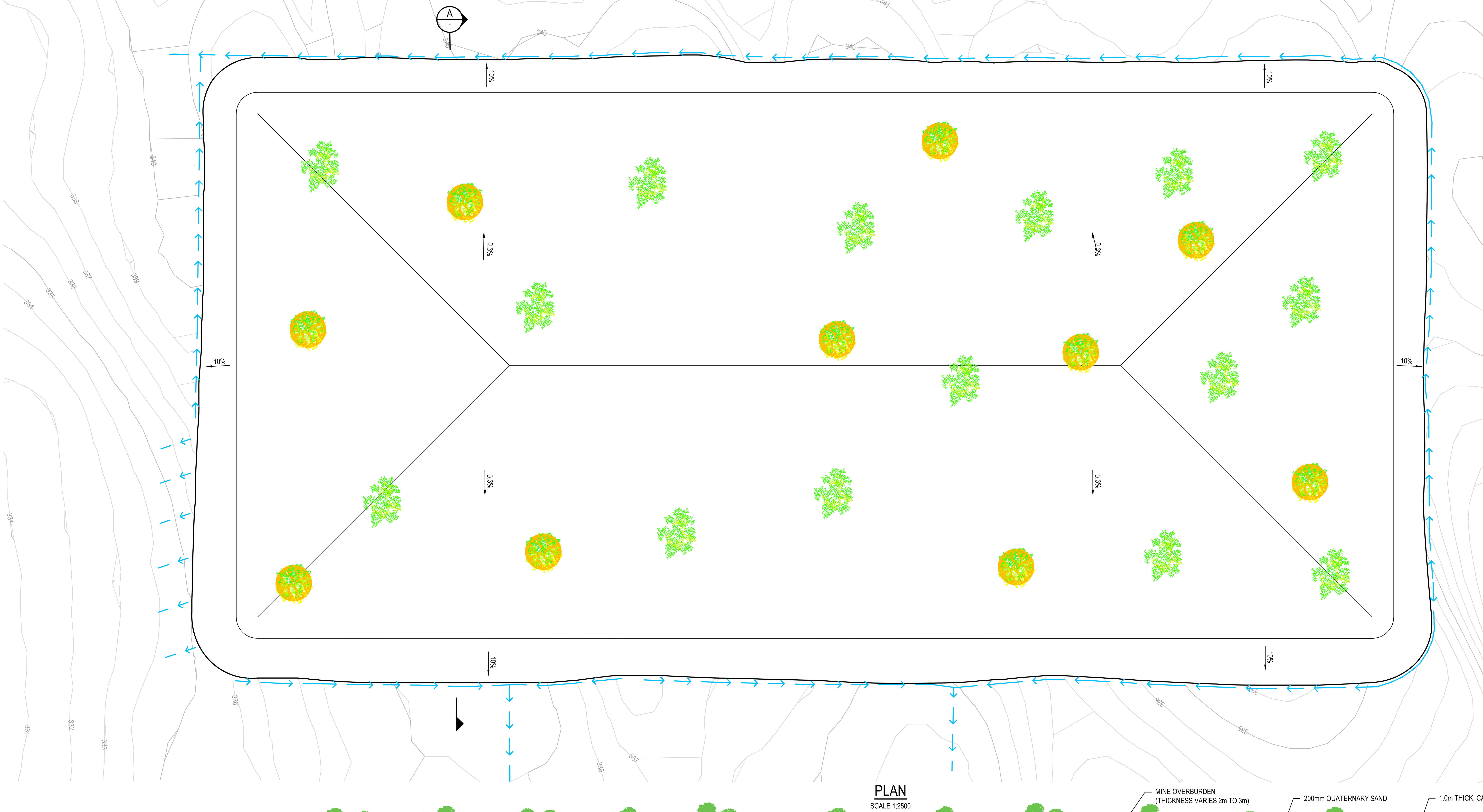
Client **VIMY RESOURCES**
Project **MULGA ROCK URANIUM PROJECT**
Title **TAILINGS STORAGE FACILITY TYPICAL SECTION AND DETAILS**

Original Size A1 Drawing No: **61-31522-C002** Rev: A

Plot Date: 11 June 2015 - 5:05 PM Plotted by: Martin Helm Cad File No: G:\61\31522\CADD\Drawings\61-31522-C002.dwg

NOTES
1. FOR LOCALITY PLAN REFER 61-31522-G001
2. FOR TSF GENERAL ARRANGEMENT REFER 61-31522-C001
3. FOR TYPICAL SECTIONS REFER 61-31522-C002
4. FOR DRAINAGE SYSTEM DETAILS REFER 61-31522-C002

LEGEND
- SURFACE WATER DRAINAGE
- MINE OVERBURDEN
- CAPILLARY BREAK
- SANDY LAYER
- TAILINGS



PLAN
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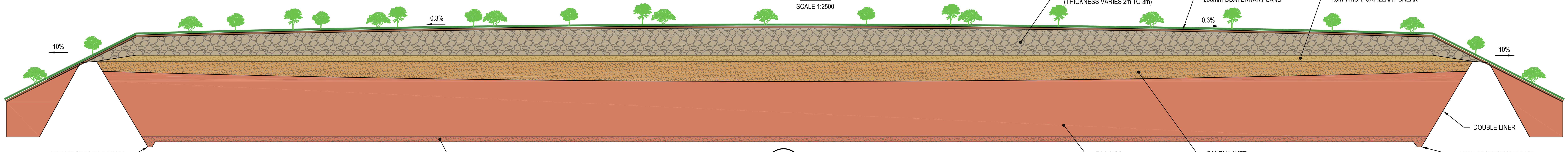

A SECTION
SCALE H 1 : 1000 V 1 : 200

PRELIMINARY

No	Revision	Note: * indicates signatures on original issue of drawing or last revision of drawing	Drawn	Job Manager	Project Director	Date

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VERTICAL 1:200 AT ORIGINAL SIZE (0, 2, 4, 6, 8, 10m)
HORIZONTAL 1:1000 AT ORIGINAL SIZE (0, 10, 20, 30, 40, 50m)

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Client **VIMY RESOURCES**
Project **MULGA ROCK URANIUM PROJECT**
Title **TAILINGS STORAGE FACILITY CLOSURE PLAN**

Original Size A1 Drawing No: **61-31522-C003** Rev: A

Plot Date: 11 June 2015 - 5:04 PM Plotted by: Martin Helm Cad File No: G:\61\31522\CADD\Drawings\61-31522-C003.dwg

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T: 61 8 6222 8222   F: 61 8 6222 8555   E: permail@ghd.com.au

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
	N. Petrovic	J. Phillips pp		A. White		12/06/2015

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Vimy Resources Limited

Mulga Rock Project

Groundwater Assessment of Tailings and Process Water Disposal to Princess Pit

June 2015

Executive summary

Report Objectives

The Mulga Rock Uranium Project (MRUP) ESD approved by the WA EPA identified Inland Water Quality as an 'Environmental Factor' and accordingly, requires the proponent to:

- Describe the long term containment of waste material and process water, designed to be consistent with best practice.
- Demonstrate A and B below through multiple lines of evidence:
  A. the effectiveness of the containment.
  B. that any release of waste material and process water to the environment does not lead to above background[1] levels of radionuclides and other contaminants; or undertake suitable modelling of the long term movement (10,000 years) of waste material and process water or until background levels are reached.

This report precisely addresses those requirements.

Project Description and Environmental Objectives

The MRUP involves mining and processing of uranium ore. Initially, it is proposed to operate an above-ground Tailings Storage Facility (TSF) however, following the exhaustion of the mined resource, it is proposed to dispose of tailings to the Princess Pit. This in-pit tailings disposal is the subject of this report.

The in-pit tailings will be below and above the elevation of the pre-mining water table. Tailings liquor will enter the local groundwater system. The consequential environmental issue is the fate and behaviour of contaminants in the tailings liquor, i.e. metalloids, metals and radionuclides, as they migrate along the groundwater flow system.

In undertaking the hydrogeological assessment, the following environmental objectives were considered:

- *Environmental criteria*: changes to groundwater quality outside its natural range
- *Point of compliance*: Mining lease tenement (M39/1080) boundary, given there are no environmental receptors potentially affected (by long term movement of waste material and process water) other than saline to hypersaline groundwaters within the lease, and
- *Timeline*: to 10,000 years after closure as per the MRUP ESD requirement.

Those objectives are set against the overarching aim of the State Environmental Protection Authority stated in its Environmental Assessment Guideline for Environmental factors and objectives (EAG #8), which stipulates the following for hydrological processes:

"To maintain the quality of groundwater and surface water, sediment and biota so that the environmental values, both ecological and social are protected."

[1] Background refers to pre-mining conditions and their natural range.

Description of in-pit disposal and nature of tailings and leachate

Once tailings are deposited in the pit, slow drainage of liquor from the tailings would occur. Based on water leachability testing completed by ANSTO (2015a), primary contaminating metals, metalloids and radionuclides of concern include copper, cobalt, uranium and zinc. Once deposited in the Princess Pit TSF, the entrained process water within the tailings, which is likely to have leachable concentrations of metals including uranium, will primarily leach vertically and seep into the underlying groundwater.

Loss of water from the tailings will occur in three ways:

- Evaporation
- Vertical drainage through the base of the pit and
- Leakage laterally through the walls of the pit.

The nature of the tailings confers a low hydraulic conductivity and, therefore, an expected low rate of movement of liquor from the tailings into the surrounding groundwater environment.

The tailings liquor geochemistry has been characterised from batch sampling and the liquor is considered to have an overall lower salinity than native surrounding groundwater, and to be slightly more acidic.

The consolidation of the in-pit tailings will be slow, controlled by the rate at which liquor can migrate from the tailings. Vimy are considering options regarding chemical and/or physical modification of tailings to facilitate the rate of settling and consolidation. Following consolidation of those tailings, further leaching of metals, metalloids and radionuclides from the solid fraction of the tailings will occur at a much lower rate given the reducing conditions that are expected to develop.

Geology

The MRUP resource occurs in sequence of layered sediments in a palaeochannel of significant lateral extent, representing an extension of the Lake Raeside palaeodrainage. The eastern portion of the MRUP is hosted by a tributary to the main palaeochannel, referred to further as the Ambassador tributary.

The sedimentary sequence is characterised by poorly consolidated Cretaceous and Eocene age sediments incised into Carboniferous-Permian age sedimentary material that forms the floor of the palaeochannel deposits. The primary host sequences range from fluviatile at the base to lacustrine in the top Eocene sediments.

The mineralisation is primarily controlled physically by the geometry of the palaeodrainage and tributaries, and geochemically by redox and weathering processes, focused on a mostly tabular main weathering front. The water table and weathering front are generally coincident.

The Ambassador deposit extends up to 8 km and is up to 1 km wide, while the nearby Princess deposit is much smaller with an overall footprint of less than 1 km x 1 km. There is clear evidence for post-depositional fault displacement, affecting even the youngest sediments of Quaternary age (dated between 150,000 and 6,000 years).

Between 25 m to 45 m of heavily weathered sediments of Eocene and Miocene age overly the deposit, effectively masking its signature at surface.

Over the course of 40 years of mineral exploration, equivalent but sub-economic uranium deposits have been identified at a number of locations in the same palaeochannel (both upstream and downstream), within similar host rocks and aquifers.

Groundwater flow system

The whole sequence from the main weathering front is saturated but the most transmissive sequence underlies the orebody, separated from it by flood plain sediments, of low hydraulic conductivity. The layered flood plain deposits include sands, silts and clays and have a much lower vertical than horizontal hydraulic conductivity. The Princess pit will only be excavated partly into the fluviatile sequence and not within its lower horizons characterised by high hydraulic conductivity.

There is no evidence of perched water tables at the mine site and surrounding leases. The closest evidence of perched water tables is along the Ponton Creek, which coincides with the downstream portion of the Lake Raeside palaeodrainage and is located more than 80 km down gradient, and at the Queen Victoria Spring (a local, ephemeral, perched water source), located about 65 km down gradient from the proposed in-pit tailings disposal facility.

The palaeochannel groundwater system is limited laterally by the margins of the palaeovalley, consisting of poorly transmissive, older sedimentary material. The groundwater flow system is broadly continuous along the length of the palaeochannel. It is likely that groundwater hydraulic heads outside the palaeochannel system are higher than within it, meaning that groundwater will tend to move into the sedimentary aquifers from the flanking and underlying basement material.

Some fault-induced disruption of aquifer units and the associated groundwater flow path within the palaeochannel system has been shown clearly by detailed analysis, resulting in localised disruption to groundwater floor and divergence between groundwater flows immediately below the water table and the deep axis of the palaeochannel/thalweg.

Local climatic conditions, Quaternary geology and the geochemistry of the groundwater both suggest low rates of recharge over long periods of time. The groundwater in the palaeochannel system increases in salinity with depth. This salinity profile means that the deep groundwater is denser and will tend to preclude downward movement of less dense, low salinity water.

The groundwater in the main palaeochannel is hypersaline, of sodium chloride type with moderately high magnesium and sulphate concentrations. Piper trilinear diagram analysis indicates that the portions of the major ions are similar to seawater.

Iron and minor elements and metals throughout the channel and tributaries are generally at low concentrations, increasing with decreasing pH (for cadmium, copper, lead, ±cobalt, nickel, uranium).

As a result of the high organic matter concentration in the tributaries, the radionuclide concentrations in groundwaters in the main palaeochannel are quite low, considering their enrichment in the host sediments. Concentrations in Radium in both the palaeochannel and the Ambassador tributary show a much greater range than that of uranium or thorium, consistent with elevated barium concentrations. All waters in the main palaeochannel appear to be in equilibrium with barite although some water samples in the mineralised zone at Ambassador showed oversaturation with a solubility index for barite often in excess of 0, pointing to possible localised precipitation.

Groundwater chemistry in the Ambassador tributary is generally less saline, acidic and reducing than in the main palaeochannel. The proposed Princess pit is located in the upstream component of the Ambassador tributary to the main palaeochannel. Based on the measured hydraulic gradients, groundwater will move from the Princess pit through the area of the proposed Ambassador pit then to the south in the main palaeochannel towards the lease boundary. Groundwater movement does not always follow the main axis of the palaeochannel because of the post-depositional faulting but is nevertheless constrained within the palaeovalley.

Predicted groundwater movement through the fine-grained sediments present at the top of the water column indicate rates ranging from less than 0.007 m/day to 5 m/d (with an average of 0.1 m/d), indicating that groundwater moving from the proposed in-pit tailing facility might reach the mining lease boundary within 150 to about 9,000 years (for a likely average transport time of about 1,500-2,000 years).

Groundwater users

The proposed Kakarook North wellfield will supply MRUP with process water. It is located 30 km upstream from the Princess pit and is regarded as essentially separated from the palaeochannel aquifer system.

There are currently no communities within 100 km of the MRUP and no other users of the groundwater within the mining lease, nor other palaeochannel-hosted mineral resource identified within that radius, other than within the Queen Victoria Nature Spring Reserve. The saline to hypersaline groundwater limits its abstractive beneficial uses to mining operations and associated dust suppression. The in-pit tailings deposition will, therefore, not affect any groundwater users.

Description of environmental receptors

Two consecutive surveys for groundwater dependent ecosystems (by the Tropicana JV and MRUP proponents) at Ambassador and the main palaeochannel have not identified any evidence of stygofauna. This outcome is consistent with groundwater chemistry (low pH and elevated salinity) and lack of macropores in the top section of the profile.

There is abundant evidence from exploration drilling that across the various habitats present on the MRUP, plant roots do not penetrate any deeper than the interface between Miocene and Eocene sediments. This is referred to as the base of the biologically active zone. That interface is typically 20 m to 25 m above the water table.

This assessment considers the effect of in-pit tailings deposition on groundwater. As there are no permanent surface water bodies, or sites of groundwater discharge on the mining lease, there is no interaction with the in-pit tailings disposal.

Therefore, the environmental receptors being considered are the saline and hypersaline groundwaters themselves and the point at the mining lease boundary where groundwater would arrive from the Princess in-pit tailings storage facility in the Ambassador tributary.

Risk assessment

A qualitative risk assessment was carried out, consistent with AZ/NZS ISO 31000:2009.

The key objective of the risk assessment is to appraise whether in-pit tailings deposition meets the environmental objectives defined above, and is consistent with best practice. An important part to this objective is to show that risk to the environment (and other users) could be assessed through a process of risk and uncertainty analysis that considers unlikely events that could result in plume spreading and unacceptable groundwater quality at the lease boundaries.

To support the risk assessment, quantitative modelling of the fate and transport of groundwater was undertaken (refer below). The outcome of that assessment suggests that the potential plume of contaminants (including uranium) will be significantly retarded with negligible increase in the concentration of uranium at the mining lease boundary.

This is consistent with outcomes of modelling and operational monitoring at other palaeochannel-hosted uranium deposits in South Australia, characterised by much lower or negligible organic matter concentrations and greater transmissivities in the sequences through which plumes might migrate.

Another outcome of the risk assessment was that an adaptive on-going program of monitoring needs to be implemented and adhered to during the operational life of the project to address findings of the risk assessment and quantitative modelling.

Fate and transport analysis: Migration and retardation

Extrapolation of conditions over a 10,000 year timeframe is problematic. Changes in climate conditions, i.e. groundwater recharge may dilute tailings liquors, however they are not anticipated to alter regional hydraulic gradients and, thus, groundwater movement rates over the 10,000 year assessment timeframe.

The groundwater flow system comprises areas of sediments of high organic matter content with high potential to fix uranium and other potential groundwater contaminants. This process is exactly what has resulted in the genesis of the deposits and is still on-going today.

The migration of metals in solution is driven by long-lived tectonic and climate change-driven regional lowering of the water table, which has allowed oxidation and metal release. Their fixation is driven by bacterially-mediated or catalysed chemical reactions along the redox boundary near the current water table.

In areas downstream from the proposed Princess and Ambassador pits, there are potential host sites that have not yet accumulated uranium and base metals, reflecting the effectiveness of the capture/fixation processes upstream.

All the analysis and interpretation of the conceptual model discussed above suggests that there will be no measureable change in downstream groundwater quality as a consequence of mining, processing and downstream operations. This conclusion was reached based on the current understanding of both mineralised and un-mineralised host material. The latter is available to capture greater amounts of potential contaminants than those proposed to be contained within the proposed Princess in-pit facility.

To further demonstrate compliance, and to inform the risk assessment, further lines of evidence were developed using both geochemical and analytical groundwater flow models.

A conservative approach was taken for the advective flow model in which it was assumed that all metals, metalloids and radionuclides from the liquid and their labile (mobile) fractions in the solids would have migrated into the surrounding groundwater over the 10,000 years' timeframe. It is conservative in that it does not consider:

- fixation and retardation processes occurring with the tailings themselves (above and below the water table);
- retardation at the water table interface through impeded drainage through the clay that occurs immediately above the water table, and
- fixation or retardation mechanisms within the low transmissivity-highly chemically reactive aquifer material through which the leachate will migrate.

The PHREEQC (USGS 2013) geochemical model was used to predict changes in key parameters in groundwater (pH, U, Cu, Co, Ni, Pb, Zn, Ba, Al, Cd, Fe) over a distance of 12,000 m (estimated distance to the lease boundary) from the tailings pit edge. Modelling involved a number of scenarios assessing the variability of uranium concentrations, organic material and aquifer cation exchange capacities. Transport of leachate constituents was based on one-dimensional advection dispersion.

Advective flow modelling was also undertaken. The results from the advective flow show that under a range of organic matter concentrations and duration of leachate pulses, natural geochemical mechanisms within the aquifer will attenuate the leachate plume sufficiently for concentrations of uranium to increase by no more than between 0.01 to 0.03 mg/L at the lease boundary within a 10,000 year timeframe (with breakthrough more likely around 5,000 years), depending on the scenarios considered, well within the natural background range. This incremental concentration change is less than the natural range of background concentrations. As discussed above, it is expected, however, that this uranium would be fixed geochemically as determined from the PHREEQ modelling whilst migrating downstream through the palaeochannel.

After 10,000 years, it was predicted that natural geochemical mechanisms within the aquifer will attenuate the majority of contaminants within the leachate plume in relatively close proximity to the Princess Pit.

Definition of Acronyms

Acronym	Description
AHD	Australian Height Datum
AMD	Acid Mine Drainage
AMG	Australian Map Grid
ANSTO	Australian Nuclear Science and Technology Organisation
ASLP	Australian Standard Leaching Protocol
CEC	Cation Exchange Capacity
DER	(WA) Department of Environment Regulation
DMP	(WA) Department of Mines and Petroleum
DOW	(WA) Department of Water
EC	Electrical Conductivity
EPA	(WA) Environmental Protection Authority
EPDC	(Commonwealth) *Environment Protection and Biodiversity Conservation Act* (1999)
ESD	Environmental Scoping Document
GDE	Groundwater Dependent Ecosystem
JV	Joint Venture
LOM	Life of Mine
MNES	Matters of National Environmental Significance
MRE	Mulga Rock East
MRW	Mulga Rock West
MRUP	Mulga Rock Uranium Proposal
NAPP	Net acid producing potential
NAG	Net acid generation
OL	Overburden Landform
OM	Organic Matter / Material
ORP	Oxidation Reduction Potential
PER	Public Environment Report
RIWI	*Rights in Water and Irrigation Act* (1914)
RL	Reduced Level
RIP	Resin in Pulp
ROM	Run of mine
SWL	Standing Water Level
TDS	Total Dissolved Solids
TSF	Tailings storage facility
U	Uranium
WIN	DoW Water Information Register

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Appendices

1. Introduction

GHD Pty Ltd (GHD) was commissioned by Vimy Resources Limited (Vimy) to undertake a Groundwater Impact Assessment of the proposed deposition of tails and process water wastes to an open mine pit within their Mulga Rock Uranium Project.

Vimy submitted an Environmental Scoping Document to the Department of Mining and Petroleum (DMP) late 2014 and are currently in the process of preparing a Public Environmental Review (PER) in order to gain mining approval.

GHD understands that a key environmental concern of the regulators relates to the concentration of potentially contaminating metals, metalloids and radionuclides within tails and process water that are being returned to the pits as backfill and the risk that these pose to the groundwater environment. GHD has, therefore, been engaged to undertake an assessment of the potential hydrogeochemical impact and provide conclusions and recommendations as to the geochemical viability of the proposed disposal method.

The objectives of this groundwater impact assessment are to:

- Characterise the existing groundwater conditions at the proposed Princess Pit Tailings Storage Facility (TSF);
- Develop a hydrogeological and geochemical conceptual model for the proposed Princess Pit TSF;
- Identify potential risks of impact to the groundwater environment and users of the groundwater resource;
- Assess the potential long term effects impacts of the in-pit TSF operations, and
- Document lines of evidence to support a case to environmental regulators that in-pit disposal of tailings residues presents a low risk to the groundwater environment.

The risks to the groundwater environment posed by other onsite processes such as groundwater resource development or mine dewatering are excluded from this assessment.

2. Project Overview

2.1 Project background

The Mulga Rock Uranium Project (MRUP) lies approximately 240 km east-north-east of Kalgoorlie-Boulder in the Shire of Menzies (refer Figure 1).

The area is remote, located on the western flank of the Great Victoria Desert, comprising series of large, generally parallel sand dunes, with inter-dunal swales and broad flat plains.

Access to the MRUP area is limited and is only possible using four-wheel-drive vehicles. The nearest residential town to the MRUP is Laverton which lies approximately 200 km to the north-west. Other regional residential communities include Pinjin Station homestead located approximately 100 km to the west, Coonana Aboriginal community situated approximately 130 km to the south-south-west, Kanandah Station homestead positioned approximately 150 km to the south-east and the Tropicana Gold Mine lying approximately 110 km to the north-east of the Project (refer Figure 1).

The MRUP covers approximately 75,700 hectares (ha) on granted mining tenure (primarily M39/1080 and M39/1081) within Unallocated Crown Land. It includes two distinct mining centres, Mulga Rock East (MRE) comprising the Princess and Ambassador Resources and Mulga Rock West (MRW) comprising the Emperor and Shogun Resources, which are approximately 20 km apart.

MRE contains over 65% of the total recoverable uranium and is of a higher grade than MRW. Mining will commence at MRE which will include the location of the processing plant. Up to 4.5 Million tonnes per annum (Mtpa) of ore will be mined using traditional open cut techniques, crushed, beneficiated and then processed at an acid leach and precipitation treatment plant to produce, on average, 1,360 tonnes (t) of uranium oxide concentrate (UOC) per year over the life of the MRUP. The anticipated Life-of-Mine (LOM) is up to 16 years, based on the currently identified resource.

As a result, the MRUP plans to develop a borefield at Kakarook North, about 30 km north-east of the Ambassador deposit, to supply low-salinity water for processing ore and camp use. A supply of about 1.8 GL/a will be needed. Dewatering of the pits is required for stability and safe working conditions, e.g. heave, bogging, flooding, in the base of the mine. Water recovered from dewatering operations is to be re-injected into the aquifers, approximately 8 km south of the active mining area.

2.2 Proposed Mine Layout

The general development area is shown in Figure 2. Major built infrastructure will include a processing plant, ore stockpile area, construction of above-ground overburden landforms for un-mineralised mined materials, an initial short-term above-ground tailings storage facility and water storage/evaporation facilities.

Required project infrastructure will include mine administration and workshop facilities, fuel and chemical storage, a diesel-fired power plant, a saline water borefield, mine water reinjection borefield and associated pipelines. Service infrastructure will include a power supply, accommodation village for a fly-in fly-out workforce, airstrip, laydown areas and other supporting ancillary infrastructure such as communication systems, roads, waste water treatment plant and solid waste landfill facilities.

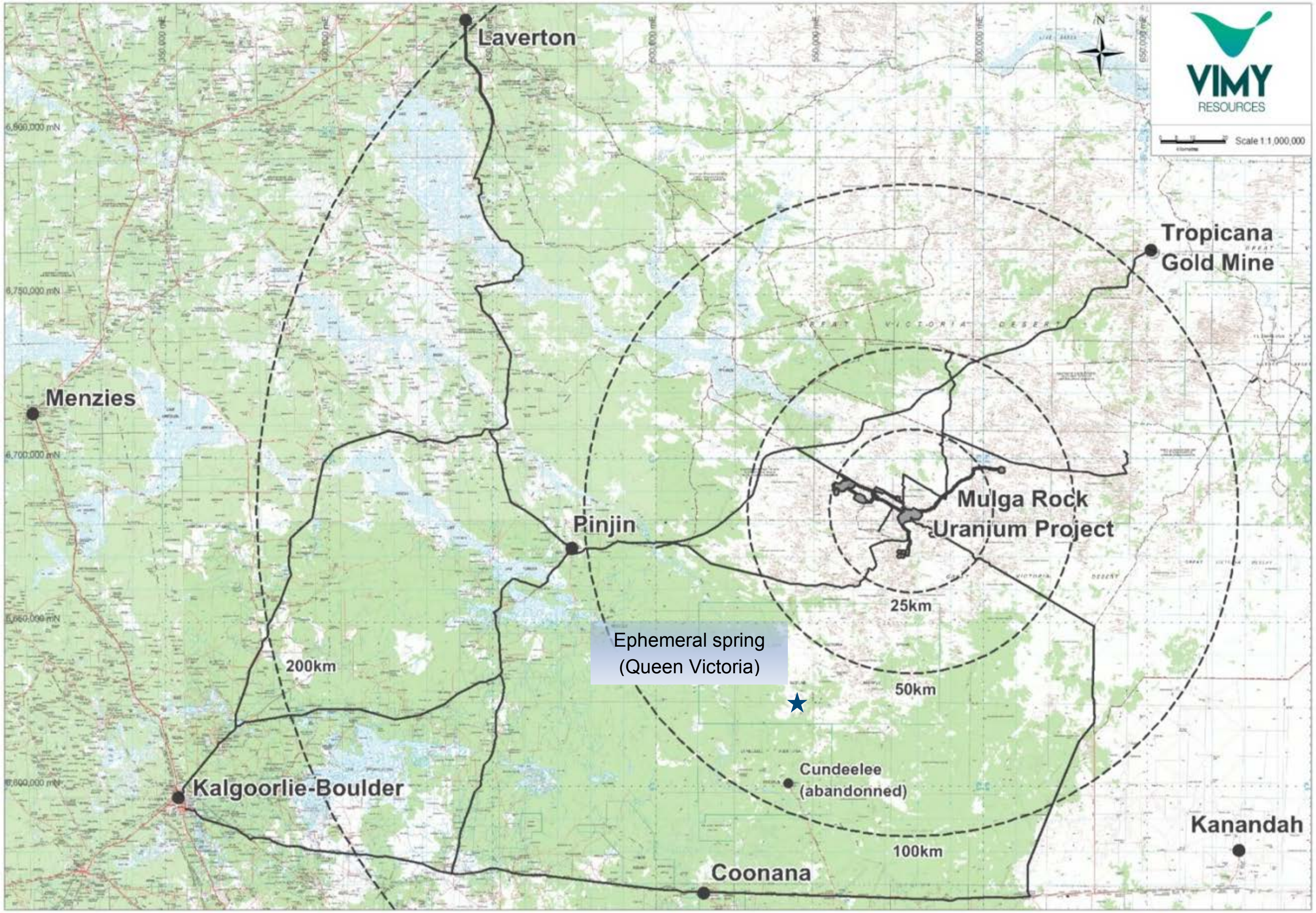

Figure 1 Mulga Rock Project – Regional location plan

(Source: Vimy)

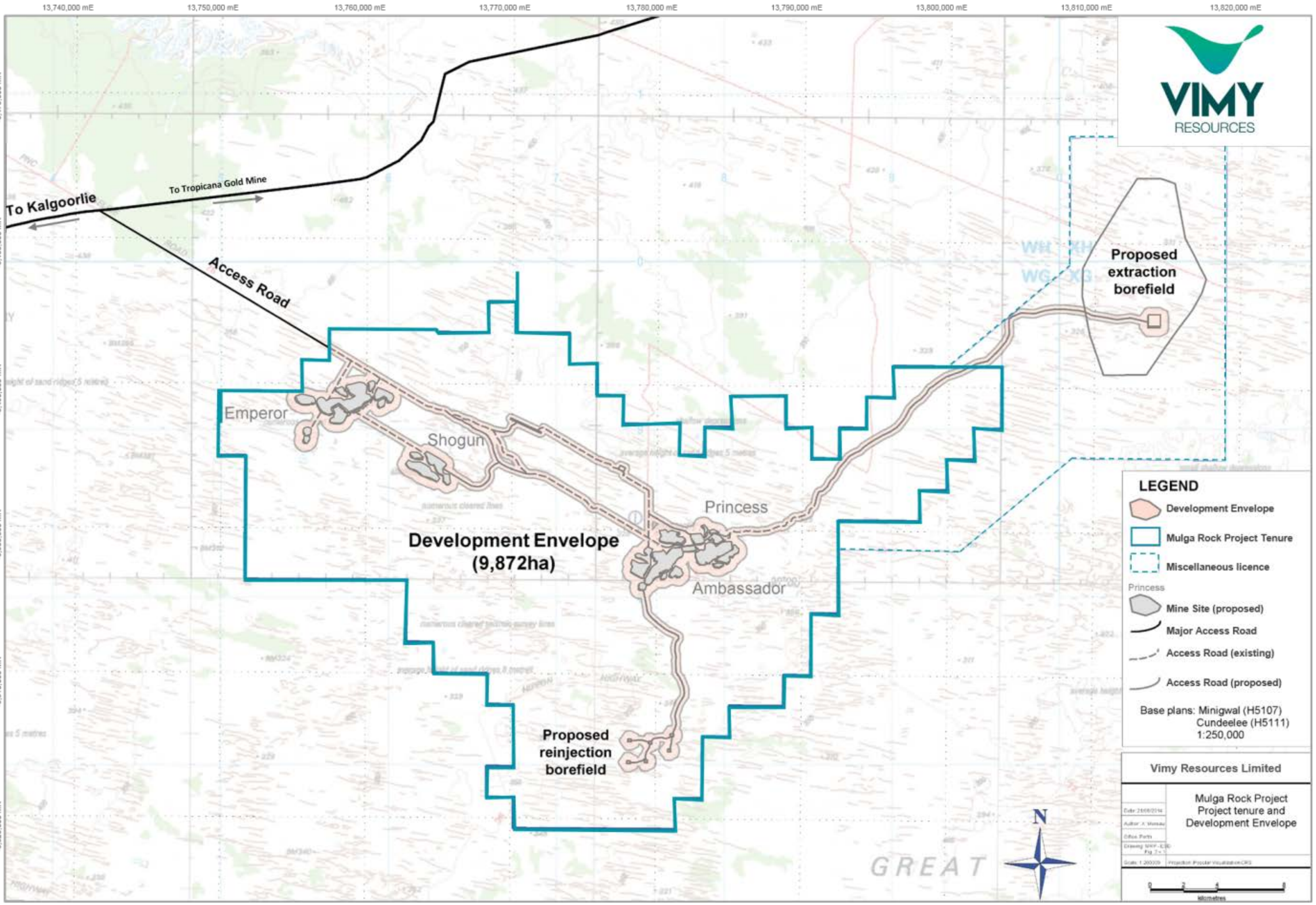

Figure 2 Mulga Rock Project - Project Tenure and Development Envelope

(Source: Vimy)

2.3 Mining Methods

The MRUP ore deposit thickness varies from 12 m in Emperor to 32 m in Ambassador, which has 26 m to 36 m of overburden. The deposits extend over some 30 km extending approximately 10 km north-south and 25 km east-west (Coffey 2015).

The deposit geometry lends itself to a strip mine mining method with both conventional truck and shovel mining equipment or mechanised strip mining systems feasible. In its most basic form, a strip mine commences with the excavation of an initial slot, cut to expose the ore, with the overburden placed in a waste rock dump or used for civil construction purposes. After mining, the ore exposed by the first slot cut, a pit void is created which is then used to place the overburden from the next mining strip along strike. In general, mining advances one strip at a time with previously mined areas backfilled and rehabilitated. This mining method will result in a small environmental footprint at any given time.

The regular geometry of a strip mine, with a fixed distance to the waste dump, lends itself to a continuous mechanised waste haulage system. A conveyor system is proposed for the MRUP to transport the barren overburden from the advancing face to the overburden dump. Loading of the conveyor can be by conventional excavator, continuous miners such as a bucket wheel excavator, or a semi-mobile dozer trap.

It is understood that to reach the maximum depth of the minable resource, dewatering is required to be undertaken in the pits. The dewatering is to be completed using sump pumping and in-pit drainage; however it is acknowledged that dewatering bores may be required in some areas to prevent pit floor heave. Numerical model estimates flow rate ranges of 0.2 ML/day to 4.1 ML/day may be required for dewatering purposes (Rockwater 2015b).

2.4 Ore Processing

Onsite processing includes crushing, beneficiation, leaching and precipitation. A schematic of the ore processing is shown in Figure 3.

Ores are beneficiated in the pit using screens and a gravity circuit to remove 50% of mass, i.e. coarse grained fractions. The slurry, rich in uranium bearing organic material then undergoes acid leaching, and resin-in-pulp circuits to recover uranium in solution.

The MRUP will have two separate ‘water’ circuits incorporated into its infrastructure, described in summary as follows:

- Ore Processing Water (refer Figure 3)

  The development envelope and Kakarook borefield, located to the northeast of the MRUP are shown in Figure 2. The extraction borefield will supply a lower salinity groundwater for ore processing.

- Pit Dewatering Circuit

  To access the ore body and create safe working conditions, each of the proposed pits, including the Ambassador and Princess Pits will require dewatering. Dewatering estimates have been provided by Rockwater (2013a). Water recovered from the dewatering activities will be used for ore beneficiation, however it is too saline for the main process plant. Excess pit water will be recharged to the aquifer, at a proposed site approximately 8 km to the south of the Princess and Ambassador Pits.

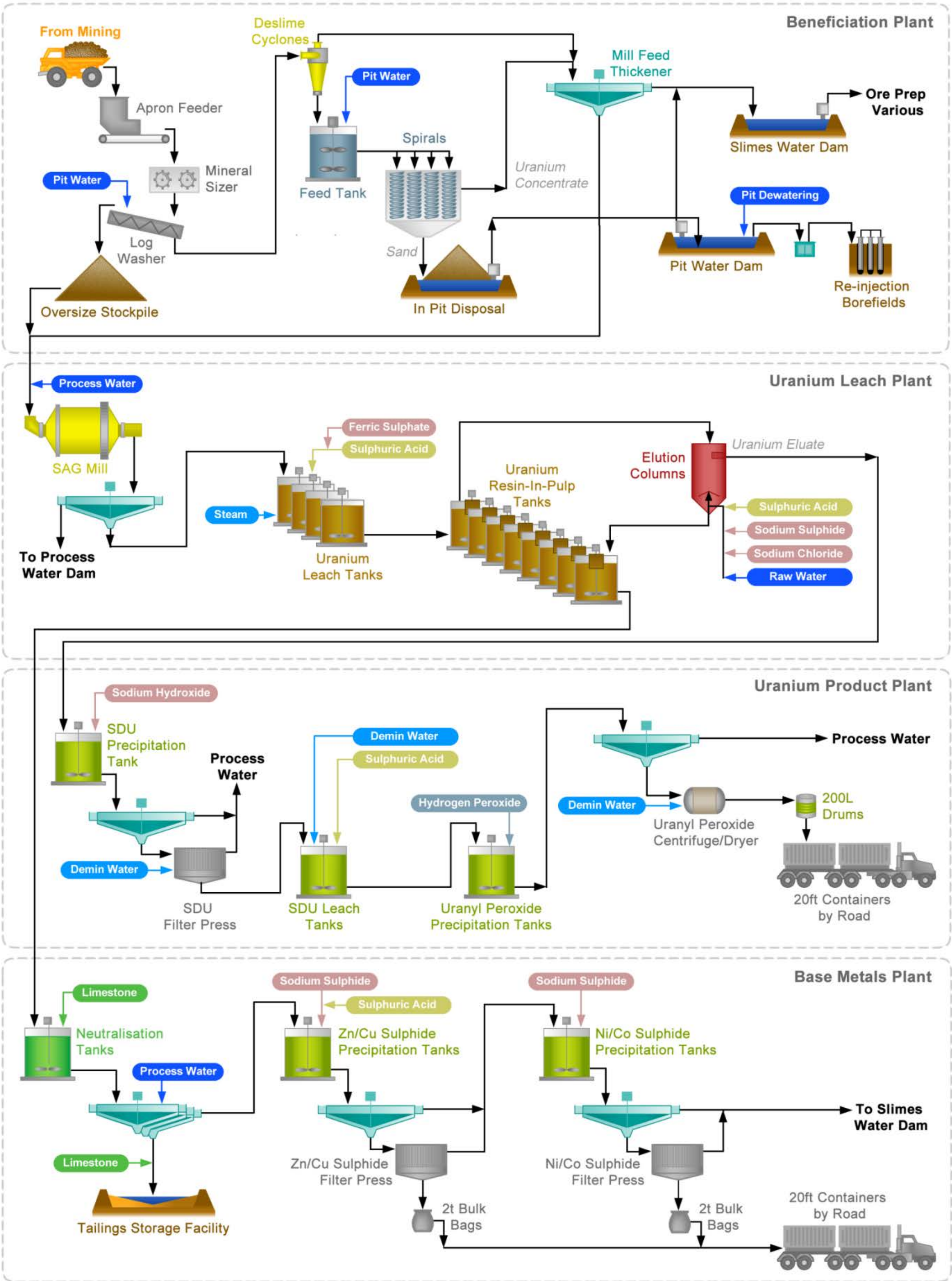

Figure 3 Ore Treatment Process

(Source: Vimy)

2.5 Tailings Management

The tailing management process described below is equally relevant to the lined surface and in-pit TSF facilities planned for the MRUP.

2.5.1 Tailings Production

The ore will be mined through free cut, load and haul, strip-mining method. As discussed above, silicate sands will be hydraulically separated from the ore and deposited in-pit, generally as a separate stream from the process tailings.

It is anticipated that the ore will be leached in a sulphuric acid solution at pH 1.5, yielding a pregnant liquor that will contain the majority of the trace elements, which will treated to remove the uranium. The gangue will then be neutralised and further processed to recover zinc, copper, nickel and cobalt. The process residue streams will be combined before being hydraulically discharged.

The total production of tailings is expected to be about 1.27 million metric tonnes of dry solids per year (1.27 Mtpa). The mine life is anticipated to be at least ten years. Tailings will be permanently stored in a lined, out of pit TSF for the first 18 months of operation and thereafter in the mined out open pit voids.

2.5.2 Tailings Characterisation

General description

The uranium tailings will comprise processed (acid-leached) lignite, some of which have been further processed to recover zinc, copper, nickel and cobalt. The uranium tailings will be blended with lime/limestone to raise the pH to around 4-4.5 before being pumped to the TSF as a slurry.

The coarser sand- and silt-sized fraction will be separated from the ore ahead of processing. The process tailings will accordingly be a fine silt, with a predicted P_{80} [2]of 80 µm. The tailings material is classified as an organic sandy silt (OH) under the Unified Soil Classification System.

The tailings' solids particle density is unusually low (1.05 t/m^3), being high in organic matter, and will result in the final in situ dry density being correspondingly low. The initial settling behaviour of the tailings has been examined by ANSTO (2015a) through bench testing. It is evident that the tailings will be slow to settle and are expected to reach 60% solids by mass after seven days under subaqueous conditions. Intervention, through addition of sand or through chemical modification (still to be identified) may be required to accelerate consolidation and densification of the tailings.

Geochemistry and AMD potential

The composition of the tailings is not yet well defined. Nevertheless, sulfides are present in the ore, with pyrite and covellite being the dominant sulfide minerals recorded. Much of the sulfidic material will be removed during the extraction processes, and hence prior to being discharged as tailings. Process residues included in the tailings stream will likely consist predominantly of calcium sulphate, sodium chloride, aluminium silicates, iron and aluminium hydroxides, but trace levels of the other elements cannot be ruled out at the present time.

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[2] P80: 80% fraction passing (particle size distribution analysis).

At the expected tailings pH of 4 to 4.5, metals that were adsorbed on to the surface of the neutralisation products (aluminium and iron hydroxides) can be expected to desorb and the silicates will gradually dissolve, releasing the aluminium and other trace elements within their matrix. This release will increase the acidity of the system over the long term. It is not expected that there will be any remaining free carbonate or bicarbonate in solution to provide neutralising capacity.

The residue will contain a high percentage of organic material, comprising a recalcitrant high molecular weight polymeric type material as it has survived an acid digest. The generation of organic acids from this material is, however, likely to be very slow.

Given the above, the tailings are considered to have acidic and metalliferous drainage (AMD) potential and are a potential source of acid to the groundwater system.

Radionuclides

The uranium and possible other trace elements will be trapped within the cell structure of the lignite ore and therefore not easily mobilised. After processing, there may be a small amount of residual uranium remaining within the cell structure of the organics. ANSTO test work (2015b) demonstrates depletion of ^{238}U, but not of the daughter products. Specific control measures will be incorporated into the TSF design and tailings operating practices, as required, in order to manage the potential for radon gas emission and radioactivity.

2.5.3 Tailings Management Approach

Tailings will be pumped to the TSF as a slurry at about 30% solids by mass, where it will be sub aqueously discharged through multiple spigots. This approach will maintain the tailings solids under water eliminating dust and radon emission risks and impeding the development of Acid Mine Drainage (AMD). For the initial 18 months of operations, tailings slurry will be deposited into a dedicated lined cell that will be formed through balancing cut and fill. It is intended to place tailings into mined out sections of the Princess Pit as soon it becomes practicable to do so. Nevertheless, a second above-ground cell is planned to provide contingency capacity of a further 18 months of tailings production.

The TSF cells will be lined to prevent seepage from adversely affecting surrounding vegetation. The sides of the TSF will be located in dune sand material in places, and will be provided with a double liner system such as HDPE over clay. The TSF floor liner will consist of compacted clay materials sourced from selected mine overburden. A drainage system and protection layer will be provided over the liner. The drainage is aimed at improving consolidation during the operational and closure phases. Recovered water will be recycled to the surface of the TSF, from where it will evaporate.

Once the tailings have consolidated and the water has evaporated from the surface, a cover will be placed over the TSF to permanently contain the tailings. The cover will comprise capillary break and other materials as required to provide resistance to erosion and a long term barrier to infiltration. Small amounts of drainage that may emanate from the facility in the long term will be evaporated from suitable containments.

2.6 Proposed Mine Schedule

Scoping studies have been commissioned by Vimy (Coffey 2015) that reference the mining schedule for the project. The schedules were based on delivering a specific quantity of U_3O_8 to the mill, with mining at the Princess Pit initially, and then moving onto Ambassador, and in turn Emperor and Shogun as resources are subsequently exhausted.

Life of mine (LOM) is estimated to be 16 years based on currently identified resources.

Project deposits commence at the eastern edge of the pits where the grade is highest. For the first two years of operation an initial strip ratio of 30:1 is used to remove overburden in the initial mining areas. Overburden from the Princess Deposit will be used to build the above-ground tailings storage facility (TSF) near the Princess Pit. Any excess overburden from Princess will be dumped adjacent to the Princess pit as a waste land form.

As previously documented, after the Princess Pit has been completed, it would be used for in-pit tailings disposal. It is noted that depending upon the capacity of the Princess Pit, and the LOM, some in-pit disposal may occur to the Ambassador Pit. This is discussed further in Section 6.6.

3. Legislation, Policy and Guidelines

3.1 Key Authorities

Key authorities regulating mining activities and related water resource management issues in Western Australia include:

- the Environmental Protection Authority (EPA);
- the Department of Mines and Petroleum (DMP);
- the Department of Water (DoW); and
- the Department of Environment Regulation (DER).

3.1.1 Environmental Protection Authority

The EPA is responsible for the administration of the *Environment Protection Act* (1986). The EPA often requires advice or endorsement from other Western Australian environmental regulators including:

- the DMP administering the *Mining Act* 1978;
- the Department of Environment Regulation (DER) administering Part V of the EP Act, the *Conservation and Land Management Act* (1984), and the *Contaminated Sites Act* (2003) (CS Act); and
- the Department of Parks and Wildlife administering the *Wildlife Conservation Act* (1950) (WC Act).

3.1.2 Department of Mines and Petroleum

The DMP is the primary regulator for mining activities in Western Australia and most water resource management issues related to mining activities will be regulated by the DMP.

In 2012 the DMP and the DoW established an Administrative Agreement to streamline interaction between the two departments in regard to their respective responsibilities for mining and water resource management within Western Australia. Under a Memorandum of Understanding between the DMP and the EPA, the DMP is required to refer to the EPA for assessment any proposal involving onshore activity which may affect water resources.

3.1.3 Department of Water

The DoW is primarily responsible for the management of the State's water resources, which include all surface water resources (watercourses, reservoirs, floodplains together with their beds and banks) and groundwater resources (aquifers and other underground water). These responsibilities concentrate on the assessment, conservation, protection and management of those water resources and their environment. The key powers and responsibilities of the DoW are derived from several pieces of legislation, including the *Waterways Conservation Act* (1976), the *Rights in Water and Irrigation Act* (1914) (RiWI), the *Metropolitan Water Supply, Sewerage and Drainage Act* (1909) and the *Country Areas Water Supply Act* (1947). In addition to its direct legislative powers and responsibilities, the DoW will provide advice to other State Government agencies on water resource management issues.

The DoW does not issue any approvals related to mining activities but is likely to provide advice to the DMP and the EPA related to the management or monitoring of water resources. The DoW will usually be consulted by DMP, particularly if a mining activity is located within an area of water conservation, protection area or management significance. Any water bores installed to abstract water for use on the project will require a licence under the RiWI Act.

3.1.4 Department of Environment Regulation

The DER is the regulating authority for all matters relating to contaminated, or suspected contaminated, sites governed under the CS Act. Reporting, assessment and remediation efforts are subject to review by the DER and, under the CS Act, companies are required to report known or suspected contaminated sites. The DMP will seek advice at mining proposal stage from the DER in relation to provided mining closure strategies. To ensure compliance with the CS Act and the *Contaminated Sites Regulations 2006*, closure strategies need to be designed to incorporate investigation and remediation of contamination.

3.2 Commonwealth Legislation

3.2.1 *Commonwealth Environment Protection and Biodiversity Conservation Act* (EPBC) 1999

The EPBC Act is the central piece of environmental legislation at the Commonwealth level. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places. These protected values are defined under the EPBC Act as Matters of National Environmental Significance (MNES). Relevant subordinate legislation to the EPBC Act includes the Environment Protection and Biodiversity Conservation Regulations 2000.

During the planning and approvals process, it is critical to demonstrate that activities associated with the proposed action can be carried out without an unacceptable impact to MNES. Furthermore, during operations, regular environmental audits would be undertaken to confirm that the extent of any impacts are consistent with those predicated in the Strategic Assessment and the Strategic and Derived Proposal documentation, and are being appropriately managed.

3.3 Western Australian Legislation

3.3.1 Environmental Protection (EP) Act 1986

The EP Act is the legislative instrument of most relevance to environmental impact assessment and environmental protection in Western Australia. The EP Act places requirements for environmental management on developments in Western Australia. Mine closure and rehabilitation are considered as part of formal assessments for mining projects under Part IV of the EP Act by the Western Australian EPA.

3.3.2 Mining Act 1978

The *Mining Act* 1978 requires that a Mine Closure Plan be submitted to the DMP for approval when applying for a Mining Proposal. Closure Plans are to be prepared in accordance with the *Guidelines for Preparing Mine Closure Plans* (DMP and EPA 2015).

3.3.3 Contaminated Sites (CS) Act 2003

The CS Act governs contaminated site management in Western Australia and is administered by the Western Australian DER. Under the CS Act, companies are required to report known or suspected contaminated sites. To ensure compliance with the CS Act and the Contaminated Sites Regulations 2006, closure strategies need to be designed to incorporate investigation and remediation of contamination.

3.3.4 Rights in Water and Irrigation Act 1914

The RiWI Act (1914) is the legislation pertaining to the use of surface water and groundwater resources in Western Australia, and is administered by the DoW. The DoW protects Western Australia's water resources and promotes the sustainable use of water through licensing and permits. Mining operations and closure planning need to consider the efficient use of water, as well as the potential for surface and groundwater impacts post-closure.

The *RiWI* Act proclaims groundwater areas and sub areas across the State in order to divide groundwater management into manageable units. The Mulga Rock project area lies within the Goldfields groundwater area and the Minigwal sub area.

The DoW reviews water abstraction licence applications based on the availability of the water resources within groundwater management units. Allocation limits have been set by the DoW for each aquifer within these areas based on determined ecological sustainable yields and current groundwater use.

Groundwater availability can be ascertained by the unit's classification. Allocation levels are classed from 1 to 4 representing allocation rates of less than 30% to 100% resource allocation, respectively. In some instances, the resource may not have significant licensed abstraction but be fully allocated due to the significance of the resource from an environmental perspective such as where the resource sustains groundwater dependant ecosystems (GDEs).

The aquifer of interest is referred to by the DoW as Combined-Fractured Rock West-Palaeochannel. The unconfined aquifer is classified as allocation level 3. Two abstraction licenses are registered within the Goldfields-Minigwal-Combined-Fractured Rock West-Palaeochannel (Table 1).

Table 1 Goldfields-Minigwal Groundwater Allocations

License Number	Allocation (kL)	Issued	Expires	Party
160210	875000	2011	2021	Crescent Gold Ltd
162374	2500000	2012	2021	AngloGold Ashanti Australia Ltd
170538(2)	34800	2014	2019	Narnoo Mining Pty Ltd[3]

Note: Allocations for the combined fractured rock west Palaeochannel aquifer.

3.4 Western Australian Departmental Guidelines

3.4.1 Guidelines for Preparing Mine Closure Plans

The aim of the *Guidelines for Preparing Mine Closure Plans* (DMP and EPA 2011) is to ensure an appropriate planning process is in place for each mine such that it can ultimately be closed, decommissioned and rehabilitated in an ecologically sustainable manner, consistent with the agreed post-mining outcomes and land uses, and without unacceptable liability to the State of Western Australia.

[3] A 100% owned subsidiary of Vimy Resources.

The Guidelines are relatively prescriptive and list the minimum required content for the Mine Closure Plan. The approved Mine Closure Plan must then be reviewed and re-submitted for approval by the DMP three years after its initial approval, or at such other time as required in writing by the DMP.

3.4.2 Environmental Assessment Guideline for Environmental Factors and Objectives

The EPA's Environmental Assessment Guideline for Environmental Factors and Objectives was developed to help proponents understand the need to consider environmental factors and objectives for the purpose of environmental impact assessment (EPA 2013). The EP Act provides for the referral and EIA of proposals and schemes likely, if implemented, to have a significant effect on the environment. The EP Act requires the EPA to provide, in its report to the Minister for Environment, what it considers to be the key environmental factors identified in the course of an assessment.

The EPA uses environmental factors and associated objectives as the basis for assessing whether a proposal or scheme's impact on the environment is acceptable. They underpin the EIA process. The guideline, therefore, sets out the EPA's environmental factors and associated objectives for the purposes of EIA.

The environmental factors and objectives that relate to groundwater impact and protection include:

- Hydrological Processes: To maintain the hydrological regimes of groundwater and surface water so that existing and potential uses, including ecosystem maintenance, are protected;
- Human Health: To ensure that human health is not adversely affected; and
- Closure and Rehabilitation: To ensure that premises are closed, decommissioned and rehabilitated in an ecologically sustainable manner, consistent with agreed outcomes and land uses, and without unacceptable liability to the State.

3.4.3 Guidelines for the Safe Design and Operating Standards for Tailings Storage

The guidelines (Department of Minerals and Energy, 1999) were prepared to assist in the design, construction, management and decommissioning of TSFs in Western Australia so as to achieve efficient, cost effective, safe and environmentally acceptable outcomes. The guidelines are intended to provide a common approach to the safe design, construction, operation and rehabilitation of TSFs, and to provide a systematic method of classifying their adequacy under normal and worst case operating conditions.

The approach adopted in the guidelines recognises the desire of the mining industry to move towards self-management by the use of a certificate of compliance for TSF design and construction.

3.4.4 Guidelines for the Assessment and Management of Contaminated Sites

Upon closure, mining tenures are subject to the clauses set out within with CS Act 2003. The DER's Assessment and Management of Contaminated Sites (Contaminated Sites Guidelines, December 2014) provides guidance on the assessment of potentially contaminated sites and management of remediation efforts in accordance with the legislative framework provided by the CS Act 2003 and the Contaminated Sites Regulations 2006 (CS Regulations); and the revised national site assessment framework provided in the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM Amendment 2013 No. 1).

Applicability of the investigation levels presented in the guidelines are assessed on the basis of identified site specific source-pathway-receptor linkages. The groundwater investigation levels (GILs) presented are based on the ANZECC & ARMCANZ (2000), NHMRC & NRMMC (2011) and NHMRC (2008) guidelines.

Assessment of Mulga Rock groundwater has identified the following:

- No groundwater dependent ecosystems (within 100 km of the site);
- No receiving water bodies (within 100 km of the site);
- No groundwater abstraction licenses within the Minigwal subarea down groundwater gradient of the site; and
- A deep (approximately 40 m below ground level) saline and acidic aquifer.

Comparison to fresh water, marine water, drinking water, domestic use water or recreational use water investigation levels is therefore inappropriate for the assessment of impacts to groundwater at the site as a result of mining activities. Establishing representative baseline groundwater quality at the site and comparing post-mining impacts at the tenement boundaries is considered a more pragmatic approach.

3.4.5 Guidelines for Baseline Water Resource Monitoring

The DMP is expected to issue an industry-specific guideline for baseline water resource monitoring later this year. The guidelines will likely follow current best-practice and be consistent with the following existing guidance documents:

- AS/NZS 5667 (Parts 1, 4, 6, 11 and 12);
- Geoscience Australia (Sundaram *et al.* 2009); and
- Department of Water (2006, 2009).

Baseline water resource monitoring will provide data on the current water quality, levels and status that represent the water resources present in the project location. Through baseline and ongoing monitoring, it can be demonstrated that site operations (particularly in this instance the in-pit tailings disposal) are not impacting water resources (groundwater).

The best baseline data is obtained from sites that have a historic record of water quality, levels and status. Locations for the baseline monitoring will need to be appropriate to the project, encompassing TSFs (above and below ground), fuel storage and use areas, chemical storage areas, processing plant, material stockpile areas and vehicle access ways. Such monitoring network does not exist at the Site, requiring design and installation.

4. Method

4.1 Regional and local scope

Although this report documents existing groundwater conditions and assesses the potential effects of an in-pit TSF on groundwater within the study area, it is particularly focused on the Princess Pit. However, it is noted that the Ambassador Pits lies within a similar hydrogeological setting. It is acknowledged that as groundwater processes can be regional such as groundwater flow, a regional perspective has been adopted for some issues.

4.2 Technical investigations

The method applied to describe the existing conditions was based on a desktop review of available literature relating to groundwater and hydrogeology. Additional geotechnical and environmental investigations were being undertaken at the time of reporting and relevant information is included in this report.

To complete the overall picture of existing conditions, the following tasks were undertaken. These tasks then formed inputs into the impact assessment, which is described later in this report.

- Review published and unpublished hydrogeological reports pertaining to the area in the immediate proximity of the MRUP;
- Provide a description of the geology and relationships between aquifers at the local and regional scale, including the degree of confinement of the systems, the protection offered to the aquifers by the soil profile, unsaturated zone or aquitards or the potential for downward seepage through to the aquifers via fissures, permeable soils;
- Describe the groundwater flow systems through the distribution of groundwater potentials, watertable depth and morphology, directions and rate of groundwater flow and seasonal fluctuations;
- Describe interpreted / inferred recharge, discharge and interactions between surface water and groundwater;
- Describe the groundwater chemistry / quality in relation to the interpreted geology and flow systems;
- Identify the groundwater segment and list the protected beneficial uses of the groundwater in relation to WA legislation;
- Identify the location of users / receptors of the groundwater systems such as bore owners, streams and wetlands;
- Provide a concise summary of the conceptual hydrogeological model for the MRUP;
- Undertake quantitative geochemical assessment of groundwater and leachate mixing to support the inferred geochemical processes influencing the fate and transport of the leachate;
- Undertake quantitative, analytical groundwater fate and transport modelling;
- Under take a qualitative risk assessment of the proposed Princess Pit TSF;
- Assess the risks and discuss the potential effects of in-pit tailing storage and interaction with the groundwater environment using multiple lines of evidence.

4.3 Assumptions

4.3.1 Hydrogeology data sources

Hydrogeological investigations have relied on a number of data sources:

- Published and unpublished geological and hydrogeological mapping;
- Groundwater monitoring completed by Vimy;
- Previous geological and hydrogeological studies associated with the deposit; and
- WIN database for groundwater bore information.

These data sources have been referenced, where relevant, throughout the report and a complete list of references is provided in Section 12 at the end of this report.

5. Existing Conditions

5.1 Site Setting

5.1.1 Location

The Mulga Rock Mine is located approximately 240 km northeast of Kalgoorlie, Western Australia, on the south western margin of the Great Victoria Desert (refer Figure 1). The Great Victoria Desert extends from the Eastern Goldfields area in Western Australia across the southern parts of central Australia to the Stuart and Gawler Ranges in South Australia. It is divided into three subregions, with the western shield subregion covering 54,427 km^2 – the only division relevant to the MRUP.

5.1.2 Topography

The terrain surrounding the MRUP is an undulating sandy plain at an elevation of approximately 300 m to 400 m AHD, crossed by east-trending sand dunes that locally can reach up to 15 m high and 10 km long (GRC, 1984).

5.1.3 Vegetation and Land Use

The bioregion at Mulga Rock comprises yellow sand plain communities with diverse mammalian and reptile fauna and distinctive plant communities. The vegetation consists predominantly of an open spinifex – eucalypt association.

Land has a limited commercial use in the area. From map data and visual inspection, it was identified that to the north land was typically unused and salt lakes, to the west was unused, creeks, salt lakes with possible agriculture, to the south was nature reserves, creeks and salt lakes, and to the east is unused crown land.

5.1.4 Climate

Site Monitoring

Vimy has established climate monitoring at the MRUP. A summary of the monthly rainfalls has been provided in Table 2 and shown graphically in Figure 4.

Whilst it is appreciated that the rainfall record is short (less than 5 years), the climate is arid, with mean annual rainfall ranging from below 150 mm to over 300 mm. Rainfall is non-seasonal and shows great variability between years hence is unreliable.

Mean daily maximum and minimum temperatures are about 34°C and 18°C respectively in January, and 16°C and 6°C in July when overnight minima can commonly fall below 0°C. Annual evaporation for the area, derived from Luke *et al.* (1987) is 3,000 mm.

Table 2 Monthly Rainfall Totals (mm)

Month	Airstrip					Emperor					Shogun					Long Term Average	
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014	Laverton	Kalgoorlie-Boulder
January	9.3	58.7	23.6	15.2	65.7	0	108.2	55.4	20.8	128.8	3	105.8	62.6	15.2	116.6	24.9	20.8
February	10.3	191.3	13.7	7.5	31.3	12.6	252.4	23	3.8	51.8	15	247.4	21.6	10.2	49.2	29.7	24.7
March	5.9	9.3	20.7	36.6	3.3	3.6	17	47.4	70	11.8	11.2	18.2	48.8	58.2	12.2	29.7	26.2
April	31.3	20.3	0.7	8.6	0.9	38.2	28.8	0.2	14.6	21.4	53	33.8	0.2	16.6	12	21.7	20.7
May	8	11.2	2.6	18.7	17.2	7.3	17.4	2.6	18.2	38.4	9.1	19.8	3	31	31.6	22.9	27.5
June	7.8	57.2	6.9	4.5	4.6	7.8	85.2	10	5.8	6.6	9.6	82.2	13.2	7.2	7.2	23.3	27.4
July	8.8	21	2.1	8.1	2.5	13.2	38.4	2.4	14.7	4	12	36.2	3.4	13	4	16	23.3
August	55.1	1.9	0.6	2.1	0.4	86.8	3	1.4	3.4	1.2	79.2	3	0.8	1.8	1.2	12.8	21.6
September	27.4	2.1	0.6	5.8	5.1	36.4	5.6	1	13.2	7.6	36.2	4	0.8	10	6.8	9	13.4
October	1.5	36.7	3.8	0.9	9	0.6	61.4	9.4	1.2	19.2	1.8	59.2	6.4	2.8	17.4	9.4	15.5
November	1.9	12.2	35.1	47.9	21.6	2	24.4	48	65.4	30	1	24.2	50.8	57.2	32	14.2	16.3
December	7.7	12.7	17.5	15	N/A	7.4	28.8	53.8	16.8	N/A	9	22.8	28.4	16	N/A	16.8	16.3
Annual Total	175	434.6	127.9	170.9	161.6	215.9	670.6	254.6	247.9	320.8	240.1	656.6	240	239.2	290.2	229.6	252.7

Source: Vimy

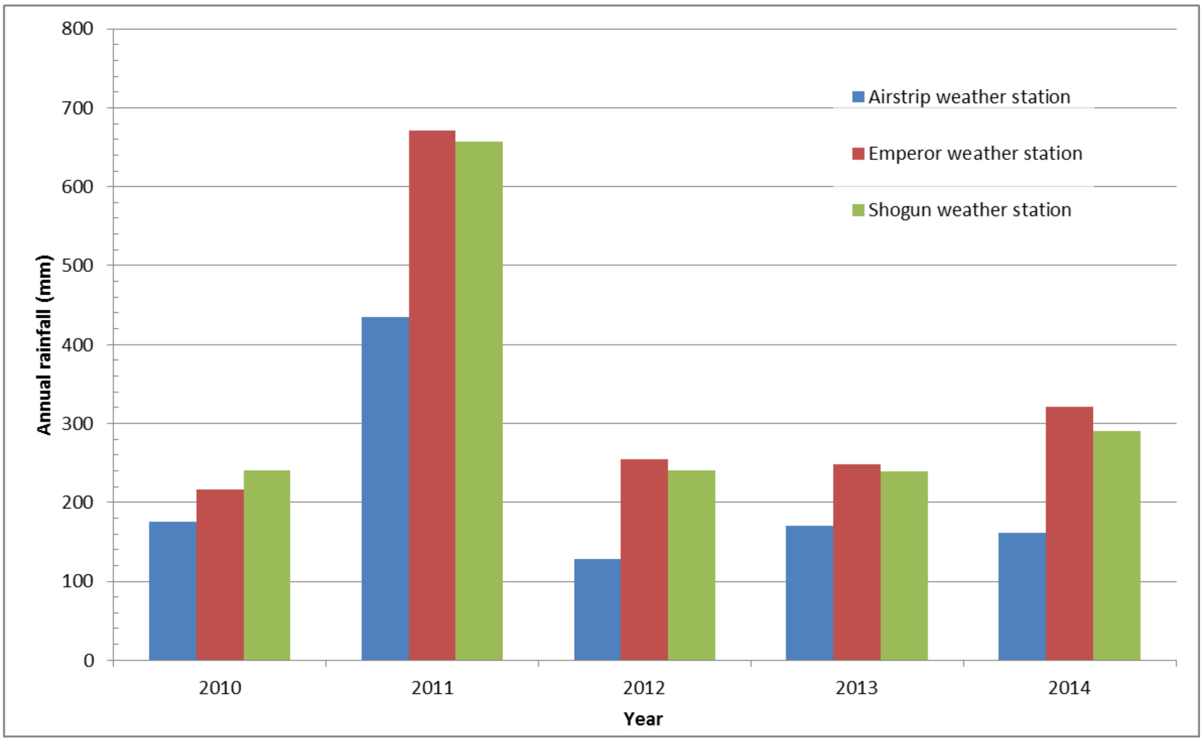

Figure 4 Annual Rainfall

Regional Monitoring

To obtain an understanding of longer term climate data, information was sourced from two Bureau of Meteorology climate stations at Laverton and Kalgoorlie-Boulder (refer Table 3). The long term average rainfall data from these two stations has been included in Table 2. Rainfall is influenced by irregular storm events.

Table 3 BOM Climate Station Summary

Element	Station	
	Laverton	Kalgoorlie-Boulder
Station Number	12045	12038
Latitude	-28.63	-30.78
Longitude	122.41	121.45
Elevation	461	365
Length of Record	1889 to present	1889 to present

5.1.5 Surface Water Drainage

No effective surface water flow occurs across the MRUP, due to the sandy nature of the surficial soils and the function and density of topographic depressions that effectively capture and store all runoff. Water ponds in these depressions only temporary and is removed by evaporation and infiltration within a short period of time after major storm events. There are no permanent surface water bodies present (Rockwater 2015c).

5.2 Regional Geology

5.2.1 Regional Setting

MRUP is located in an embayment in the southwest corner of the Officer Basin, which is a Proterozoic trough containing Phanerozoic sediments.

The project covers a significant portion of the Narnoo Basin, a small Late Eocene sub-basin within the larger Gunbarrel Basin (mostly filled with Late Carboniferous-Early Permian glacio-fluvial sediments), located at the contact between an Archaean basement of the Yilgarn craton (Burtville Terrane) and a Palaeo-Proterozoic metamorphic basement (Northern Foreland, reworked Archean). The position and scale of the basin in respect to surrounding tectonic units is shown in Figure 5.

As shown in Figure 5, a palaeodrainage system has been mapped regionally which indicates a number of drainage systems which trend generally eastwards and southwards e.g. Lake Raeside, Lake Minigwal and Lake Rebecca, before draining to the Eucla Basin and the Southern Ocean. It is suspected that the Lake Minigwal drainage flowed into the Narnoo Basin, however this was disrupted by more recent tectonism.

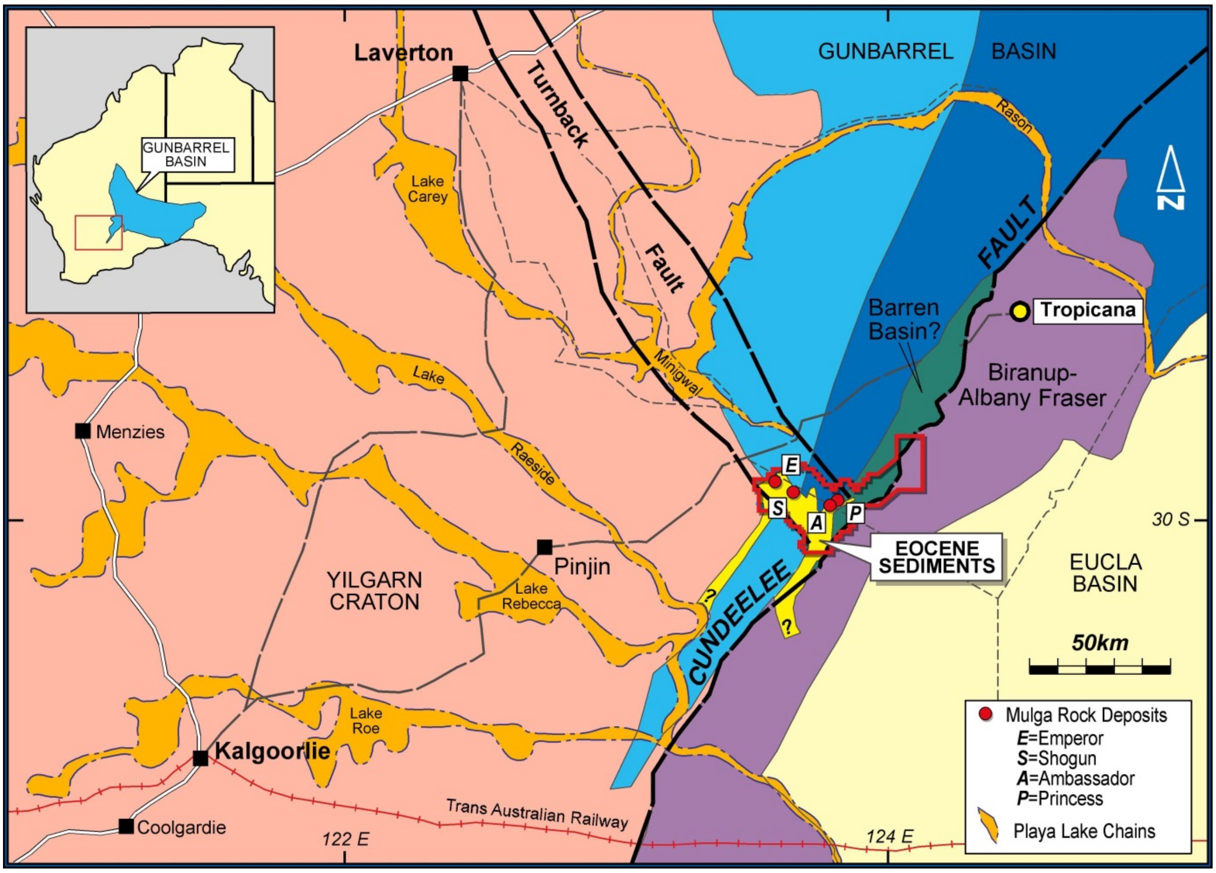

Figure 5 Regional Geological Setting

Source: Vimy

5.2.2 Stratigraphy

The geology of the region is complex and the following information is focussed on the Princess and Ambassador Pits, however information from other parts of the MRUP has also been used to further characterise the site.

A detailed summary of the regional stratigraphy of Mulga Rock is presented in Figure 6 which includes lithological descriptions. As noted in the previous section, the palaeochannel has incised through the Late Cretaceous – Eocene Narnoo basin sediments.

Mineralisation is indicated in Figure 6 and discussed in Section 5.2.4. The primary ore zones are associated with ligneous and carbonaceous sediments which are near-coincident with the water table. Underlying the primary ore zone are saturated, interbedded sediments, with the coarser grained beds constituting aquifers.

5.2.3 MRUP Geology

The Mulga Rock deposits lies in a structurally controlled palaeovalley / palaeochannel, within the Narnoo basin, which contains fluvial, lacustrine and marine sediments that include sandstone, claystone, lignite and minor conglomerate, commonly occurring in graded beds (Rockwater, 2013). As shown in Figure 5, the palaeochannel has an eastern and western ‘arm’, with the latter potentially connected with the Lake Raeside and Lake Rebecca drainage systems.

The palaeochannel is incised through the Eocene to Late Cretaceous Narnoo basin sediments and has subsequently been infilled with Palaeogene/Neogene age sediments and covered by Quaternary sediments (GRC, 1984).

The MRUP has been subjected to continental conditions since the Cretaceous, and planation and sedimentation have continued under humid (Palaeogene/Eocene Epoch) and then arid (Neogene/Miocene Epoch) conditions.

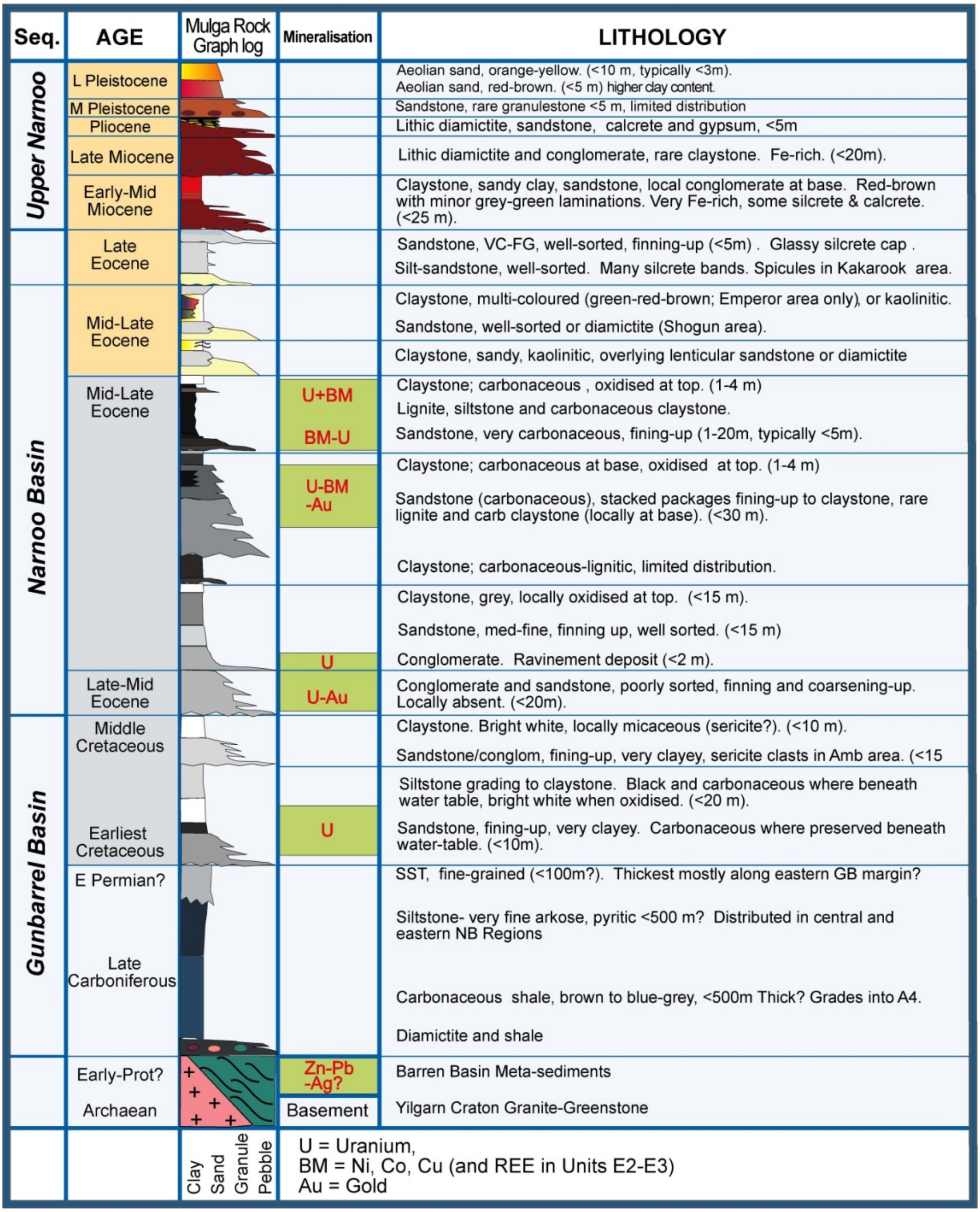

Figure 6 Simplified Mulga Rock Regional Stratigraphy

Source: Vimy

The sequence of Palaeogene/Neogene sediments within the palaeochannel are of fluviatile – lacustrine origin, deposited in a humid environment, with abundant vegetation (GRC, 1984). The sequence has been further subdivided:

- The upper part of the sequence (Miocene – Late Eocene) comprises sandstone and siltstone, with minor clay with a total thickness of 20 m to 30 m. The upper strata has been oxidised, silcretised and lateritised by weathering. Interpreted to be deposited under fluvial conditions, with interbedded lacustrine sediments.
- The middle part of the sequence (Eocene) comprises carbonaceous clay and lignite, with minor sandy interbeds, and generally ranges 5 m to 20 m, up to 50 m thick (GRC, 1984). The upper part of the unit is generally oxidised, forming white-light brown kaolinitic clay. Uranium mineralisation occurs mainly at the redox interface within this carbonaceous clay and peat sequence. Interpreted to be deposited under lacustrine to paludal conditions.
- The lower sandy section consists of basal sand and conglomerate approximately 2 m to 3 m thick overlain by approximately 40 m thick sands (commonly carbonaceous and pyritic and generally unconsolidated) interbedded with silt, clay and peaty clay. Interpreted to be deposited under fluviatile conditions.

Overlying the Palaeogene/Neogene sequence are Quaternary-age aeolian sands, varying from <1 m to a maximum of 20 m in thickness.

5.2.4 Mineralisation

A concept of the mineralisation of the ore body has been shown in Figure 7 and Figure 8, and mineralised zones within the stratigraphic sequence have been shown in Figure 6. A description of the formation of the ore body has been summarised in Section 7.1.6. The ores are confined to the ligneous (Eocene) sequences, with enrichment occurring generally within a 1 m to 2 m interval immediately below a sharp redox front with overlying clay (Douglas *et al.* 2011).

It is understood that the bulk of the ore targeted by Vimy occurs within the carbonaceous Eocene sediments, however uranium mineralisation also occurs within other parts of the sequence (refer Figure 7) within carbonaceous sandstones. The High Grade Ore has appreciably higher Total Carbon (C) contents (25.3%), compared to the Run of Mine (ROM) Ore, which in the ANSTO Minerals (2015) work varied from 6% to 21%, with an average of 11.2% (Soil Water Consultants 2015a). Tertiary (Eocene) to Late Cretaceous sediments may be targeted depending upon grades, otherwise these sequences tend to be either too deep, or too poor a grade to be economical.

These lignites comprise organic matter, clay, minor sand with some secondary gypsum and salt. The difference in uranium grades between lignite, silt, claystone and sandstone ore is primarily related to the concentration and nature of the organic matter. Lower disseminated uranium mineralisation seems associated with a matrix (made up primarily of detrohumite) enriched in sulphides, with higher grade typically associated with preserved woody tissue, spores, pollen, reflected in macerals analyses, as elevated liptinite and exinite fractions.

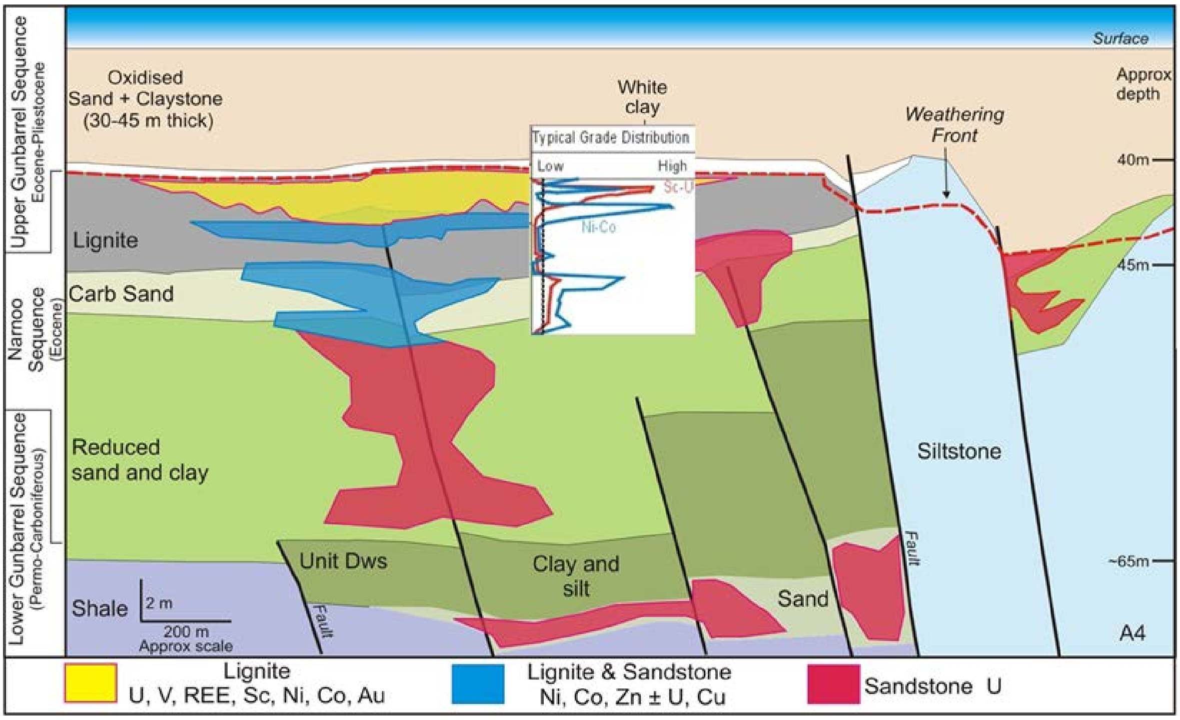

Figure 7 Conceptual Mineralisation Model

Source: Vimy

The geochemical data from the ore show a significant enrichment of economically valuable metals. This enrichment highlights the efficacy of the carbonaceous sediments acting as a trap for mineralisation (Soil Water Consultants 2015a). It is important to note that the carbonaceous material or PRB is extensively distributed within the Narnoo Basin palaeodrainage channel, and occurs downstream of the proposed MRUP (see also Section 6.8). A summary of the major constituents within the ore from the MRUP has been summarised in Table 4.

Table 4 Summary of MRUP Ore Constituents

Location	Aluminium	Total Carbon	Calcium	Copper	Nickel	Sulphide	Silica	Uranium[2]	Zinc
High Grade Ambassador Ore (MP2)	3.0	25.3	0.27	0.12	0.18	3.6	21.7	2070	0.18
Princess	2.6	6.5	0.017	0.11	0.057	0.77	38.1	604	0.20
Ambassador (East)	3.5	21.0	0.029	0.055	0.072	1.1	28.5	670	0.22
Ambassador (West)	5.0	6.0	0.031	0.18	0.018	0.15	35.7	628	0.006

Source: ANSTO (2015)

Note:

1. 1%wt = 10^5 mg/L

2. Uranium in ppm

3. Chloride content <1% (for all samples)

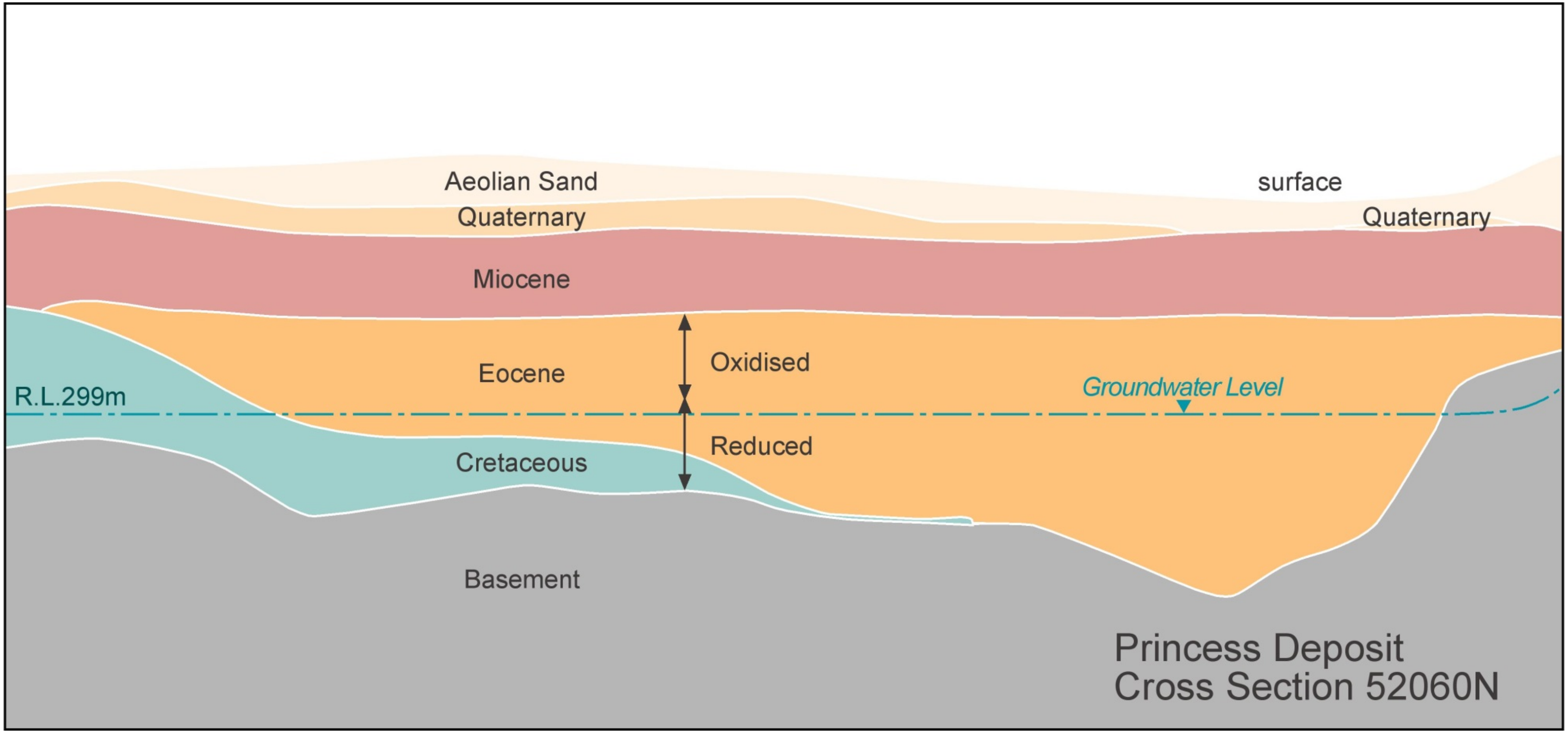

Figure 8 Princess Pit Interpretative Section

(Source : Vimy)

6. Hydrogeological Characterisation

6.1 Hydrogeology

6.1.1 Identified aquifers / aquitards

Interpretation of the aquifers present has been based on water intersections noted during drilling, and potentiometry (refer Section 6.3) and trial pit excavations.

Lithological logs of bore construction were documented by GRC (1986) and early reporting (e.g. GRC 1984, 1985 and 1986) focussed upon the thicker sand lenses within the Tertiary sequence. GRC (1986) reports drilling bores to 70 m depth (e.g. PNP 2557 / OF-1-1327) that did not make water.

The water levels in the Princess Pit region are is estimated to be between 296 mAHD and 298 m AHD (Rockwater, 2015), which suggests water levels are at depths of greater than 20 m below the surface. This suggests that the Quaternary and upper Tertiary (Miocene) sediments are largely unsaturated.

Groundwater may be present as isolated, perched systems where fine grained sediments create perching layers within the aeolian sediments or clays and sandstones. Whilst there are no shallow bores to confirm this, trial pit excavations were dry, confirming unsaturated conditions to the primary mineralised zone.

The mineralisation is primarily controlled physically by the geometry of the palaeodrainage and tributaries, and geochemically by redox and weathering processes, focused on a mostly tabular main weathering front. The water table and weathering front are generally coincident. First water intersections occur within the deeper portions of the Eocene sediments. The primary host sequences range from fluviatile at the base to lacustrine in the top Eocene sediments. The ligneous sediments which host the uranium mineralisation are therefore saturated. The lithology of these sediments, i.e. lignitic and ligneous clays and sands, suggest that they are not highly transmissive.

Underlying the primary zone of mineralisation, are interbedded sands, clays and silts. The coarser-grained beds may be transmissive and constitute aquifers. Exploration drilling and investigations for water supply have identified a coarse-grained basal sand sequence within the palaeochannel. These tend to form the main aquifers of a palaeovalley and lie in the deepest parts of the infill sequence. The fine-grained sediments may impart confinement to these deeper sands, however due to the nature of deposition with the channel, these bands will vary laterally, be discontinuous, and may not be extensive, either longitudinally or transversely to the palaeochannel drainage alignment.

Pumping tests are the preferred means of assessing nature of confinement. Pumping test investigations documented by GRC (1985) reported aquifer storativities for the deeper sand aquifer that were consistent with confined conditions.

The Carboniferous-Permian age sedimentary material forms the floor of the palaeochannel deposits. The relative permeability contrasts between the palaeochannel and the adjoining basement rocks, although subject to limited characterisation, is inferred to be such that groundwater would preferentially migrate through the transmissive sediments of the palaeochannel. This is discussed further in Section 6.6.

6.1.2 Distribution of the Palaeochannel

The MRUP resource occurs in sequence of layered sediments in a palaeochannel of significant lateral extent, representing an extension of the Lake Raeside palaeodrainage. The eastern portion of the MRUP is hosted by a tributary to the main palaeochannel, referred to further as the Ambassador tributary.

The extent of the palaeochannel has been shown in Figure 10 which has been interpreted from exploration drilling. The palaeochannel has two branches or arms:

- A west arm which extends southwards from the Emperor and Shogun deposits; and
- An east arm which extends southwards from the Ambassador deposit.

Nearest to Ambassador, the channel is estimated to be 6 km wide, and extending to a depth of 95 m (Rockwater, 2013). A number of faults have also been interpreted based on drilling and geophysics (Rockwater, 2013). GRC (1984) described the sides of the palaeochannel to be very abrupt in places and probably fault-controlled.

6.1.3 Lithology

A simplified lithological profile was developed by Rockwater (2013) as part of the development of a numerical groundwater model to support dewatering investigations was based on Bore 7 (GRC, 1985). The borehole lithological log has been summarised in Table 5.

Table 5 Simplified Lithology for Princess and Ambassador Deposits

<table>
<tr><th colspan="2">Depth below Surface (m)</th><th rowspan="2">Description</th><th rowspan="2">Water level</th><th rowspan="2">Oxidation State</th><th rowspan="2">Ore Zone</th><th rowspan="2">Organic Content</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td>0</td><td>2</td><td>SAND</td><td rowspan="6">Unsaturated</td><td rowspan="6">Oxidised</td><td rowspan="6"></td><td rowspan="6"></td></tr>
<tr><td>2</td><td>10</td><td>Clayey SAND</td></tr>
<tr><td>10</td><td>14</td><td>SAND</td></tr>
<tr><td>14</td><td>24</td><td>SILCRETE</td></tr>
<tr><td>24</td><td>29</td><td>SAND, with SILCRETE bands</td></tr>
<tr><td>29</td><td>33</td><td>CLAY</td></tr>
<tr><td>33</td><td>37</td><td>PEAT</td><td>Saturated</td><td>Reduced</td><td>Ore Zone</td><td>10% to 50%</td></tr>
<tr><td>37</td><td>43</td><td>Interbedded clay, lignite and sand</td><td rowspan="3">Saturated</td><td rowspan="4">Reduced</td><td>Ore Zone</td><td rowspan="3">2% to 10%</td></tr>
<tr><td>43</td><td>55</td><td>SAND; coarse</td><td rowspan="3"></td></tr>
<tr><td>55</td><td>65</td><td>SAND with interbedded CLAY</td></tr>
<tr><td>65</td><td>100</td><td>SAND, with variable CLAY</td><td></td><td>0% to 2%</td></tr>
</table>

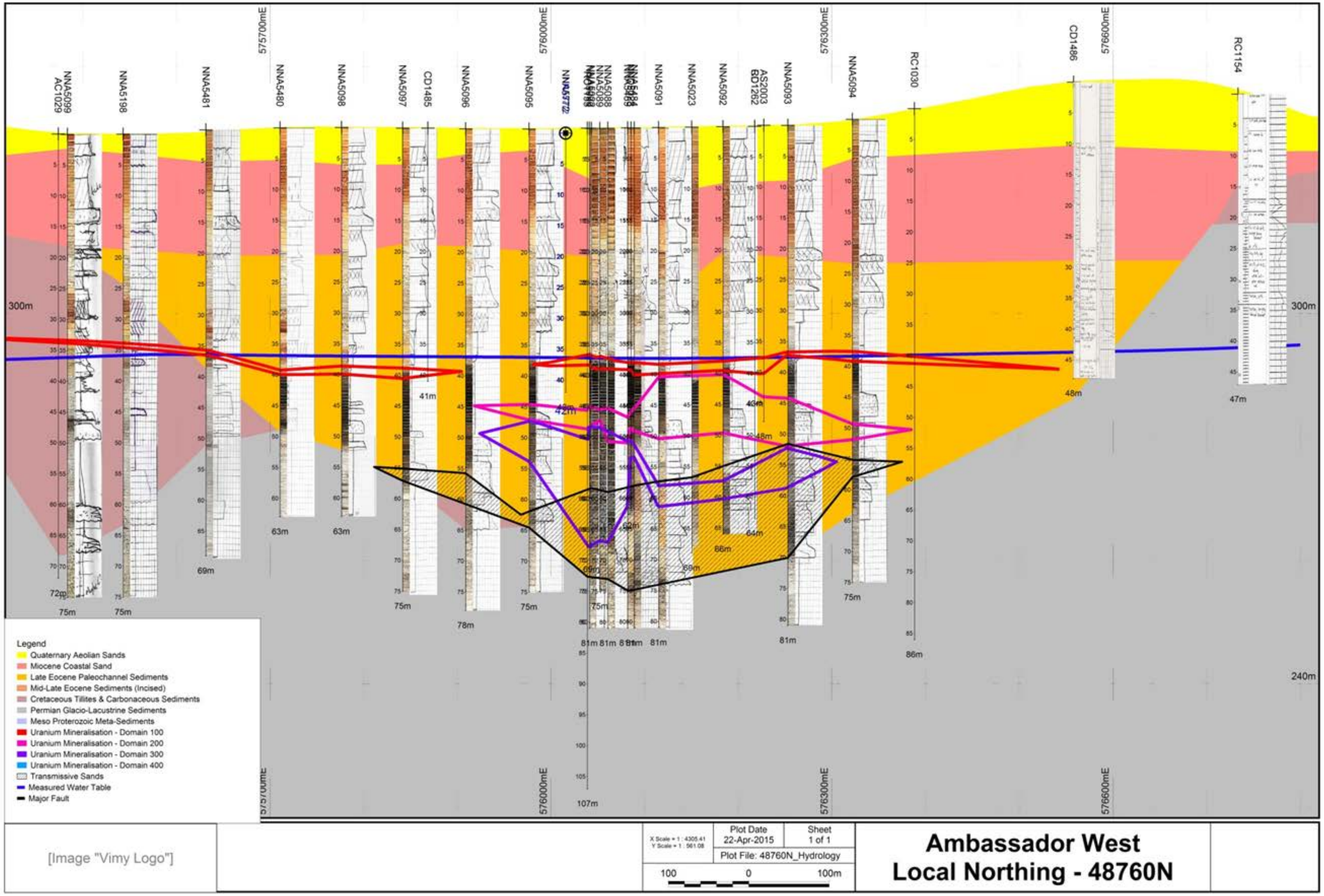

Figure 9 Cross section of the Ambassador West deposit with mineralisation zones

(Source: Vimy)

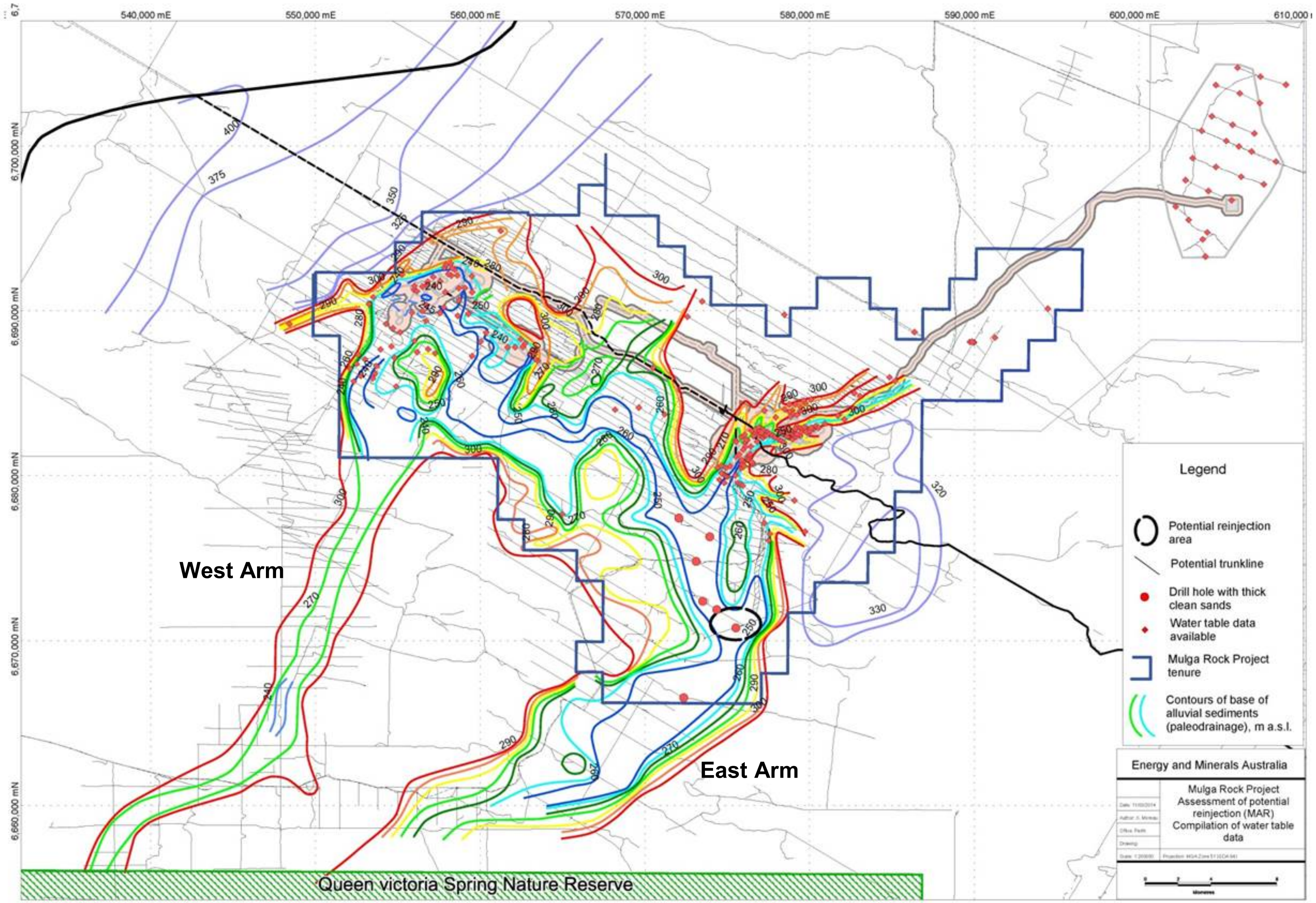

Figure 10 Mapped Extent of Palaeochannel

(Source: Vimy)

6.2 Monitoring Bore Network

Vimy has established a groundwater monitoring bore network over the mine lease. The network has evolved from a series of groundwater investigation phases completed by various parties throughout the exploration and development of the deposit. The groundwater monitoring network (and characterisation) is perhaps best developed around the abstraction borefield (for ore processing).

The groundwater monitoring network is used by Vimy to characterise groundwater quality and potentiometery. Groundwater bore locations are shown in Figure 11.

Water level data were reviewed from 129 locations in the vicinity of Princess and Ambassador Pits. Depth of bores generally ranged from 27 m to 65 m below ground level. The majority of these locations correspond to previous exploration drillholes, and thus do not correspond to constructed bores. Location details are presented in Figure 11.

A review of the monitoring bore construction notes the following:

- Limited information was available regarding monitoring bore construction details (none in the area of interest being Princess and Ambassador deposits, given monitoring locations were predominantly installed for mineral exploration purposes).
- Some early bore construction did not include annular seals, based on logs documented by GRC (1985).
- More recent bore construction, e.g. injection borefield, have bores which do not incorporate annular seals.

It is noted that some bores did not include annular seals and therefore the construction of some bores may not be consistent with the NUDLC (2012) minimum requirements (or earlier additions of these guidelines). Where the construction of monitoring bores is unknown, a number of issues are created:

- Water samples obtained from bores may not represent discrete aquifers, but rather a mixture of waters throughout the saturated profile (screened interval). Note that specific water sampling was incorporated into exploration drilling program (refer Section 6.4.1).
- Potentiometry from the bores is also a combination of the aquifers intersected by the bore.
- The unsealed bores, or bores with large screens may enable mixing between aquifers.
- Characterisation of confinement within a stacked sedimentary sequence becomes problematic.

Whilst there are a number of short comings in parts of the bore network, the bore data consistently identify deep groundwater levels across the MRUP, and confirm the relationship between mineralisation and the regional water table within the palaeochannel.

Furthermore, the use of the exploration boreholes enables a broader understanding of water levels spatially within the palaeochannel across the MRUP. It is therefore concluded that whilst there are uncertainties with the bore construction, they provide a reasonable basis upon which to make hydrogeological interpretations.

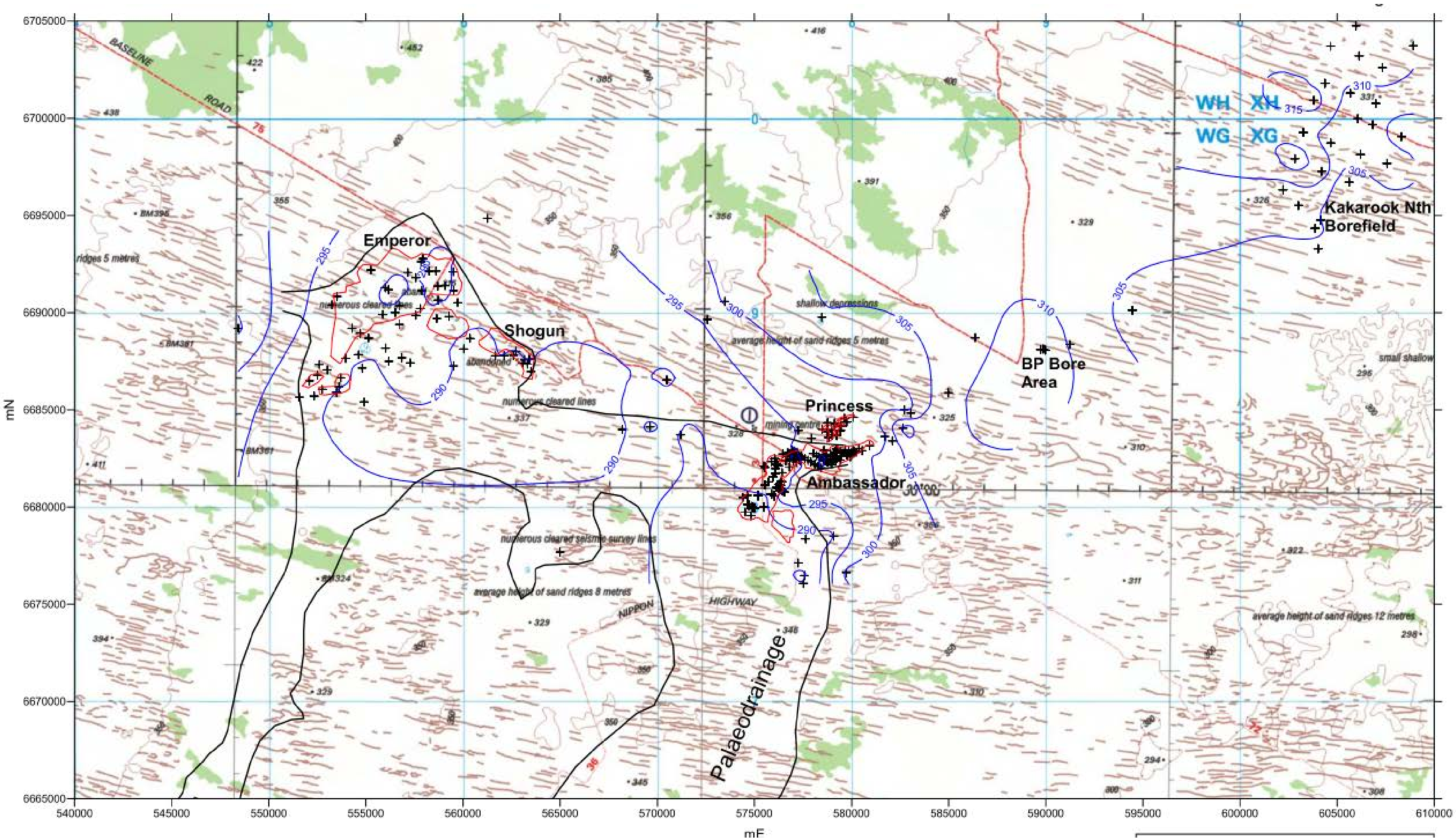

Figure 11 Vimy Groundwater Monitoring Network

(Source: Rockwater 2015b)

6.3 Water Level Mapping and Flow Directions

6.3.1 General information

To aid interpretation of the groundwater potentiometry, GHD undertook an assessment of the water level monitoring information. This included:

- Review of monitoring bore construction;
- Compilation of water level monitoring statistics;
- Preparation of monitoring bore hydrographs; and
- Inspection of monitoring bore hydrographs.

A number of monitoring bores had anomalous monitoring responses and these were not included in the water level assessment. Anomalies included:

- Stepped water level response - this could potentially be a result of alterations made to monitoring datum levels;
- Erroneous readings – several metres variation from the long-term trend;
- Anomalous behaviour - recovery or sudden rising responses possibly the result of recording levels during pumping and sampling.

In general terms, the water levels in most bores were relatively flat-lying with negligible seasonal variation and this is the expected response given the climatic conditions (low rainfall and high evaporation), deep water levels, and lack of existing abstraction.

Water level characterisation is predominantly biased to the palaeochannel, which has been the focus of the mineral exploration activities. It is acknowledged that there is limited water level information in the basement geology, or towards the flanks of the palaeochannel. Interpretation of interaction between the basement rocks and palaeochannel is therefore problematic, however permeability contrasts between these systems suggests that flow within the palaeochannel would be predominantly consistent with its thalweg.

6.3.2 Regional Potentiometery

Previous Interpretations

A review of previous reporting on water table interpretations has been summarised in Table 6.

Table 6 Groundwater Depths

Deposit	Description
Ambassador / Princess	Groundwater level data were interrogated to obtain an estimated of the depth of the water table at the Ambassador and Princess deposits. For the Ambassador deposit area, water level data were available from 01/05/1984 to 12/04/2014 for 194 bores; over this period water levels ranged from 1.42 m (erroneous reading in blocked PVC) to 63.70 m. Following filtering and validation of data, an average depth of the standing water level from surface of 37.65 m was determined across this region of the MRUP. For the Princess deposit area, water level data were available from 12/01/2012 to 11/11/2013 for 54 bores. Over this period water levels ranged from 28.61 m to 57 m with an average depth of 42.4 m. Groundwater flow directions reflect the alignment of the palaeochannel, i.e. southwards flow direction.

Deposit	Description
Emperor / Shogun	For the Emperor Deposit area, water level data were available from 15/11/1983 to 13/02/2012 for 64 bores. Over this period, water levels ranged from 13.05 m to 60.5 m. Validated water level data produced an average depth of 31.25 m. For the Shogun deposit area water level data were available from 1/05/1984 to 18/02/2012 for 12 bores, and over this monitoring period water levels ranged from 25.73 m to 36 m with an average of 30.7 m. Flow directions are interpreted to be towards the southeast.

Source: Rockwater (2013a)

GHD Interpretation

Groundwater level data provided by Vimy were analysed to characterise the water levels at each deposit. The following assessment has bulked all water level information within the palaeochannel as a single unconfined aquifer system, i.e. the permeable lenses within the palaeochannel act as a single, inteconnected unit. The nature of confinement of the deeper permeable lenses within the palaeochannel is not known.

GHD used April 2013 (largest data set available) water level data as a snapshot event and average water levels (after removing anomalous and erroneous data) to produce groundwater elevation contours for the assessment of groundwater flow. Average water levels were also used to construct hydrographs to assess the spatial water level variability and assess the presence of any seasonal effects.

Little variability was observed between the April 2013 and averaged groundwater elevation contours. In addition, discounting anomalous data, little variability over time is evident in the hydrographs thus supporting the use of an averaged data approach.

Groundwater contours indicate a general south westerly flow direction across Princess and Ambassador Pits at a gradient of approximately 0.002. This assessment is consistent with that reported by Rockwater (2013).

At a broader scale, incorporating the Emperor and Shogun deposits to the west, groundwater within the palaeochannel appears to flow from the east across these deposits and converge with the south-westerly flow across Princess and Ambassador deposits. This is considered a slight misrepresentation based on contouring and a lack of water level data to the south which would otherwise indicate the converging of groundwater from the west and east and continuing south consistent with the meandering of the palaeochannel.

Other Aquifers

As noted previously, characterisation of water levels in the margins of the palaeochannel and bedrock is problematic as there are no bores. These areas are expected to have deep water levels, and be subject to low hydraulic gradients based on conditions within the palaeochannel and low groundwater recharge rates from significant rainfall events. Interaction between the palaeochannel and the abutting bedrock could occur, however the finer grainsize (lateral facies changes) towards the margins of the palaeochannel are likely to restrict this, with flow occurring preferentially along the coarse grained sediments within the main channel axis.

6.3.3 Groundwater Recharge

Groundwater is principally recharged by infiltrating rainfall. Infiltration rates are expected to be extremely low, given the low annual rainfall rates, high evaporation, and deep unsaturated overlying sedimentary profile. Recharge would be event based, i.e. major rainfall events resulting in ponding of water in lower lying topographies that would allow infiltration over time.

Interpretation of groundwater level across the MRUP does not indicate any obvious recharge areas, i.e. shallow water tables / mounding of water tables, and there is no expression of groundwater levels at, or near, the surface.

The influence of faults on groundwater recharge is not known, and likely to be very minimal given the long-lived nature of the recharge and minimal impact from major rainfall events (Rockwater 2015b).

6.3.4 Groundwater Discharge

Groundwater flow is interpreted to be consistent with the drainage systems of the palaeochannels:

- East to south east in the Emperor and Shogun deposits
- South westerly in the Princess and Ambassador deposits

6.3.5 Influence of Geological Structure on groundwater flow

The orebody and palaeochannel have multiple mapped faults. The influence of faults on regional groundwater flow is not yet well understood. Some mounding and pooling is noted in contour maps and may represent the influence of lower permeability in clay-filled faults, however this cannot be confirmed using the current data set. There is also likely to be some compartmentalisation of the groundwater system, which will likely influence the flow and transport of solutes along the palaeochannel.

The combination of drilling and airborne EM data supports the segregation of shallow saline aquifer from the hypersaline brine present at the base of the palaeochannel (Figure 12 and Figure 13). This diverted flow and layering of groundwaters by salinity will force tailings leachate from the proposed Princess TSF through organic-matter rich sediments characterised by elevated cation exchange capacity (CEC) (refer Figure 14).

Pumping test investigations with monitoring bores on either side of the mapped faults have not been undertaken and therefore the direct influence of faults cannot be confirmed. It is unlikely that faults present a significant barrier or conduit to groundwater flow. It is important to reiterate that this study is primarily focused on the solute fate within water column and that the intricacies of groundwater flow are not captured (i.e. PHREEQC is 1D and assumes relative homogeneity).

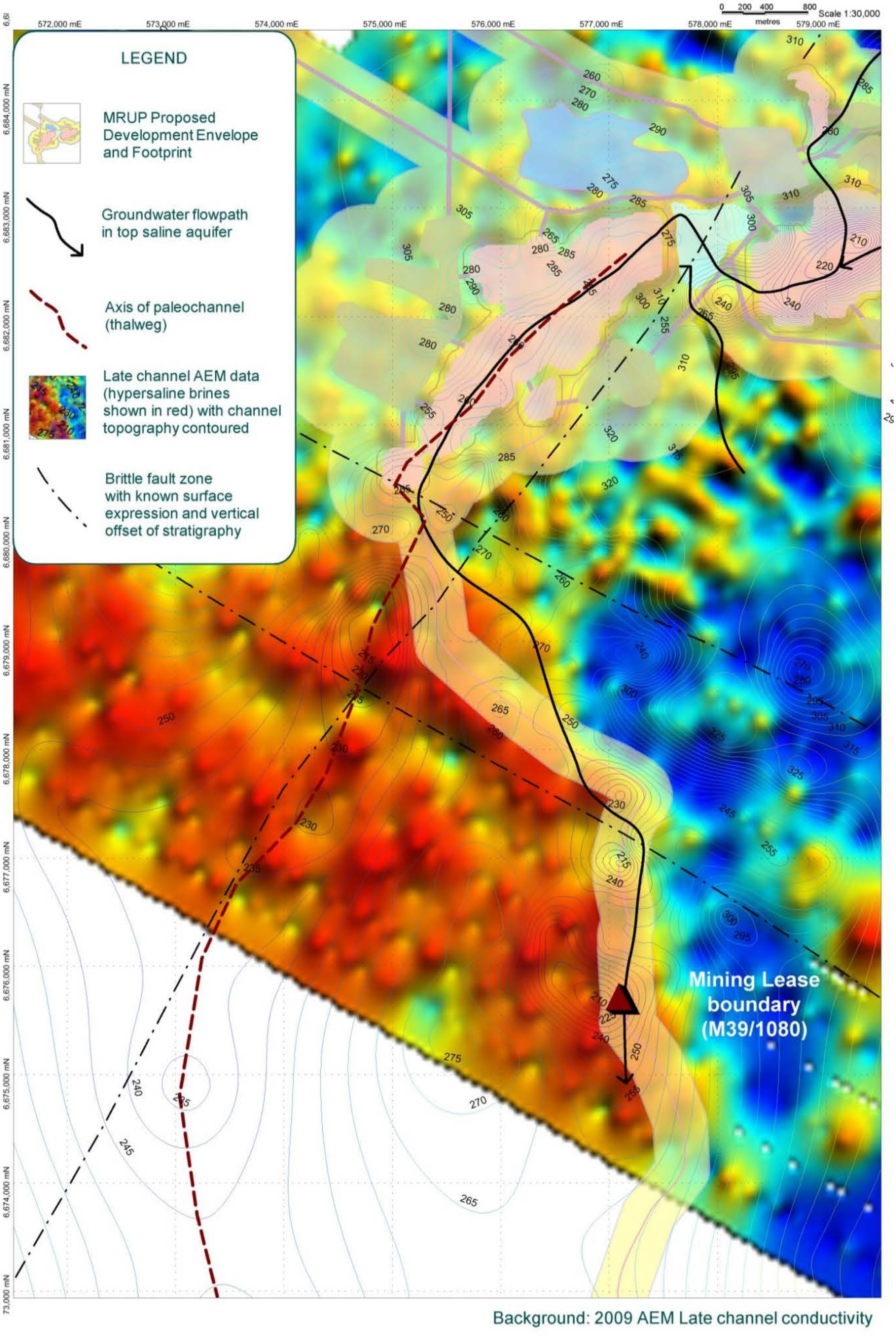

Figure 12 Distribution of basal palaeochannel hypersaline brine and palaeochannel axis

(Source: Vimy)

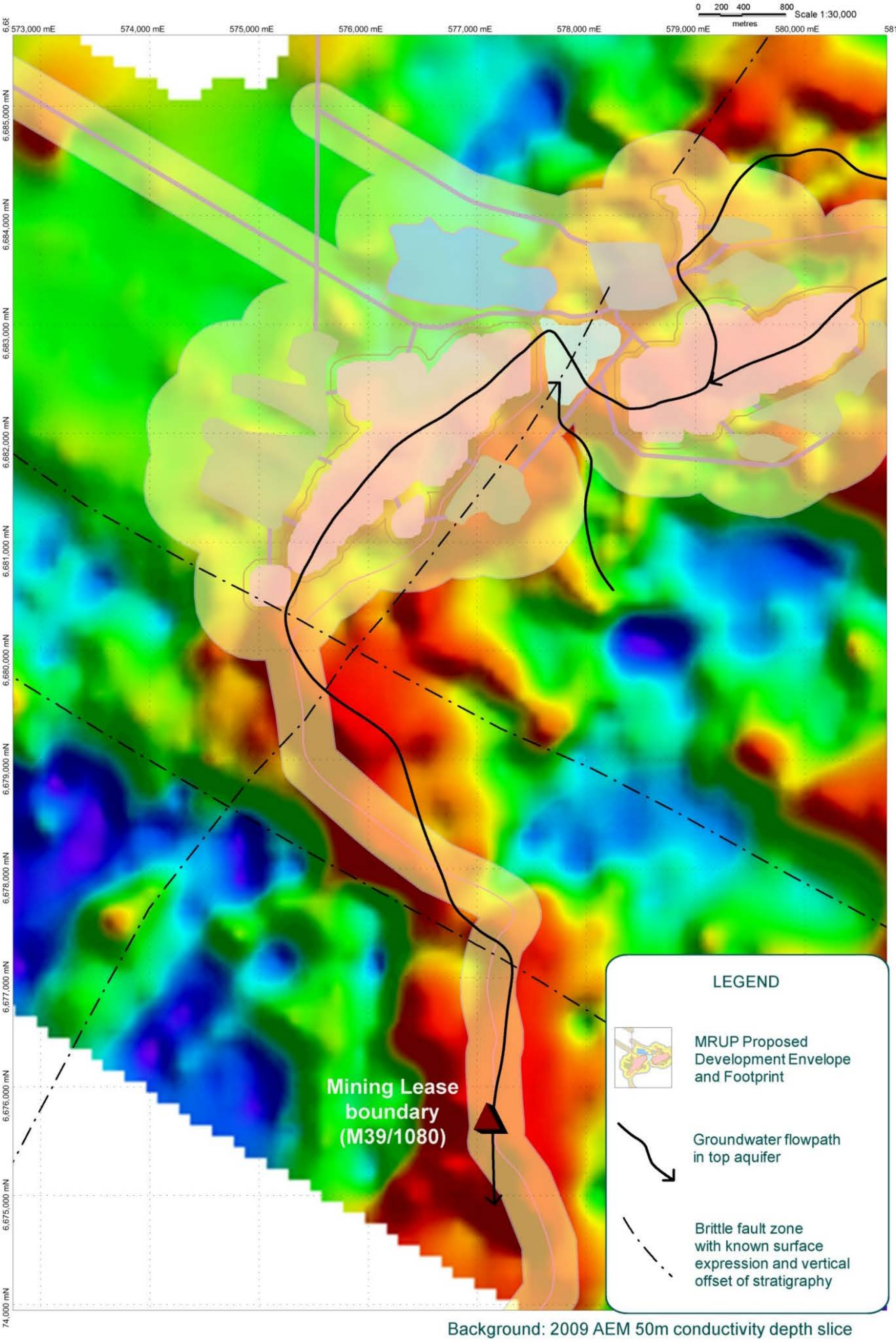

Figure 13 Interpreted groundwater flow path in upper aquifer

(Source: Vimy)

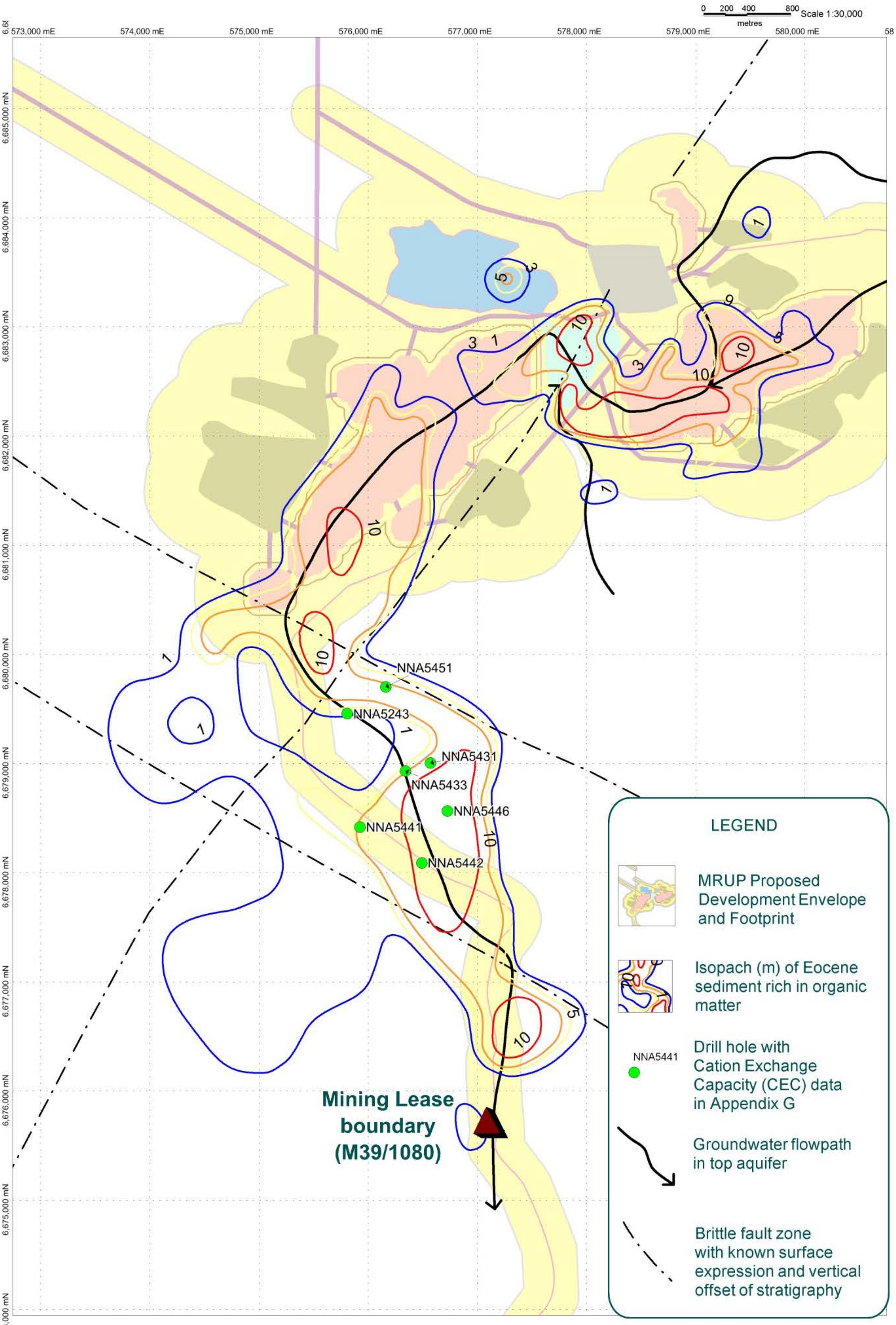

Figure 14 Upper aquifer flow path and organic matter rich sediments

(Source: Vimy)

6.4 Background Hydrogeochemistry

6.4.1 Groundwater Sampling Methods

Vimy advises that current groundwater sampling techniques are consistent with the standard industry guides (Sundaram *et al*., 2009). It is understood that a variety of sampling methods have been applied across the monitoring record (i.e. 1985 through to the present) which have included air-lifting, pumped sampling and low-flow sampling methods.

Whilst a small proportion of the historical sampling records reviewed by GHD had QA/QC discrepancies, a significant volume of water quality data has been obtained from the palaeochannel. Water quality information in the dataset reviewed included data obtained from the exploration drilling program. It is understood that groundwater sampling was undertaken progressively in exploration boreholes, i.e. drilling was halted, sampling occurred, and then drilling progressed to a deeper interval. Under these conditions the dataset contains large numbers of analysis in both a spatial and vertical sense throughout the palaeochannel, however repeat samples over multiple time periods are only available at selected monitoring bores.

It was noted that Oxidation Reduction Potential (ORP) readings are highly variable throughout the lease, the majority of which were measured on samples obtained via airlifting, which can result in significant elevation of ORP values. This is suspected to be a reflection of the difficulties in obtaining ORP in boreholes disturbed via drilling progresses, e.g. air core / rotary air drilling, air-lift sampling methods (consistent of sampling methods and field measurement) and other sampling QA/QC issues. Due to the deep water table and narrow diameter of a number of bores, Vimy has advised that conventional low-flow pumping or bailing have not been effective options. Some filtering of the data was undertaken by GHD to remove outliers / anomalous values, prior to it being used in the geochemical modelling.

Whilst it is acknowledged that some filtering or date validation of the water quality data was required, these data deficiencies are not considered to alter the understanding that the groundwater quality does not vary greatly over short distances.

6.4.2 Historical Sampling

A summary of historical groundwater sampling has been summarised in Table 7.

Table 7 Historical Groundwater Quality Characterisation

Period	Summary
1984-1991	• Salinity 7,500 mg/L to 37,600 mg/L, – Tendency to increase spatially to the southwest in the direction of groundwater flow; – Tendency to increase with depth (density stratification); • pH 4.3 to 7; • NaCl type groundwater with elevated Mg and SO4; • Generally low metals/halides excepting: – iron up to 16 mg/L – bromine up to 23 mg/L • Oxidation potential ranging -167 mV to 335 mV. The wide range in historical ORP data is consider to reflect sampling methodologies and discrepancies, as discussed in Section 6.4.1.

Period	Summary
2010-2015	• Salinity 8,000 mg/L to 80,000 mg/L, within Princess and Ambassador deposits salinities ranged from 20,000 mg/L to 35,000 mg/L TDS • pH 2.6 to 8; • Generally low metals/halides (below detection including uranium) excepting: – iron up to 56 mg/L – bromine up to 23 mg/L – boron up to 8 mg/L – strontium up to 12 mg/L

Source: Rockwater (2013a and Appendix F)

6.4.3 Summary Statistics

Physicochemical parameters concentrations

A summary of the salinity and pH data from the Ambassador and Princes Pits is proved in the Table 8.

Table 8 Summary of physiochemical parameters at MRUP

Area	Parameter	pH (pH units)	TDS (mg/L)	EC range (µS/cm)
Ambassador	Range	3.5 to 8.0	720 to 38,144	16,800 to 62,100
	Average	6.33	20,468	34,521
Princess Pit	Range	2.9 to 7.1	8,740 to 64,572	16,996 to 42,751
	Average	5.32	19,578	35,978

Copper, Cobalt, Zinc and Uranium concentrations

Based on a review of the process water leachability results (ANSTO, 2015), the metals and metalloids that show the appreciable availability and mobility in the aqueous environment, and thus are of primary concern in this study include, include copper, cobalt, uranium and zinc. Cobalt, copper, zinc and uranium concentration data is available on limited drill holes/monitoring bores at Ambassador East/West only, however a summary has been provided in Table 9.

Table 9 Summary of Selected Metal Background concentrations

Area	Parameter	Cobalt (µg/L)	Copper (mg/L)	Zinc (µg/L)	Uranium (µg/L)
		N = 16	N = 10	N = 20	N= 12
Ambassador	Range	0.005 to 3.96	0.005 to 1.904	0.005 – 12.89	0.009 - 68
	Average	0.61	0.27	1.89	17.75
Princess Pit		No data available	No data available	No data available	No data available

Notes:

1. N = number of samples
2. No copper data were available for any bores near the Ambassador and Princess Pit in the raw monitoring data provided by Vimy. Copper data has been included based on monitoring results presented in Rockwater (2013a)
3. The uranium concentration compares with a value of 8 ± 13 µg/L published in Douglas *et al.* (1996).

The groundwater in the main palaeochannel is hypersaline, of sodium chloride type with moderately high magnesium and sulphate concentrations. Piper trilinear diagram analysis indicates that the proportions of the major ions are similar to seawater.

Iron and minor elements and metals throughout the channel and tributaries are generally at low concentrations, increasing with decreasing pH (for cadmium, copper, lead, ± cobalt, nickel, uranium). The iron concentration appears to be strongly Eh dependent, with peak concentrations for Eh between 125 mV to 175 mV, present in the main palaeochannel. The CSIRO (Douglas *et al.*, 1996) also documented that all MRUP groundwaters are reduced relative to other palaeochannel aquifers from the Yilgarn, with most of the samples at or below the Eh required for the reduction of iron oxides/hydroxides (Figure 15).

As a result of the high organic matter concentration in the tributaries, the radionuclide concentrations in groundwaters in the main palaeochannel are quite low, considering their enrichment in the host sediments. Concentrations of radium in both the palaeochannel and the Ambassador tributary show a much greater range than that of uranium or thorium, consistent with elevated barium concentrations. All waters in the main palaeochannel appear to be in equilibrium with barite although some water samples in the mineralised zone at Ambassador showed oversaturation with a solubility index for barite often in excess of 0, pointing to possible localised precipitation (Douglas *et al.*, 1996).

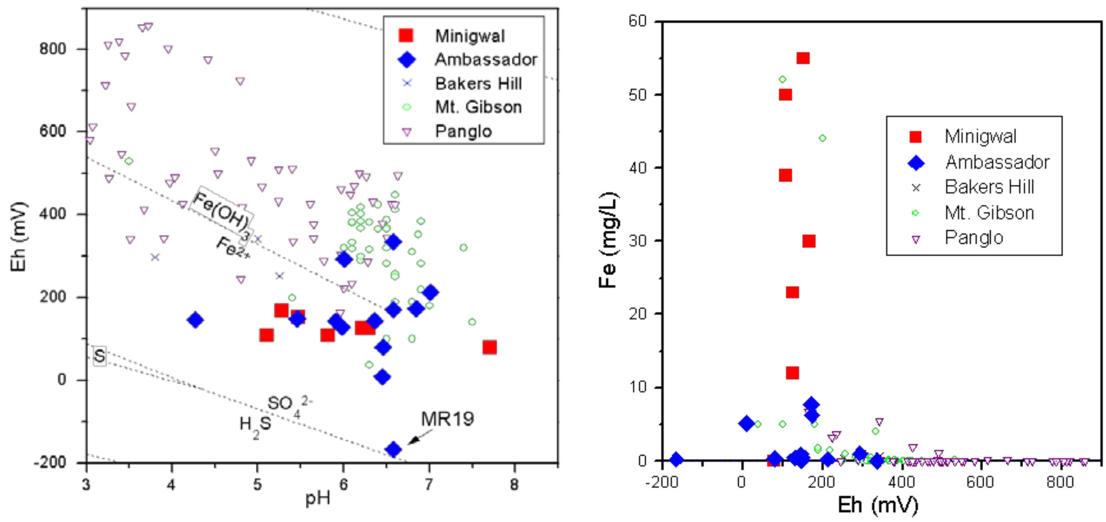

Figure 15 Eh/pH and Iron vs. Eh for groundwaters in the MRUP - Main palaeochannel referred to as Minigwal

(data from Douglas *et al.* 1996)

6.4.4 Salinity Variation with Depth

There is a general tendency for groundwater salinity to increase with depth at the MRUP. This is considered reasonable based on:

- Deeper groundwater likely to have greater disconnection from the rainfall recharge
- Greater opportunity for interaction with the saline waters within the bedrock aquifers.

The groundwater salinity has important implications both on the mineralisation and on migration of leachate. To confirm this, groundwater samples were plotted against depth to determine if an obvious relationship could be identified. Bore construction was unknown, therefore the total bore depth was applied (on the assumption that some pre-collaring would be incorporated in the borehole, or the screen interval was towards the base of the bore.

The salinity depth relationships are shown in Figure 16 and Figure 17 for TDS. The ASLP leachate indicated in Figure 16 represents that salinity of the processing water.

No apparent trend of salinity with increasing depth was observed at the Princess Pit. Conductivities generally range between 29,000 µS/cm and 41,000 µS/cm.

Salinities at Ambassador show a possible, yet not consistent, trend of increasing salinity with depth. Confirmation of the salinity stratification within the palaeochannel could, in future, be determined from geophysical investigations.

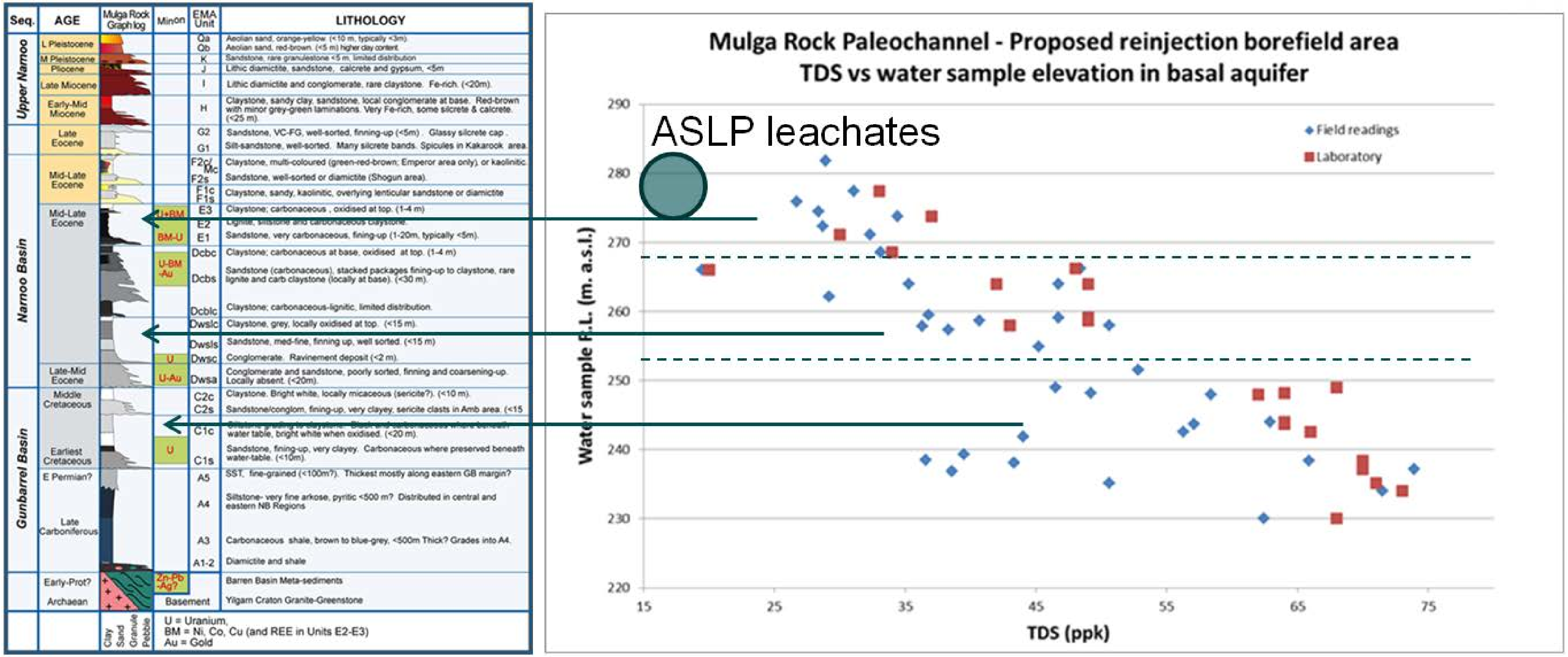

Figure 16 Salinity (TDS) versus depth downstream from Ambassador

Source: Vimy 2015

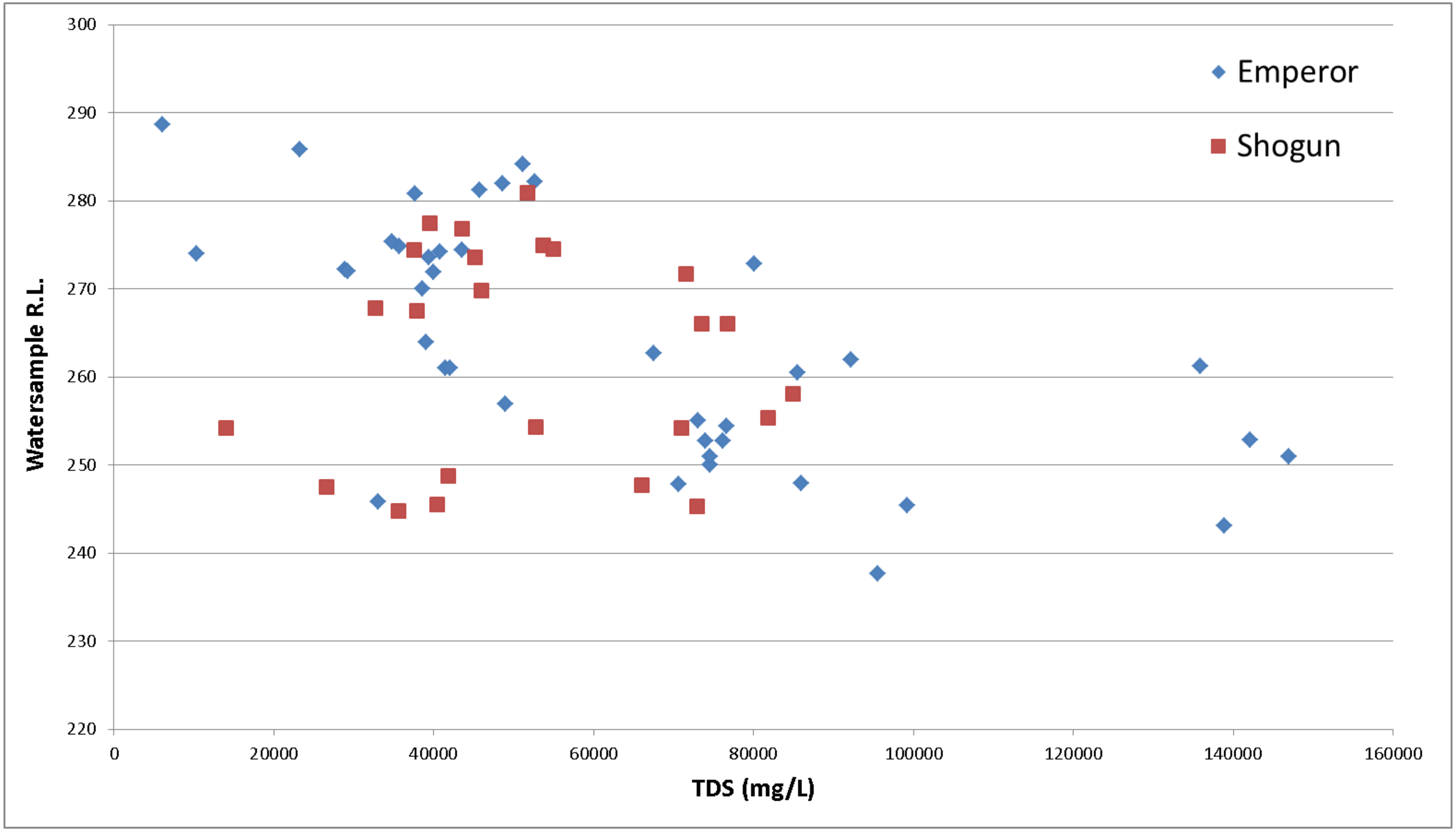

Figure 17 Salinity (TDS) versus depth downstream from Emperor and Shogun

Source: Vimy

6.4.5 Kakarook Borefield

The Kakarook borefield has been previously characterised (Rockwater, 2013a), and is to provide water for ore processing. Therefore, its water quality will influence indirectly the quality of the tailings liquor. The groundwater salinity ranges between 3,950 mg/L TDS and 8,070 mg/L and is less saline than groundwater at either the Princess of Ambassador Pits.

6.5 Aquifer Hydraulic Parameters.

6.5.1 Pumping Test Investigations

Pumping tests have been undertaken as part of previous investigations to identify a process water supply and therefore targeted the thicker, more permeable beds within the palaeochannel alluvial sequence. A summary of testing completed by GRC (1985) has been provided in Table 10.

Table 10 Summary of Constant - Discharge Test Results from MRUP

Element	GRC Bore Identification					
	1	2	3	4	6	7
Location	Ambassador	Ambassador	Shogun	Emperor	Emperor	Ambassador
Test Duration (hrs)	8	1	4	8	24	24
Discharge Rate (m^3/day)	240	25	290	110	980	1045
Final drawdown (m)	3	2	1.2	13.6	7.2	1.9
Screened Thickness (m)	3	3	3	4.5	12	24
Screened Lithology	-	-	-	-	Medium and coarse sands (basal sequence above Permian)	Medium and coarse sands
Aquifer Interval (m)	71-73	71-74.5	64-75	45.5-71	56-70.5	65-97.5
Transmissivity (m^2/day)	50	15	125	15	450	210
Hydraulic Conductivity (m/day)	16.5	5	41.5	3.5	37.5	9

Source: GRC (1985)

Note: Location approximate only.

A pumping test was also undertaken on bore 5 (Shogun area) which was specifically undertaken to assess the likelihood of leakage of confined groundwater into the future Shogun mine pit. At this location, shallow and deep monitoring bores were located 10 m and 50 m from the pumping bore 5. GRC (1985) reported a transmissivity of 2.5 m^2/day and storativity of 2.5×10^{-4} which highlights the variability in the alluvial aquifer system when compared to the estimates in Table 10. The analytical results should, however be treated with some caution as:

- Non-constant pumping conditions were applied during the test.
- Observation bores had greater penetration than the pumping bore (it is not known whether partial penetration effects were considered)

- GRC (1985) report two differing screen intervals for Bore 5:
  - screened carbonaceous sands directly underlying the carbonaceous peats (primary ore zone), between 44.2 m and 46.2 m (Table 1)[4]
  - screened 44.2 m to 62.2 m, which would include additional lenses of sands, sandy clays and carbonaceous sands (Table 5).

6.5.2 Other Sources

Parameters Used in Numerical Modelling

The specific yield of the lignite is not known. Rockwater (2013) assumed a value of 0.05 for numerical modelling purposes. Rockwater (2013) prepared a four-layer numerical model to support assessment of the dewatering requirements for the MRUP. The aquifer hydraulic parameters adopted by the numerical model are summarised in Table 11.

Table 11 Rockwater (2013) Adopted Aquifer Parameters

Parameter	Layer 1	Layer 2	Layer 3	Layer 4
Represented Lithology	Lignite	Thin Sand (Sandstone) underlying lignite	Interbedded sand and clay	Sands (thick)
Horizontal hydraulic conductivity (m/d)	0.1	8.8	1	9
Vertical hydraulic conductivity (m/d)	0.01	0.4	0.02	1
Storage Coefficient	-	0.0002	0.0002	0.0002
Specific Yield	0.05	0.2	0.1	0.2

Source: Rockwater (2015)

Particle Size Distribution

Data were not available.

Slug Tests

Vimy has undertaken slug (falling head) permeability tests on monitoring bores in the Princess and Ambassador areas (Rockwater 2015b). The bores were interpreted as developing the main zone of mineralisation near the redox interface, i.e. the lignitic materials (Layer 1 or the groundwater model) or sediments directly underlying these materials (Layer 2). Hydraulic conductivities were reported to range from very low (assumed to be <0.01 m/day) to over 5 m/day. The average hydraulic conductivity was 0.1 m/day.

6.5.3 Discussion

Some additional inferences can also be made based on the lithological description of the various sedimentary sequences, and published hydraulic conductivities have been summarised in Table 12.

[4] It is suspected that Table 1 of GRC (1985) is incorrect. To assess leakage, it is common practise to adopt similar aquifer intersections between the pumping bore, and observation bores.

Table 12 Published Hydraulic Conductivities

Material (unconsolidated)	Hydraulic Conductivity (m/day)	
	From	To
Marine clay	7×10^{-08}	2×10^{-04}
Clay	9×10^{-09}	4×10^{-04}
Clay, homogenous, below zone of weathering	9×10^{-07}	9×10^{-05}
Silt (loess)	9×10^{-05}	1.7
Very fine sands, organic and inorganic silts, mixtures of sands, silts and clay, stratified clays, till	9×10^{-05}	0.9
Sand (fine)	0.02	20
Sand (medium)	0.07	45
Sand (coarse)	0.07	500
Clean sands, sands and gravel mixtures	0.8	900
Gravel	25	2500
Till	7×10^{-07}	0.2

Source: Domenico & Schwartz (1998) and AS1726-1981

6.6 Conceptual Site Model (Princess Pit TSF)

The conceptual hydrogeological model focuses upon the sedimentary sequences infilling the palaeochannel as these contain the aquifers relevant to the impact assessment. The understanding of the hydraulic properties and behaviour external to the palaeochannel is poor, which is largely a reflection of the focus of the mineral exploration activities.

Representing ancestral river systems, the Palaeogene/Neogene sediments have been deposited in valleys carved in the older bedrock, depositing variable mixtures of sands, silts and clays. The basal sequences tend to be coarser-grained (more transmissive) with upwards fining. The beds are of varying thicknesses and lateral extent as a result of the sedimentary processes that created them.

In areas where the clay and fine-grained beds are laterally extensive, they may confine the underlying aquifers. In other areas where the fine-grained beds are discontinuous or thin, leakage between the various layers within the profile may occur; however, density stratification will likely limit this leakage to deep, more transmissive layers.

The flow of groundwater through an old braided river bed can often be unpredictable due to complex channels and bars (braids) that are formed during deposition. The complex channels that are formed are also highly variable and very difficult to characterise with borehole data (refer Figure 18).

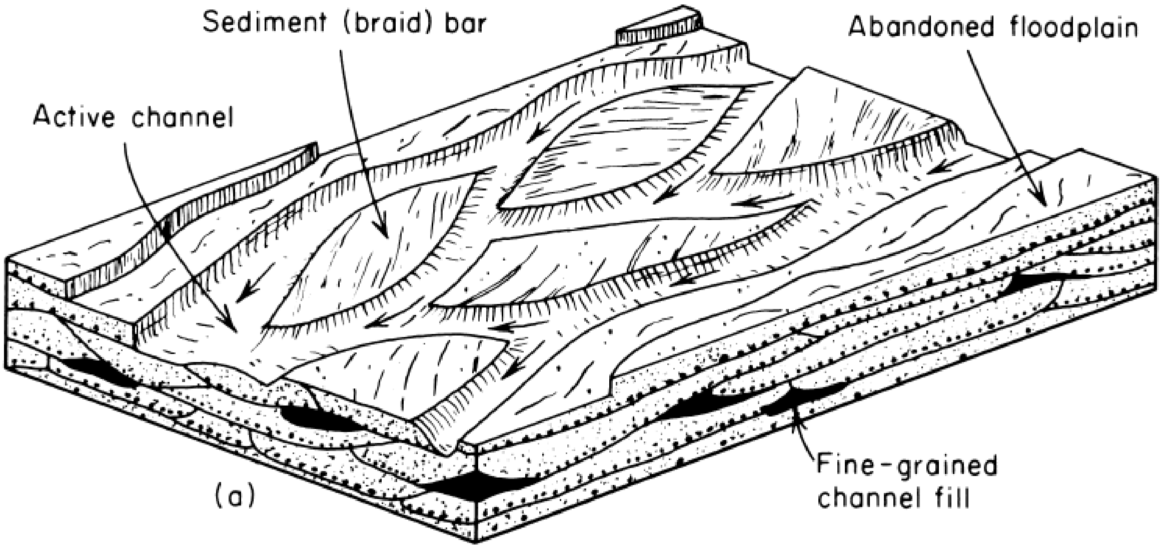

Figure 18 Sedimentary facies within a Palaeochannel

Source: Freeze & Cherry (1979)

A conceptualised schematic of the Ambassador (East and West) and Princess deposits (and TSF) is provided in Figure 19. The schematic illustrates the four phases of the MRUP project:

- Pre-mining
- During mining operations (deposition into the Princess Pit)
- During mining operations (potential deposition into the Ambassador Pit)
- Post mining.

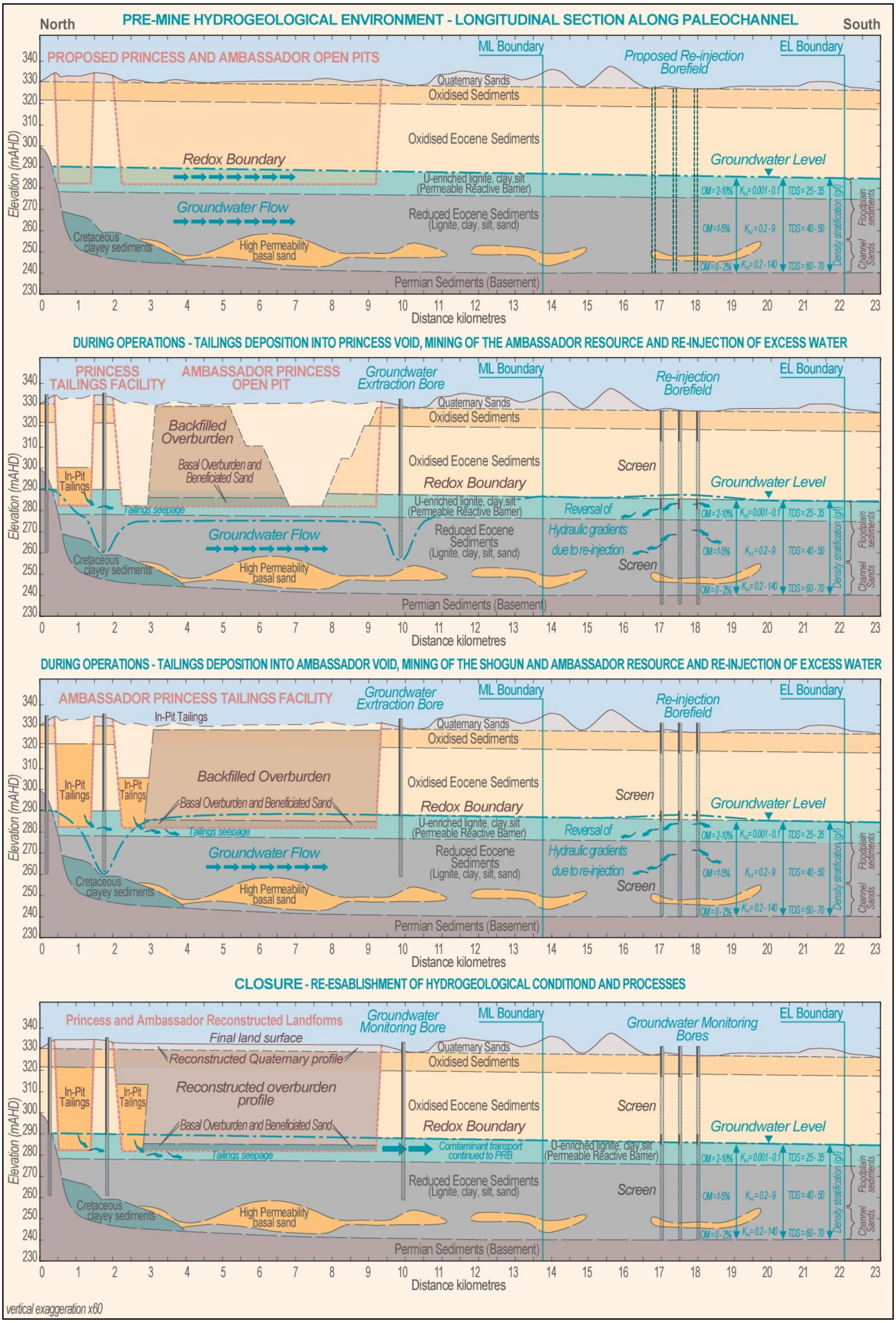

Figure 19 Conceptualised different stages of the MRUP

(Source: Vimy)

The geology has been simplified in the following four layers, from deepest to shallowest:

- Permian (and older rocks)

  The Permian (and older) rocks, belonging to the underlying Gunbarrel Basin, comprise mudstones, claystones and fine grained sandstones. Although the permeability of these Permian sediments has not been characterised, on a regional scale it is considered to be significantly less than the overlying the Palaeogene to Late Mesozoic sediments within the overlying Narnoo Basin. Therefore interaction between the palaeochannel and the older rocks can be ignored.

- Cretaceous – Palaeogene (Eocene)

  Containing uranium mineralisation, the basal sequences are considered to be the most transmissive of the saturated profile. Figure 19 shows these basal sands, which are specifically targeted by the re-injection borefield to dispose of surplus water recovered from the pit dewatering operations.

  Whilst the more permeable units are expected to be below the base of Princess Pit TSF (approximately 10 m to 20 m), limited potential exists for TSF fluids to migrate vertically towards these beds as there is a density gradient between the lower salinity tailings liquors, and the deeper, hypersaline groundwater.

  The orebody (refer Section 7) has been formed through supergene enrichment, with uranium being mobile under oxidising conditions, and precipitation under reducing conditions. The presence of a reducing groundwater environment is essential for the formation of the deposit. Groundwater conditions are therefore reducing in these sediments.

- Palaeogene (Eocene)

  The primary ore zone is located within the lower parts of this sequence which includes lignite and carbonaceous sediments, i.e. high organic content, which forms a natural trapping mechanism. Groundwater conditions are therefore reducing in these sediments below the water table. These lower permeability materials of the primary ore zone would be removed through the mining process.

  The upper parts of the Eocene are above the water table and are unsaturated, and have been oxidised. The sediments will be adjacent to the TSF and the coarser grained lenses may represent pathways that enable drainage of the tailings and leachate migration.

- Neogene (Miocene)

  These sediments are unsaturated, and contain silcretes, and variable mixtures of fine and coarse-grained materials, sandy clays, conglomerate and diamictites (poorly sorted sedimentary rocks, sands within mud matrix). This zone has also been oxidised and leached.

  Roots of vegetation extend into the upper parts of the Miocene and this has been a consideration in the design of the proposed Princess Pit TSF. The final tailings level within the TSF would be maintained below this biogenic zone to prevent interaction.

- Quaternary

  The Quaternary sediments are unsaturated aeolian sands. Filling of the Princess Pit TSF would be below base of the Quaternary and therefore there is limited likelihood of interaction between these sediments and the TSF.

Based upon the mining sequence, the Princess Pit would be mined initially with tailings going to a surface TSF. The nearby Ambassador Pit would be subsequently mined with tailings from its ore-processing proposed to be deposited in the Princess Pit. The process will be repeated for the Emperor and Shogun Pits, however as the mineralisation and hydrogeology are similar, the focus of the conceptualisation would be on the Princess and nearby Ambassador Pit. Approximate dimensions of the proposed pits are summarised in Table 13.

Table 13 Approximate Pit Dimensions

Element	Princess	Ambassador	
		East	West
Length (m)	750	2,300	2,600
Width (m)	250	600	500 (1,200)[1]
Depth (m)	46	55	65
Axis Orientation	WNW - ESE	WSW - ENE	SW – NE

Source: Vimy

Notes:

1. Dimensions approximate only (and subject to change)
2. The Ambassador West Pit has a NW-SE orientated spur around its middle hence the large width noted in parenthesis.

The uranium ore is concentrated in the organic-rich ligneous clays within the Eocene sequence, which constitute a redox boundary, however additional uranium mineralisation has been identified within the carbonaceous sandstones and upper Permian sequences. The groundwater is close to the top of these ligneous materials as indicated in Figure 19.

Pre-mining water levels are relatively deep within the Princess and Ambassador Pits with estimated average depth to waters of 47.2 m and 37 m respectively. Mine dewatering would be required as the ore body is approached. As the ore is being mined, and with the dewatering, oxidising conditions would be formed as the ore is exposed, however this would be over a short duration only. Water levels in the Princess Pit would recover after the cessation of mining and dewatering activities within the pit. Water level recovery in the Princess Pit may be disturbed by dewatering activities in the neighbouring Ambassador Pit, subject to the amount of dewatering required and level of ‘water level interference’. The extent of dewatering (radius of influence) is currently being investigated by Vimy.

The deposition of tailings from Ambassador would commence following exhaustion of the mined resource of the Princess Pit. It is understood that beneficiation of the ore would result in the base of the Princess Pit being lined with relatively coarse grained material. The saturated tailings material would be deposited above this material. The tailings material is expected to have a low permeability given its fine grained nature. With water level recovery post-mining, a significant proportion of the tailings would be deposited above the regional groundwater level.

Once deposited in the Princess Pit TSF, process water within the tailings, which has leachable concentrations of heavy metals including uranium, would be removed by three processes:

- Evaporation – as the upper surface is exposed to the atmosphere;
- Leakage vertically through the base of the TSF (beyond the regional water table); and
- Leakage laterally through permeable, unsaturated beds within the walls of the TSF.

Give the proximity of the Ambassador deposit, lateral migration may result in leachate inflows from the Princess Pit TSP towards the Ambassador Pits. Furthermore, dewatering within the Ambassador Pit would create a 'hydraulic sink' that would facilitate migration of groundwater towards it. It is noted that the bulk of the Ambassador East Pit is mined within the first 4 years and therefore estimated groundwater seepage velocities suggest that breakthrough during mining is unlikely. These processes are also shown on Figure 19.

There are multiple processes that could subsequently influence the migration of the constituents within the leachate:

- Process water, sourced from the Kakarook borefield (refer Section 6.4.5) is less saline than the native groundwater within the deeper transmissive beds underlying the Princess Pit (refer Section 6.4.4). There would be a natural tendency for the lower density tailings leachate to stratify above the saline native groundwater.
- Carbonaceous sediments left in-situ beneath the pit may offer some adsorption capacity to reduce concentrations within the leachate.
- Tailings leachate migrating through permeable beds above the regional water table has the potential to drain vertically through the organic rich sediments constituting the redox boundary.

The tailings water would continue to migrate under regional hydraulic gradients along the palaeochannel. The regional groundwater flow at the Princess / Ambassador Pits is interpreted to be southwards and therefore flow from the Princess Pit TSF flow towards the Ambassador Pit would occur, as indicated in Figure 19.

There are other influences upon the groundwater flows which could potentially influence the migration of the fluids leaching from the Princess Pit TSF. Groundwater recovered from dewatering operations is to be disposed through re-injection. This is estimated to occur approximately 10 km to the south of the Ambassador deposit. Directly analogous to dewatering, injection of waters into the aquifer hydraulically down-gradient of the deposits would alter hydraulics, but creating a mound within the water table / potentiometric surface. Whilst injection is occurring, it would retard the migration of waters as hydraulic gradients are locally reversed.

Groundwater extraction from the Kakarook borefield is considered to be hydraulically disconnected from the palaeochannels at MRUP and therefore would not influence hydraulic gradients (Rockwater 2013).

6.7 Characterisation of Neighbouring Groundwater Use

6.7.1 Data limitations

Information regarding regional groundwater occurrence was obtained using the DoW's Water Information Register (WIN). The following comments are made regarding the available data:

- The WIN register does not provide information regarding the operational status of groundwater bores;
- The WIN register does not provide information regarding the casing condition status of groundwater bores;
- Many bore collars have not been surveyed. In many instances drilling contractors could not gain access to these sites and final locations often have a positional error greater than ± 250 m;
- The information registered is subject to the accuracy of bore completion reports submitted by drilling contractors;

- Information registered is subject to change since the completion of the bore e.g. water level information, pump setting depth, groundwater quality; and
- Some information is not available on the WIN, e.g. pump setting depth, bore ownership.

6.7.2 Results

A total of 18 bores were identified within a 100 km radius of the MRUP with two (2) possibly located within the lease boundary. Available information regarding bore location, construction and water quality data has been summarised in Appendix A.

Under the terms of an access agreement with Vimy Resources, AngloGold Ashanti Australia (on behalf of the Tropicana Joint Venture) operates a production bore at the Emperor deposit for dust suppression purposes. The water is taken from the main palaeochannel 20 km to the northwest of the proposed processing plant.

6.7.3 Discussion on Groundwater Quality

The value of a groundwater resource can be determined based on its broad salinity. Whilst the available water quality from the neighbouring groundwater bores are limited (and are based on samples collected over 10 years ago), they suggest a salinity range of 5,000 mg/L to over 50,000 mg/L TDS. At such salinities, the groundwater is too saline for direct potable applications (potability is generally acceptable at salinities below 1000 mg/L TDS) and irrigation applications. The latter potential use of groundwater is not consistent with regional landuse, with limited likelihood of it being realised in the long term.

Stock watering applications become limited above 5,000 mg/L and is generally considered too saline for stock at salinities above 10,000 mg/L TDS. Stock salinity tolerances are summarised in Table 14. The groundwater salinities indicated that the groundwater, at least for direct, untreated applications, is suitable for some industrial purposes only.

Table 14 Livestock Salinity Tolerances

Type	Salinity (mg/L)		
	No adverse effects on animals expected	Animals may have initial reluctance to drink or there may be some scouring, but stock should adapt without loss of production.	Loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually.
Beef cattle	0 – 4,000	4,000 – 5,000	5,000 – 10,000
Dairy cattle	0 – 2,500	2,500 – 4,000	4,000 – 7,000
Sheep	0 -5,000	5,000 – 10,000	10,000 – 13,000
Horses	0 – 4,000	4,000 – 6,000	6,000 – 7,000
Pigs	0 – 4,000	4,000 – 6,000	6,000 – 8,000
Poultry	0 – 2,000	2,000 – 3,000	3,000 – 4,000

Source: Berkman 2001

6.8 Other Deposits

Information provided by Vimy indicates that there are other uranium prospects, e.g. Double 8, Highway South and Stallion South (Manhattan Resources Ltd) south of the MRUP at Ponton. These deposits are further down-gradient (approximately 20 km) within the east and western arms of the palaeochannel identified at MRUP. The deposits are mostly south of the Nippon Highway, and either inside, or adjacent to the northern boundary of the Queen Victoria Spring Nature Reserve. The location of these deposits is shown in Figure 20.

Whilst specific information regarding the hydrogeology of these deposits is not publicly available, it is considered a reasonable expectation that given that the deposits are located within Palaeogene/Neogene age palaeochannels within the Gunbarrel Basin, that there are hydrogeological similarities with MRUP.

It also provides evidence that aquifers are enriched with uranium (and other base metals) in other palaeochannels in the region, i.e. a natural analogue of the uranium enrichment processes have occurred elsewhere.

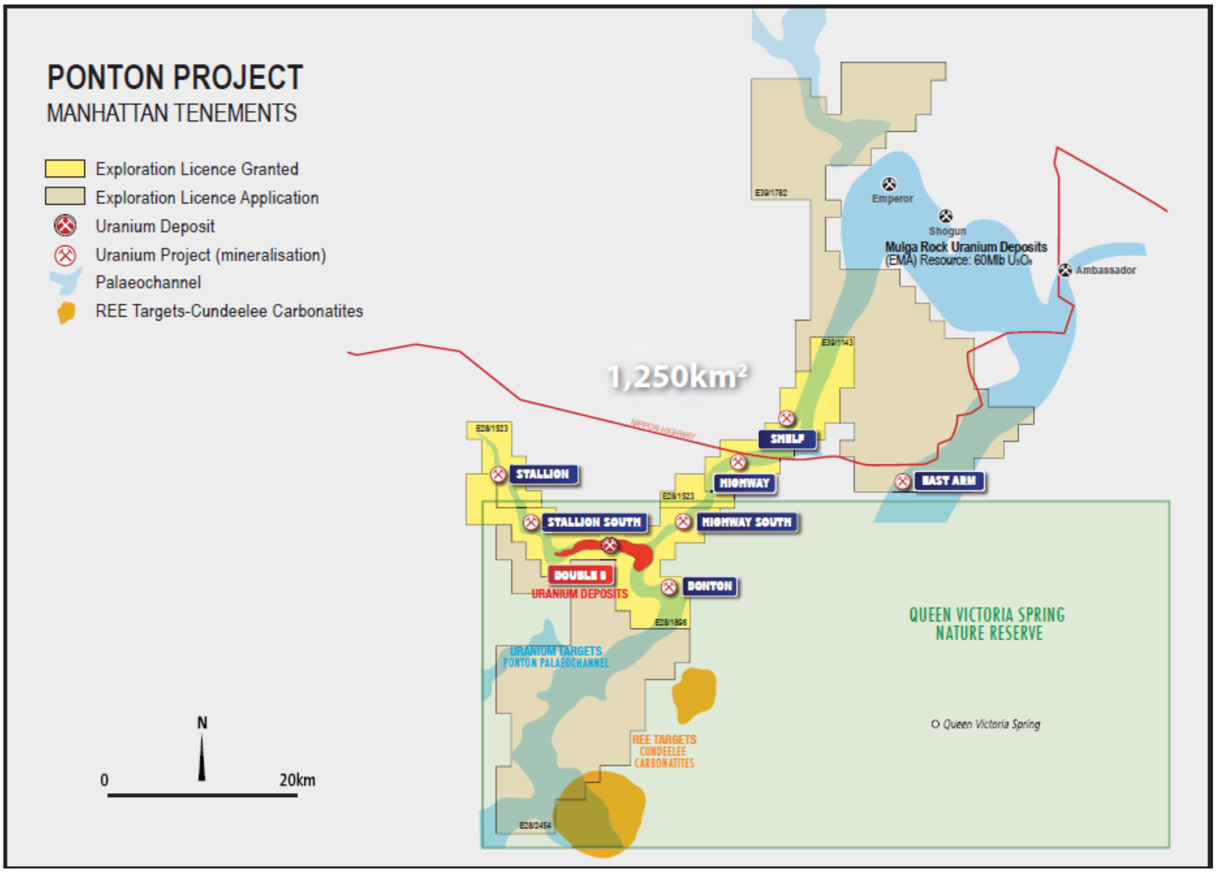

Figure 20 Other Regional Uranium Deposits

Source: Manhattan Corporation Ltd (2014)

6.9 Groundwater Dependent Ecosystems

6.9.1 Definition

A groundwater dependent ecosystem (GDE) is an ecosystem which has its species composition and natural ecological processes determined by groundwater (ARMCANZ & ANZECC, 2000). That is, they are natural ecosystems that require access to groundwater to meet all, or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services. If the availability of groundwater to GDEs is reduced, or if the quality is allowed to deteriorate, these ecosystems will be impacted (Hatton & Evans, 1998).

It is widely acknowledged that a poor understanding exists in recognising GDEs, or understanding the hydrogeological processes affecting GDEs, or their environmental water requirements. GDEs can be broadly grouped into three categories:

- Ecosystems that depend on the surface expression of groundwater:
  - Swamps and wetlands can be sites of groundwater discharge and may represent GDEs. The sites may be permanent or ephemeral systems that receive seasonal or continuous groundwater contribution to water ponding or shallow water tables. Tidal flats and inshore waters may also be sites of groundwater discharge. Wetlands can include ecosystems on potential acid sulphate soils and in these cases maintenance of high water levels may be required to prevent waters from becoming acidic.
  - Permanent or ephemeral stream systems may receive seasonal or continuous groundwater contribution to flow as baseflow. Interaction would depend upon the nature of stream bed and underlying aquifer material and the relative water level heads in the aquifer and the stream.
- Ecosystems that depend on the subsurface presence of groundwater. Terrestrial vegetation such as trees and woodlands may be supported either seasonally or permanently by groundwater. These may comprise shallow or deep rooted communities that use groundwater to meet some or all of their water requirements. Animals may depend upon such vegetation and therefore indirectly depend upon groundwater. Groundwater quality generally needs to be high to sustain the vegetation growth.
- Ecosystems that reside within a groundwater resource. These are referred to as hypogean ecosystems. Micro-organisms in groundwater systems can exert a direct influence on water quality, for example, stygofauna typically found in karstic, fractured rock or alluvial aquifers.

6.9.2 Review of the National GDE Atlas

A search of BOMs Atlas of Groundwater Dependent Ecosystems for GDEs in the area of the Mulga Rock Project Site identified one GDE in the area, Ponton Creek (salt lake). This creek lies to the south west of the site and has been identified to have a high potential for groundwater interaction. The GDE is located more than 40 km from the site and the land around the GDE site is used for nature conservation and livestock grazing.

The wetlands of national significance (DIWA listings) showed that there are no wetlands of national significance in the subregion. There are two wetlands of subregional significance near the site there are Lake Minigwal and Ponton Creek. The threatening processes at Ponton Creek are unknown but at Lake Minigwal they are animals such as foxes, cats, rabbits and goats (occasional camels), and dewatering of mine sites and discharge of hypersaline water into the lake beds. There is one type of riparian zone vegetation that is threatened by groundwater related processes. It is the ephemeral creek lines which are impacted by mine dewatering lowering the water tables, the vegetation is limited and confined to major creek systems with intermittent flow. There are no threatened ecological communities (TECs) in Great Victoria Desert 1 (GDV).

A search was completed into the possible groundwater receptors that may be affected from works at the Mulga Project Site, the list below summaries the findings:

- Queen Victoria Spring Nature Reserve (approx. 55 km South-South West of site)
- Ponton Creek (approx.. 60 km South West of site)
- Lake Rebecca (approx. 90 km South West of site)
- Lake Raeside (approx. 90 km West of site)

Lake Rebecca was identified as being the receptor of Saracen Gold Porphyry Gold Mine dewatering (Lake Rebecca Dewatr.pdf).

One endangered species was identified near the site, Eucalyptus Articulata – Ponton Creek Mallee, as listed in the *Wildlife Conservation Act* (1950).

Queen Victoria Springs is a riverine system of large pools or springs and is seasonally water logged which assists the support of ferns and herbs and *Eucalyptus Camaldulensis* woodlands (from dpaw-deserts-veg-and-flora.pdf). It is understood that the naming of the Nature Reserve is not related to a natural spring or expression at this site, but rather a bore.

6.9.3 Surface Water Dependent GDEs

Permanent surface water is not present on the mine lease.

6.9.4 Subsurface Presence of Groundwater GDEs

There are a number factors which suggest that the surface flora (and fauna) are not accessing the groundwater system. This is based upon:

- The depth to groundwater at the Princess and Ambassador Pits is approximately 40 m below surface.
- Observations made during lithological logging by Vimy geologists that roots and organic materials were not identified below the base of the Miocene sediments (estimated depth of around 20 m to 30 m below the surface).
- Groundwater is generally saline to hypersaline.

6.9.5 Stygofauna

To identify if there would be any impact to the subterranean fauna from the proposed uranium mine, a pilot study was undertaken in 2013 by Vimy with identification carried out by Dalcon Environmental (Vimy 2015) and a follow-up survey in 2014 by Rockwater (2015). This pilot study included sampling for stygofauna at the Kakarook North borefield, and troglofauna sampling at Mulga Rock.

The presence of troglofauna is dependent on the local geology, they are typical confined to fissures and voids that are have some connectivity to the surface. Typically the geology at Mulga Rock does not represent this, however, lateral voids and wash zone may provide a suitable habitat but it is unclear whether these are suitable or have been cleared (Rockwater, 2015).

Vimy (2015) conducted sampling at the Mulga Rock Project site from eleven bores, these bores were located at Ambassador (7), Shogun (1), Emperor (1) and Kakarook North (2). The sampling program showed that seven from the eleven drill holes sampled at Mulga Rock yielded 104 invertebrates.

Similar sampling of long established water bores in the main palaeochannel by the proponent of the Tropicana Joint Venture (ecologia Environment 2009, Figure 21) failed to locate any stygofauna, which reinforces the fact that the channel and tributaries groundwater chemistry and host sediments at the water table are not conducive to groundwater dependent ecosystems.

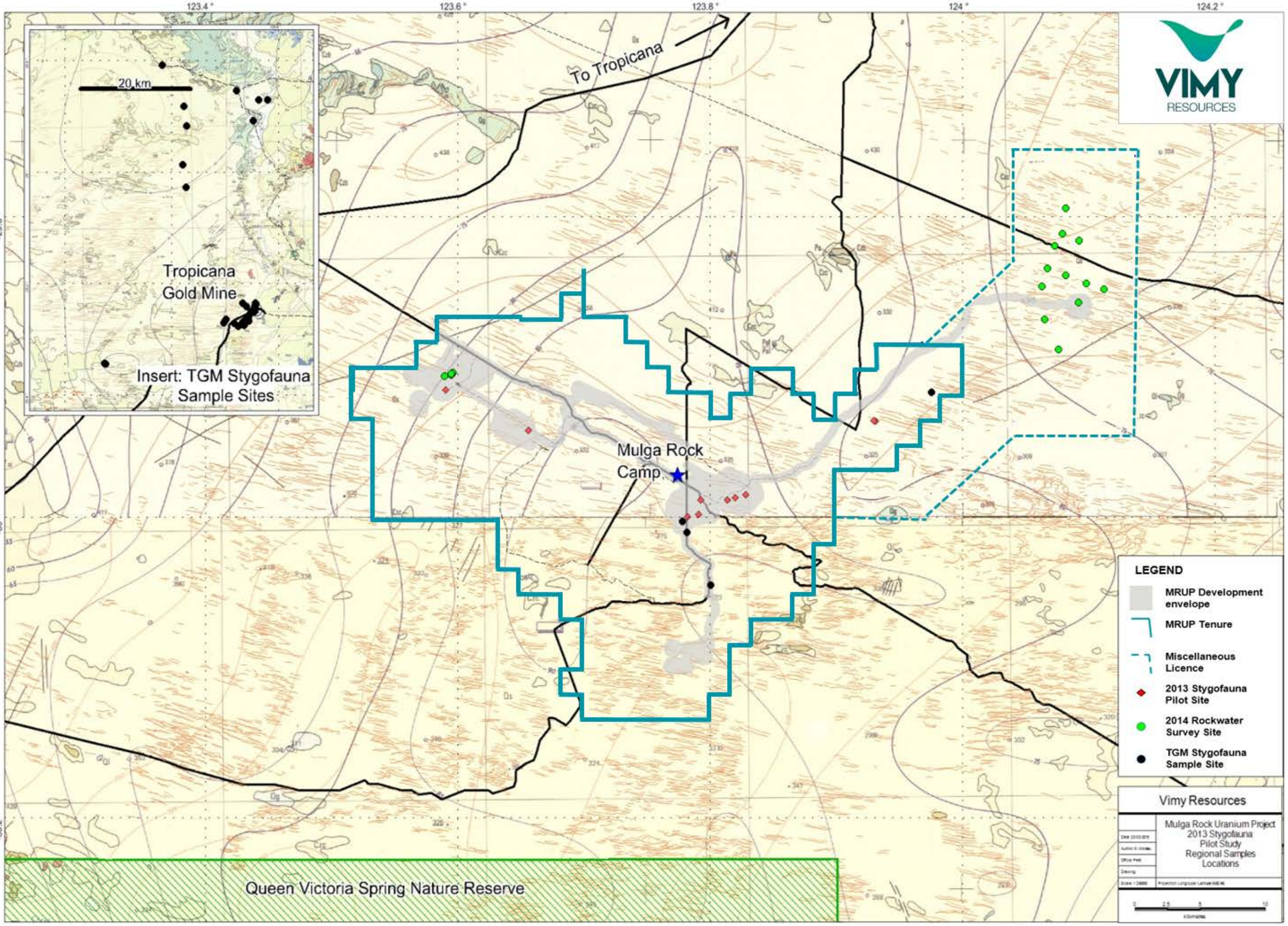

Figure 21 Stygofauna survey sites at MRUP and nearby Tropicana Gold Mine

(Source: Vimy)

7. Geochemical Characterisation

7.1 Geochemistry of Uranium

7.1.1 Uranium and its Occurrence

The metal uranium forms several oxides:

- Uranium dioxide or uranium(IV) oxide (UO_2, the mineral uraninite or pitchblende)
- Uranium trioxide or uranium(VI) oxide (UO_3)
- Triuranium octoxide (U_3O_8, the most stable uranium oxide; yellowcake typically contains 70% to 90% percent triuranium octoxide)
- Uranyl peroxide (UO_2O_2 or UO_4)

The most common forms of uranium oxide are U_3O_8 and UO_2, with the latter, uraninite or pitchblende perhaps the most common. Deposits can host a large range of uranium minerals, including coffinite which is a hydrated uranium silicate.

7.1.2 Solubility

Uranium is a highly soluble metal, however this solubility is redox dependent. It can be easily dissolved, transported and precipitated within groundwater but is subject to subtle changes in oxidation conditions. Uranium also does not usually form very insoluble mineral species, which is a further factor in the wide variety of geological conditions and places in which uranium mineralization may accumulate.

Dissolved U(III) easily oxidizes to U(IV) under most redox conditions found in nature. The U(V) aqueous species (UO2+) readily disproportionates to U(IV) and U(VI) and therefore U(IV) and U(VI) are the most common oxidation states in nature. In general terms, uranium is found in the U(VI) oxidation state in oxidising environments, and in the U(IV) oxidation state in reducing environments. Dissolved U(VI) readily hydrolyses to form several aqueous complexes, (depending upon pH) and the presence of carbonate, because of the predominance of neutral or negatively charged species (US EPA, 1999).

Under the reducing conditions U(VI) species normally present in oxic water are reduced to the less soluble +4 valence state resulting in precipitation of sparingly soluble U(IV) species or mixed U(IV)/U(VI) solids. The total concentration of dissolved U(IV) species in reducing groundwater is quite low because of the low solubility of U(IV) solid phases (Bruno *et al*. 1988, 1991).

7.1.3 Adsorption

Uranium (IV) forms strong complexes with naturally occurring organic materials. Thus, in areas where there are high concentrations of dissolved organic materials, U(IV)-organic complexes may decrease U(IV) solubility. The most important of these parameters include redox status, pH, ligand (carbonate, fluoride, sulphate, phosphate, and dissolved carbon) concentrations, aluminium- and iron-oxide mineral concentrations, and uranium concentrations (US EPA, 1999).

Aqueous U(IV) is inclined to form sparingly soluble precipitates, adsorb strongly to mineral surfaces, and partition into organic matter, thereby reducing its mobility in groundwater. In the presence of lignite and other sedimentary carbonaceous substances, uranium enrichment is believed to be the result of uranium reduction to form insoluble precipitates, such as uraninite.

In low ionic strength solutions with low U(VI) concentrations, dissolved uranyl concentrations will likely be controlled by cation exchange and adsorption processes. The uranyl ion and its complexes adsorb onto clays, organics and oxides. As the ionic strength of an oxidized solution increases, other ions, notably Ca^{2+}, Mg^{2+}, and K^{+} will displace the uranyl ion from soil exchange sites, forcing it into solution.

Aqueous pH is likely to have a profound effect on U(VI) sorption to solids. There are 2 processes by which it influences sorption. First, it has a great impact on uranium speciation such that poorer-adsorbing uranium species will likely exist at pH values between about 6.5 and 10. Secondly, decreases in pH reduce the number of exchange sites on variable charged surfaces, such as iron-, aluminium-oxides, and natural organic matter.

7.1.4 Radioactivity

Uranium is weakly radioactive and contributes to natural background environmental radiation. Natural uranium comprises three radioactive isotopes: U234, U235 and U238. The percentage of each by weight is respectively about 0.0054%, 0.72% and 99.27%. Some 48.9% of the radioactivity is associated with U234, 2.2% with U235 and 48.9% with U238.

The half-lives (time for the radioactivity to decay to half its original value) of the uranium radioisotopes are very long: 244,000 years for U234, 710 million years for U235 and 4500 million years (or about the age of the Earth) for U238.

The original uranium atoms of U238 and U235 decay to a number other radioisotopes, ending in the decay chain as stable (non-radioactive) isotopes of lead. As a result of its long radioactive half-life in comparison to the age of the solar system, uranium is considered to be a naturally-occurring primordial radioelement.

7.1.5 Redox (Chemistry Overview)

It is important to understand oxidation reduction chemistry as it is a primary factor in the mobility and stability of uranium ores. Chemical reactions occurring within aqueous solutions are referred to as Oxidation – Reduction (redox) reactions. Some key redox definitions are summarised in Table 15.

Table 15 Redox Definitions

Process	Change in valency	Change in electrons	Agent / Chemical
Oxidation	Increases	Loss	Reducing
Reduction	Reduces	Gain	Oxidising agent

One way to quantify whether a substance is a strong oxidizing agent or a strong reducing agent is to use the oxidation-reduction potential or redox potential. Strong reducing agents can be said to have a high electron-transfer potential. Strong oxidizing agents have low electron-transfer potential. Oxidizing and reducing agents occur as couples, with a strong reducing agent coupled with a weak oxidizing agent and vice versa

The Oxidation Reduction Potential or ORP, which can be determined with field measurements during groundwater sampling, is a measure of the capacity of an aqueous solution to either release or collect electrons. A solution with a higher (more positive) ORP has the potential to oxidise a solution with a lower ORP.

It is important to understand that ORP provides an indication if a redox reaction can happen, however it does not provide an indication if, or how fast the reaction will occur.

7.1.6 Mulga Rock Uranium Mineralisation

The International Atomic Energy Agency assigns uranium deposits to 15 main categories of deposit types, according to their geological setting and genesis of mineralization, arranged according to their approximate economic significance.

Roll front sandstone, or palaeochannel deposits describe the mineralization at Mulga Rock, and represent one of the more common forms of uranium mineralization. As noted above, uranium is mobile under oxidising conditions and precipitates under reducing conditions, and thus the presence of a reducing environment is essential for the formation of uranium deposits in sandstone.

Roll-front uranium deposits are generally hosted within permeable geological materials such as sands, sandstones and conglomerates. The mechanism for deposit formation is dissolution of uranium from the formation or nearby strata and the transport of this soluble uranium into the host aquifer. Rainfall recharge to groundwater comprises oxygenated groundwater. Dissolved oxygen oxidises uranium, typically to the U(VI) and therefore it becomes mobile within the aquifer. This is shown in the Figure 22.

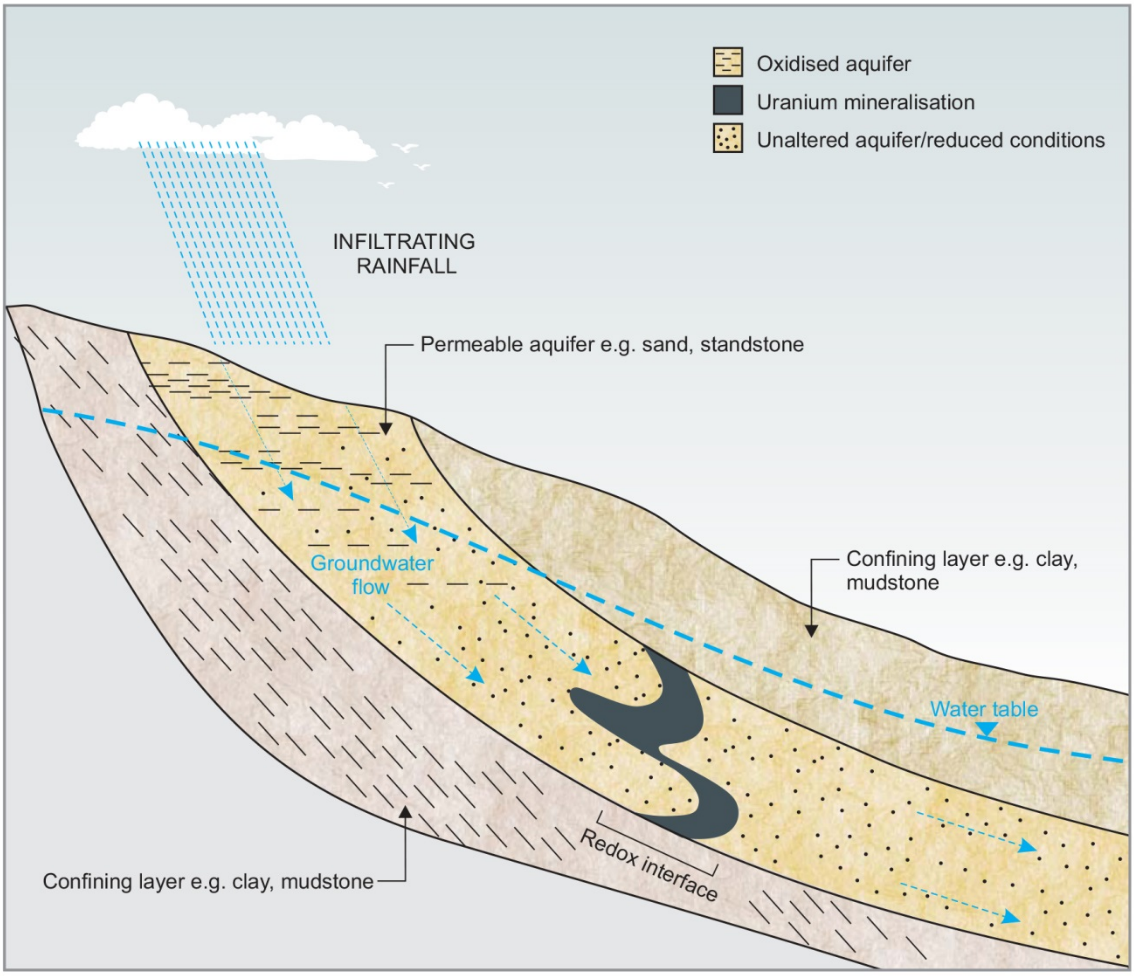

Figure 22 Schematic of roll fonts

Deeper within the aquifer, oxygen becomes depleted and typically a curved or convex redox interface is formed with oxidising conditions on the up-gradient side, and reducing conditions on the down-gradient side. The reduced groundwater commonly has high concentrations of iron sulphide minerals, and organic matter. Uranium dissolves in the oxidising zone but is immobilised at the redox front and so precipitates as uraninite (or in some cases coffinite).

The oxidised U(IV) transported in the oxic groundwater is subsequently reduced to U(IV) at this front and precipitated. Langmuir (1975) coined the term ‘roll front’ as over time, as more oxygen is transported into the aquifer by on-going recharge, the redox interface, and associated mineralisation migrates or rolls down-gradient. The U front moves in the direction of groundwater flow, but at a much slower rate than the water itself. The accumulation of U at the front can lead to the development of economic deposits

When the fluids change redox state, i.e. at a reduced boundary, uranium precipitates to form a 'front'. In palaeochannels such as those at MRUP, which are filled in the lower parts by ligneous materials or brown coal, these carbon rich sediments can be an efficient reductive trap for mobile uranium. In some cases, other metals such as scandium, gold and silver may be concentrated within the lignite hosted uranium.

There is no specific threshold ORP for uranium mobility, because mobility is also influenced by other factors such as pH, aqueous complex formation and sorption (to mineral surfaces) (Grassi *et al*, 2005). Uranium can mobilise at either high or low pH. Immobile uranium minerals tend to form when dissolved oxygen is less than 1 mg/L (Grassi *et al*, 2005). Carbonate species (e.g. bicarbonate and carbonate), and phosphate can complex with uranium and facilitate mobilisation.

In addition to aqueous complexes, the mobility of uranium depends upon soil (and aquifer) characteristics. Iron oxides, clays and organic matter can form strong bonds for uranium sorption. The type of sorption site and their surface area are key factors determining sorption. Furthermore, sorption sites compete with aqueous complexes to bind uranium, e.g. uranium sorbed to a soil may be desorbed by changes in local groundwater chemistry.

7.2 Characterisation of the Tailings

7.2.1 Permeability

The tailings generated from the processing plant are expected to be clayey in nature following beneficiation. Particle size distribution of tailings derived from the high grade ore have been summarised in Table 16. Based on the particle size distribution, a hydraulic conductivity function was generated for the non-beneficiated and beneficiated tailings of 0.24 m/day and 0.08 m/day respectively (Soil Water Consultants 2015a).

Table 16 Particle Size Distribution

Particle Size Class	Sieve Size (µm)	MUL-2AR	MUL-3A
		% Passing	
Medium Sand	600	100	100
	425	100	99
Fine Sand	300	99	99
	150	82	82
Coarse Silt	75	63	65
	50	52	47
Fine Silt	20	47	40
	10	40	37
	5	18	26
Clay	2	14	14

Source: Soil Water Consultants (2015a)

As the tailings drain of liquor, its permeability will decrease rapidly towards 0.001 m/day and will reduced the potential for continual seepage from the TSF into the surrounding environment (Soil Water Consultants 2015a). Evaporative drying of the upper 1 m to 4 m prior to capping closure would prevent infiltration of meteoric water recharging the in-pit tailings and supply a source to drive further dissolution and mobilisation (Soil Water Consultants 2015a).

It is understood that initial studies into the consolidation and settling of the tailings slurries indicated that settling rates were very slow and therefore Vimy are commissioning additional studies to test the efficacy of flocculants and coagulants to improve the settling behaviour.

7.2.2 Carbon Content

The carbonaceous material with the palaeochannel has been fundamental to trapping the mineralisation, which is directly analogous to a passive or permeable reactive barrier. The ore processing will involve leaching of the ore material. The total carbon content of the ore would increase as other matrix constituents are lost from the ore during processing. It is therefore expected that the tailings will contain an appreciable carbon content, estimated to be approximately 42% (Soil Water Consultants 2015a).

Given the strength at which metals and metalloids are bound to the carbonaceous material, the risk of metalliferous drainage occurring following stockpiling of the ore material is considered low (Soil Water Consultants 2015a).

7.2.3 Leachate Chemistry

Australian Standard Leaching Procedure (ASLP) tests were carried out on tailings samples by ANSTO (2015) and reported by Soil Water Consultants (2015a) to characterise the potential for metalliferous drainage from the tailings. The ASLP testwork, which used both Site Water and MilliQ Water to extract leachate, identified that Co, Cu, Mn, Ni, Pb and Zn may potentially mobilise from the leachate in the presence of Site Water.

The ASLP results were used to establish the input chemistry for the PHREEQC geochemical model described in Section 8.2.

8. Quantitative Assessment

8.1 Overview

8.1.1 Objective

A quantitative assessment of the effects of the in-pit tailings storage on groundwater is required to both inform the risk assessment process (Section 9) and satisfy the requirement of the MRUP ESD.

Under these conditions, GHD applied two modelling approaches, a geochemical model (with advective transport) and analytical groundwater flow modelling. The former considered the various reactions that could occur within the aquifer between the tailings liquor and the native groundwater. The later assessed hydrodynamic dispersion, and the sensitivity of hydraulic conductivities and source loading.

8.1.2 Discussion on long-term conditions

A requirement of the MRUP ESD is to undertake suitable modelling of the long-term movement of waste material. Long term movement was specified as a 10,000 year timeframe and extrapolation of conditions over such a timeframe is problematic.

The migration of metals in solution is driven by long-lived tectonic and climate change-driven regional lowering of the water table, which has allowed oxidation and metal release. Their fixation is driven by bacterially-mediated or catalysed chemical reactions along the redox boundary near the current water table.

The wide distribution and thicknesses of palaeovalleys in the Cenozoic period are testimony to significantly higher rainfall, run-off and river flow, and lower evaporation rates throughout there formation, compared to the present day. Changes in climate conditions, such as increased rainfall may result in rises in water level, however it is reasonable that this would not result in changes to hydraulic gradient owing to broad spatial distribution of recharge. Higher water levels may remobilise uranium, however the same natural trapping mechanisms would still exist. Additional rainfall recharge would dilute tailings liquors.

An increase in groundwater abstraction could alter hydraulic gradients, however such would be short lived and insignificant over the 10,000 year timeframe. Groundwater at the site has limited value, primarily due to high salinity, and there are no obvious drivers for abstraction to occur, other than for mining. The region is also stable tectonically and therefore earth movements that could alter hydraulically gradients regionally, or increase recharge are also considered insignificant within the assessment timeframe.

The groundwater flow system comprises areas of sediments with high organic matter content, with high potential to fix uranium and other potential groundwater contaminants. This process is exactly what has resulted in the genesis of the ore deposits and is still on-going today.

In areas downstream from the proposed Princess and Ambassador pits, there are potential host sites that have not yet accumulated uranium and base metals, reflecting the effectiveness of the capture/fixation processes upstream.

8.2 Geochemical Modelling

8.2.1 Approach

Geochemical modelling has been undertaken to investigate the fate and transport of COPC (Contaminants of Primary Concern) into the receiving aquifer. Geochemical modelling software PHREEQC (Parkhurst and Appelo, 1999) was used to establish the speciation and saturation of aqueous species and predict geochemical changes in groundwater quality that may occur in response to proposed emplacement of tailings.

The following assumptions have been made:

- All reactions are instantaneous and at equilibrium.
- The system is closed with respect to CO_2.

A description of the modelling undertaken has been documented in 0.

8.2.2 Discussion

The PHREEQC geochemical model has been used to predict changes in key parameters in groundwater (pH, Al, Ba, Cd, Cu, Fe, Ni, Pb, U, Zn) over a distance of 12,000 m from the proposed tailings pit. Attenuation processes have been modelled within a one dimensional advection-dispersion module.

Ten scenarios have been modelled to address uncertainty of input parameters. The majority of scenarios are based on a continuous source condition whereby leaching from the tailings pit is assumed to occur at constant source concentrations over the full modelling period of 10,000 years. This condition does not consider the reduction in leachate concentrations over time and therefore models a greater contaminant load that what will actually be introduced into the aquifer.

After 10,000 years, it is predicted that natural geochemical mechanisms within the aquifer will attenuate most contaminants within the leachate plume in relatively close proximity (i.e. within approximately 700 m) to the tailings pit. This is the case under the worst case condition of a continuous contaminant source, demonstrating the capacity of the aquifer to naturally attenuate the leachate. The attenuation is primarily attributable to adsorption of protons and metals onto organic matter (OM) binding sites (and potentially amorphous iron oxide surfaces), noting that the influence of redox conditions on uranium attenuation is minor in the geochemical model since the existing groundwater environment was not found to be sufficiently reducing to immobilise (by reduction and precipitation) oxidised uranium from the tailings pit.

Interaction between the leachate and groundwater is predicted to result in the formation of the lead phosphate minerals pyromorphite and plumbogummite and the slight dissolution of the aluminium sulphate mineral jurbanite. No zinc minerals are predicted to form since the initial groundwater environment is not sufficiently reducing to form ZnS (based on available data). Cuprous ferrite ($CuFeO_2$), barite and the uranium minerals coffinite and uraninite are predicted to occur in groundwater under existing conditions and predicted to remain in saturated form.

The geochemical assessment has identified aluminium and uranium as potential contaminants of concern, however this is only the case under the worst case condition of a continuous source input.

When the initial uranium concentration in groundwater is 0 mg/L, the clay exchange and OM binding sites are dominated by the major cations (sodium, calcium and magnesium). As the leachate migrates into groundwater, protons and metal cations from the leachate exchange with the sodium on the clay exchange sites and the calcium and magnesium on the OM surface binding sites. However, when the initial uranium concentration in groundwater is higher, uranyl ions held onto OM binding sites are released as protons and metal ions from the leachate interact with the groundwater resulting in an increase in the uranium concentration in groundwater. When the pulse of leachate input to groundwater is limited to 100-200 years, any increase in the uranium concentration in groundwater would be localised (i.e. a few hundred metres from the pit), however under the worst case scenario of continuous source conditions over 10,000 years an increase in uranium concentration further down gradient of the tailings pit is predicted. It is considered that this is an overly conservative assessment of down-gradient uranium concentrations (based on a continuous source input over 10,000 years) and therefore does not warrant further investigation.

8.3 Analytical Groundwater Modelling

8.3.1 Approach

Analytical groundwater fate and transport modelling was undertaken to evaluate the effects of hydrodynamic dispersion, but also to assess differing source loading rates to the aquifer. Uranium was the only heavy metal that was considered. A description of the modelling undertaken in documented in 0.

The modelling was an exact, three dimensional analytical solution for Fickian transport from a patch source boundary in a semi-infinite aquifer. The solution considered the transport of uranium with advection, hydrodynamic dispersion (diffusion was ignored), and sorption within a steady and uniform groundwater flow field.

The source was treated as a patch perpendicular to the saturated thickness and therefore conservatively assumed that tailing liquors leaching from the in-pit TSF were in direct contact with the saturated aquifer system. In this way it ignored any fixation mechanisms that could occur within the carbonaceous rich tailings, and the low vertical hydraulic conductivities within the tailings themselves, and interbedded sand and clay sediments of underlying the primary ore zone.

The advective transport is sensitive the hydraulic conductivity, and two scenarios were considered:

- A probable scenario where a bulked horizontal hydraulic conductivity representing a 15 m zone of primary ore zone and underlying interbedded sands and clay sediments, i.e. hydraulic conductivity of 0.7 m/day. The basis of this scenario was that salinity contrasts between the process / tailings liquor, and saline native groundwater would restrict the vertical migration of any plume.
- A worst case scenario where a bulked horizontal hydraulic conductivity representing both the ore zone and underlying interbedded sands and clays, and the basal, transmissive coarse grained sands, i.e. hydraulic conductivity of 2 m/day. This scenario ignores any density contrasts.

8.3.2 Discussion

Modelling without any form of retardation of uranium, indicated that breakthrough at the lease boundary would occur within 5000 years under scenario 1. Using an initial source concentration of 0.14 mg/L (sourced from ANSTO (2015) ASLP testing), hydrodynamic dispersion resulted in concentrations reducing by 50% or greater, depending upon the applied source load. Continuous sources, and long source pulses (or decaying half-lives) resulted in less reduction in concentrations. Pulses of 100 years resulted in concentrations at the lease boundary being 10% of that of the source, i.e. 0.01 mg/L above background levels within the aquifer.

However, this advective modelling does not consider the carbonaceous material within the aquifer, which formed a natural mechanism for trapping the uranium and formation of the deposit with the aquifer.

Modelling with retardation (adsorption of metals to aquifer minerals) under scenario 1 suggests that the uranium plume would be significantly retarded, and would not reach the lease boundary after 10,000 years. The sensitivity was assessed based on a high (20%) and low (1%) organic content. It is acknowledged however, that retardation and the assessment of adsorption based on literature results is subjective, and may not necessarily reflect the site-specific geochemical reactions occurring at the MRUP. The analysis is also sensitive to advective groundwater flow and therefore horizontal hydraulic conductivities of the aquifers underlying the Princess Pit TSF.

Further laboratory analysis, e.g. column testing, of material along the predicted flow path, would be required to determine site-specific adsorption coefficients, and verify the advective-retardation analytical modelling. Therefore these results should be considered in the context of the geochemical modelling also undertaken.

8.4 Summary

Two forms of modelling were undertaken to quantitatively assess the fate and transport of the constituents within the tailings. Both methods assumed that concentrations of uranium and heavy metals would be not be fixed within the carbonaceous rich tailings, but would leach over time into the groundwater system.

The geochemical modelling indicates that after 10,000 years, natural geochemical mechanisms within the aquifer will attenuate the majority of contaminants within the leachate plume in relatively close proximity to the Princess Pit.

Analytical groundwater modelling evaluated potential source loading rates to the aquifer system. Incorporating retardation, concentrations would not breakthrough the lease boundary, the adopted point of compliance (approximately 12 km down-gradient of the Princess Pit), within the 10,000 year timeframe.

9. Groundwater Risk Assessment

9.1 Approach

9.1.1 Methodology

A qualitative, probabilistic approach was used to conduct the risk assessment. This type of assessment provides a high level (broad) understanding of the possible risks to the receiving environment, and is consistent with AS/NZS ISO 31000:2009 (which supersedes AS/NZ 4360:2004).

The key objective of the proposal to use the Princess Pit as a TSF is to determine whether it represents an effective option for minimising the effects on the environment and other users of the groundwater resource. An important part to this objective is to show that risk to the environment (and other users) could be assessed through a process of risk and uncertainty analysis that considers unlikely events that could result in plume spreading and unacceptable groundwater quality at the lease boundaries.

The resulting risk assessment is aimed at:

- Identifying risk areas that require further investigation to characterise risk;
- Identifying potential mitigation measures;
- Identifying monitoring programs to provide assurance to regulators.

In terms of mechanisms that might result in the off-lease discharge of contaminated (i.e. concentrations above background) groundwater, there are a number that need to be considered such as:

- Would the leachate degrade the integrity of aquifers and increase permeabilities and migration rates;
- The role of faults as preferred conduits for groundwater migration;
- The retardation processes that occurring to immobilise or retard the transport of contaminating substances; and
- Supporting qualitative discussions with quantitative modelling.

The risk register was compiled using the in-house resources of GHD and Vimy only.

9.1.2 Process

The following methodology was used to determine the groundwater impact pathways and define risk ratings for the project:

1. Determine the ‘pathway of effect’ – how the proposed Princess Pit TSF could affect the aquifer, given groundwater value or issue
2. Describe the ‘consequences’ of the impact pathway to define levels of consequence (Table 17)
3. Determine the ‘likelihood’ of the consequence occurring to the level assigned in step 2. Likelihood descriptors are provided in Table 18
4. Determine the maximum credible ‘consequence level’ associated with the effect as defined in Table 17. The method for defining these criteria is described below

5. Form the consequence and likelihood levels assigned to the effects pathway. Use the risk matrix to determine the risk rating (Table 19)

6. Define the level of data / information availability associated with the risk assessment rating (Table 20).

9.1.3 Consequence criteria

Consequence describes the potential impact of a threat on a value, and can provide a measure of possible change to groundwater and receptors relying upon it. Consequence descriptions have been applied to both environmental aspects, i.e. a direct impact to a receptor, but also social aspects, such as broad public perception of the proposal and potential costs to the organisation. The organisation costs also reflects the level of engineering required to prevent, manage or enable recovery of the water quality impacts, e.g. clean-up of contaminated groundwater should these arise from Princess Pit TSF operations.

With the groundwater assessment, impacts are generally simplified into those that affect groundwater quality and/or groundwater level. Falls or rises in groundwater level affect hydraulic gradients and groundwater movement. The effect on movement or groundwater flow translates to a change in transport rates towards the receptors, i.e. receiving environment or other resource users. Changes in groundwater quality can result in breach of regulations, or impacts to receptors and receiving environments.

In terms of assigning criteria, consequences were split into two categories. Direct effects to the groundwater environment may take the form of changes to water quality, changes to water level or changes to access (either abstractive use) or an environmental asset or function, such as a groundwater dependent ecosystem.

Consequence criteria (Table 17) range on a scale of magnitude from ‘insignificant’ to ‘catastrophic’. Magnitude was considered a function of the size of the impact, the spatial area affected and expected recovery time of the environmental system.

Consequence criteria descriptions indicating a minimal impact over a local area (and with a recovery time potential within the range of normal variability), were considered to be at the ‘insignificant’ end of the scale. Conversely, ‘catastrophic’ consequence criteria describe scenarios involving a very high magnitude event, affecting a statewide area or requiring over a decade to reach functional recovery.

The groundwater environment (e.g. groundwater level) may recover to pre-existing conditions, although these effects may still exist and require engineering controls or solutions to either mitigate or enable recovery.

Table 17 Groundwater consequence criteria

Consequence Level		Insignificant	Minor	Moderate	Major	Catastrophic
Environmental	**Direct effects to the groundwater environment**	Negligible change to groundwater regime, groundwater quality and availability	Localised changes to the groundwater regime, groundwater quality and availability, but no implications for groundwater users or the environment	Changes to the groundwater regime, groundwater quality and availability with minor implications i.e. existing users still viable or negligible impact to receiving environments	Groundwater regime, groundwater quality significantly compromised in local area (existing uses of groundwater no longer viable, and/or impact on waterway flows/receiving environment	Widespread groundwater quality degradation beyond lease boundary
Organisation Cost	**Effects associated with changes to the groundwater where engineering controls are available**	Effects not detectable or not requiring intervention	Detectable change with effects less than $100,000 and able to be mitigated	Detectable change with effects more than $100,000 and less than $0.5 million and able to be rectified	Major change with effects more than $0.5 million and less than $1 million, and able to be rectified	Major changes to groundwater regime with effects more than $1 million to rectify, or irrecoverable damage to the environment
Social	**Perception**	Minimal effects that alter perception of Project	Some localised effects or complaints that alter perception of Project.	Numerous effects or complaints that alter perception of the Project and environmental management.	Community perception that the area is significantly damaged.	Community perception that the area has experienced major environmental damage.

Table 18 Likelihood categories

Descriptor	Description
Almost Certain	The event is expected to occur in most circumstances The event will occur at least once per project >50% chance of occurring during the project
Likely	The event will probably occur in most circumstances This event could occur up to once during the project 25–50% chance of occurring
Unlikely	The event could occur but not expected This event could occur up to once every 10 projects 5–25% chance of occurring
Very Unlikely	The event could occur but is improbable This event could occur up to once every 10 to 100 projects 1–5% chance of occurring
Rare	The event occurs only in exceptional circumstances This event is not expected to occur except under exceptional circumstances (up to once every 100 projects) Less than 1% chance of occurring

Table 19 Risk rating matrix

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Low	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Unlikely	Negligible	Low	Medium	High	High
Very Unlikely	Negligible	Low	Medium	Medium	High
Rare	Negligible	Negligible	Low	Medium	Medium

The level of data / information availability relating to the assessment of risk was considered in the following categories shown in Table 20. The rating of data / information availability was used to determine where any additional focus was required in mitigating the risk. For example, if a risk has a ‘catastrophic’ consequence and a low level of data or information available then more effort should be focussed on understanding and mitigating this risk, than an ‘insignificant’ consequence with a high level of data and information available.

Table 20 Data / information availability ratings

Criteria	Low Availability	Medium Availability	High Availability
Data / Information	Data and information is not specific to the region, conditions and industry and has very limited historical records or statistical support.	Data and information has some aspects specific to project region and conditions but not all. Historical records / statistical data is limited in some areas.	Data and information is specific to the region and conditions, and industry has sufficient historical records / statistics to support risk rating.

9.2 Dealing with data / information availability

Key data / information availability factors influencing the groundwater assessment relate to the following areas:

- Understanding the kinetics of geochemical reactions
- The influence of faulting on groundwater flow.

In terms of assessing groundwater effects, data / information availability has been managed through the following approaches:

- A conservative approach was applied when assigning consequences
- Simplified quantitative analysis has been undertaken, adopting conservative analytical inputs for assessing some impacts
- Performance criteria can be specified requiring that investigations are undertaken as part of the operation of the facility to address uncertainty. Examples of this include the implementation of a groundwater monitoring program.

9.3 Risk Register

The risk register has been attached as Appendix B. The risk assessment was compiled by GHD hydrogeologists and geochemists. The risk register comprises a total of 11 risks, which each risk having the same hazard, concentrations of uranium (and heavy metals) above background. Each of the risk items have been applied a consequence and likelihood assessment, and an assessment of uncertainty. It is expected that Vimy would continually review and update the risk register as an understanding of the mine development, and TSF operations improves.

Whilst it is appreciated that the assignation of risks can be subjective, at a minimum it identifies areas where further investigation to characterise risks of the implementation of the monitoring is required to support the risk ranking. The majority of risks in the register were ranked as High. A discussion of the effects of the in-pit TSF on the groundwater environment is provided below.

9.4 Evaluation of Effects

9.4.1 Migration

The assessment of plume migration was undertaken using two approaches. The first approach used a geochemical model to predict the changes in key constituents of the leachate, and the reactions and attenuation mechanisms that could occur along the groundwater flow path. The second approach used analytical groundwater transport techniques to predict the migration of the leachate, and effects of differing source loadings.

In both cases, a number of assumptions were made to simplify the analysis, however a conservative approach was adopted for the screening analysis, i.e. assumes that the leachate is in direct contact with the aquifer (ignoring flow and geochemical processes occurring within the unsaturated zone), i.e. it assumed that concentrations of uranium and heavy metals would be not be fixed within the carbonaceous rich tailings.

The PHREEQC geochemical model was used to predict changes in key parameters in groundwater (pH, U, Cu, Co, Ni, Pb, Zn, Ba, Al, Cd, Fe) over a distance of 12,000 m (estimated distance to the lease boundary) from the tailings pit edge. Modelling involved a number of scenarios assessing the variability of uranium concentrations, organic material and aquifer cation exchange capacities. Transport of leachate constituents was based on one-dimensional advection dispersion.

After 10,000 years, it was predicted that natural geochemical mechanisms within the aquifer will attenuate the majority of contaminants within the leachate plume in relatively close proximity to the Princess Pit. The attenuation is primarily attributable to adsorption of protons and metals onto OM binding sites.

Analytical groundwater modelling assessed the migration under 3-Dimensional advective transport, and under a variety of source loadings (continuous, 100 year, 200 year and 500 year pulse, and a decaying source with 100 year, 200 year and 500 year half-lives). The longer the source loading, the less reduction in concentration after 10,000 years.

Modelling with retardation (adsorption of metals to aquifer minerals) suggested that the uranium plume would be significantly retarded, with negligible increase in the concentration of uranium at the lease boundary after 10,000 years. This is consistent with the geochemical modelling.

It is noted that retardation and the assessment of adsorption based on literature results is generalised and may not necessarily reflect the site-specific geochemical reactions occurring at the MRUP. Further investigations to quantify adsorption co-efficient are required to verify the analysis.

9.4.2 Influence of Exploration Boreholes on Migration

The influence of exploration boreholes acting as conduits for the preferential migration of Princess Pit TSF leachate is considered low based on the ability of the sediments to swell or collapse, which would prevent significant volumes of water from migrating.

Implementing appropriate decommissioning procedures would minimise the creation of preferred pathways for the migration of fluids.

9.4.3 Influence of Faults on Migration

These have been ignored, i.e. considered to be absent, in the modelling.

9.4.4 Effects to other groundwater users

There are a number of factors that suggest the risk of groundwater quality changes impacting existing groundwater users is low. Available bore databases have been interrogated which indicates that existing groundwater use in the region is limited. This is a reflection of the land use, but also the poor groundwater quality. The groundwater quality is has limited application for stock use, but could be used for industrial purposes.

There is one existing bore on the mining lease which is currently used for supplying water for dust suppression. Management measures can be implemented to ensure that use of this bore is monitored.

Accordingly the risk of in-pit tailing disposal effecting abstractive use is low.

9.4.5 Effects to Stygofauna

There are no records of stygofauna within 100 km of the MRUP area and the geology and groundwater conditions (salinities) are not conducive to stygofauna occurrence, however stygofauna were identified in sampling at the Karkarook borefield (Rockwater 2015). The Quaternary aeolian geology is not conducive to troglofauna, however the Miocene geology potentially represents a habitat for troglofauna (Rockwater 2015).

The proposed Princess Pit is highly unlikely to interact with the Miocene geology and result in adverse effects to troglofauna based on the following:

- Tailings fill levels to be kept below the Miocene (and below the identified biogenic zone)
- The Miocene at Princess Pit is unsaturated. Therefore groundwater level or quality would not be affected.

Habitats of troglofauna could be effected by:

- Vegetation clearing;
- Changes to the surface hydrologic regime and runoff; and
- Vibration from heavy plant and blasting.

However, these activities would occur during the mining stage and are not specific to tailings disposal within the Princess Pit.

Accordingly the risk of in-pit tailing disposal effecting stygofauna is low.

9.4.6 Effects to Other Mines

There are other exploration activities identified to the south of the MRUP (refer 6.8) which occur within palaeochannel hydrogeological settings. Based on the results of the modelling (geochemical and transport), and the separation distances from MRUP, interaction with these deposits is considered to be highly unlikely.

Accordingly, the risk of in-pit tailing disposal effecting other mines is low.

9.4.7 Effects to Vegetation

There is a limited likelihood of adverse effects to vegetation that is potentially reliant upon groundwater. This is based on a number of factors:

- Existing groundwater levels are deep (>30 m at Princess Pit);
- Existing groundwater quality in the palaeochannel tends to be highly saline (approximating 20,000 mg/L TDS or greater); and
- TSF tailings levels are to be deposited below the biogenic zone, with final levels to be designed to prevent wicking or capillary rise of tailings water upwards into the root zone. It is noted that the salinity of the process water (and thus tailings liquors) range between 4000 mg/L and 8000 mg/L which suggests it is only suitable for salt-tolerant species.

Accordingly the risk of in-pit tailing disposal effecting vegetation is low.

9.4.8 Effects to Receiving Waters

There is a limited likelihood of tailings leachate having an impact to receiving surface waters. This is based on a number of factors:

- There is no permanent waterways within the mine lease
- Groundwater discharge to surface water systems does not occur within the mine lease.

As noted previously, the Queen Victoria Spring Nature Reserve is located approximately 55 km to the southwest of the proposed Princess Pit and approximately 47 km to the south of the MRUP mining lease boundary. The ‘spring’ was discovered by the early Australian explorer, Ernest Giles as part of his exploration of the Great Sandy Desert in the mid-1870s. The spring is described as seepage above a clay plan. The ‘springs’ are ephemeral, and subsequent expeditions, e.g. the Lindsay led Elder Scientific Exploration Expedition of the early 1890s described the springs as being dry. The ephemeral nature of the springs suggests that they are a perched system (Rockwater 2015b).

Accordingly, the risk of in-pit tailing disposal effecting the Queen Victoria spring is negligible.

9.4.9 Maintaining 'Aquitard' Integrity

The low permeability clays and interbedded sandy clays separating the primary ore zone from the basal coarse grained main channel of the palaeochannel are interpreted to retard vertical migration and potentially add confinement.

Mining deeper ore zones would be determined by economics, i.e. ore prices, but also the costs in accessing these areas, e.g. increased dewatering, and mine planning. Monitoring of the mine plan to maintain a buffer above the coarse grained basal aquifer could be undertaken to mitigate against this risk of scalping or thinning the aquitard. Monitoring of re-injection pressures and water quality within upper and lower zones of the palaeochannel can be undertaken to preserve aquifer integrity at the re-injection borefield. It is noted, however, that the borefield is 16 km down-gradient of the proposed Princess Pit TSF.

9.5 Benefits

Below-ground storage of tailings has potential environment benefits in terms of:

- Post-closure issues such as dust emissions are removed;
- Run-off to surface ecosystems is eliminated;
- No post-closure geotechnical stability issues; and
- Greater potential to re-establish reducing conditions (below the water table) and therefore the entrapment of uranium.

9.6 Preventative and Mitigation Measures

9.6.1 Monitoring

If groundwater monitoring identifies a trend or deviations from baseline groundwater quality conditions, or significant deviations from geochemical and contaminant transport predictions, then management could implement mitigation measures, or if already existing, modify, test or add additional measures. The monitoring plan needs to be adaptive, considering the results of the monitoring, but also as the understanding of the deposit and TSF storage improves.

Should ongoing groundwater monitoring identify continued issues despite the review of mitigation measures, then contingency plans can be implemented. These contingency actions are generally the more aggressive and costly groundwater management actions, and in some cases, may actually form remedial actions, for example, hydraulic control on plumes or *in situ* treatments to geochemically fix or retard plume migration.

Recommendations regarding some of the components to an adaptive groundwater monitoring program (GMP) have been attached as Appendix C.

9.6.2 Addressing Uncertainty

To address uncertainty, consideration should be given to the following actions:

- Review of monitoring bore construction
  A consolidated database of monitoring bore construction should be prepared. Monitoring bores with unknown construction (both in terms of screen interval and seal) should be omitted from the monitoring program.

- Undertake salinity profiling in boreholes
  Using wireline geophysics, e.g. fluid conductivity) or via sampling methods to confirm the assumptions made regarding the native groundwater salinity and density contrasts within the tailings process water.
- Review of existing groundwater monitoring program
  Confirmation of the quantitative predictive analysis of groundwater fate and transport following review of groundwater monitoring information, characterisation of the aquifer permeabilities, and assessment of adsorption coefficients from the strata underlying the underlying the Princess Pit TSF.
- Implementation of a monitoring program around the TSF
  Baseline water resource monitoring will provide data on the current water quality, levels and status that represent the water resources present in the project location. Through baseline and ongoing monitoring, it can be demonstrated that site operations (particularly in this instance the in-pit tailings disposal) are not impacting water resources (groundwater).
  The best baseline data are obtained from sites that have a historic record of water quality, levels and status. Locations for the baseline monitoring will need to be appropriate to the project, encompassing TSFs (above and below ground), fuel storage and use areas, chemical storage areas, processing plant, material stockpile areas and vehicle access ways. Such monitoring network does not exist at the Site, requiring design and installation.

9.6.3 Mitigations

The select of a mitigation measure after consideration of a number of factors including:

- effectiveness;
- cost to implement;
- timeliness of implementation;
- robustness or flexibility;
- preferences of regulatory agencies;
- outcome of Groundwater Monitoring Program; and
- final engineering design/layouts.

In some cases, further investigation may be required to support the selection of the most appropriate mitigation measure or its engineering design.

In terms of mitigation measures, the two key identified actions involve either hydraulic containment, or chemical treatment. The former involves establishing controls to either physically intercept groundwater, or to impart controls on hydraulic gradients to reverse flow. Groundwater restoration is required for in situ leach mines in the US (US DOE, 1995) and therefore analogies can be drawn regarding potential mitigation measures. Aquifer restoration generally involves pumping to remove leaching chemicals and to draw in natural groundwaters, or flushing, with large volumes of water, often augmented by chemicals to stabilise formation chemistry.

9.7 Comparison against other studies

The Beverley Uranium Project is located approximately 550 km northeast of Adelaide (South Australia). It comprises multiple operating mines, e.g. Beverley North, South, and proposed mines, e.g. 4 Mile. The operator, Heathgate Resources applies in-situ leach technology, i.e.

borefields, to extract uranium (coffinite) from aquifers (Namba Aquifer) located within 200 m of the surface. Groundwater in the aquifer is naturally radioactive and highly saline.

Potential hydrogeological impacts of mining were considered to be:

- Drawdown and reduced flow to existing groundwater users (livestock) from mine process water extraction from underlying Great Artesian Basin aquifers.
- Migration of contamination (including radiological) from the Namba Aquifer to the underlying Great Artesian Basin aquifer, created by deep aquifer abstraction.
- Contamination of shallow aquifers by leakage from above ground waste management
- Contamination of the Namba Aquifer through offsite migration.

Beverley (Heathgate Resources 2008) reports that no excursions of mining solution or injected wastewater into the official monitoring bore network have been recorded after 7 years of operations. To address the risks of the project on the groundwater environment, a number of measures are implemented including:

- Monitoring of groundwater (multiple aquifers)
- Management of Great Artesian Basin water use, e.g. metering, water savings measures
- Bore construction methods
- Exploration bore decommissioning methods
- Controls to preserve aquitard integrity (resistances against fracturing from re-injection).

GHD is aware that quantitative geochemical modelling was undertaken as part of the assessment of the Beverley 4 Mile planning (UIT 2008), along with characterisation testwork of attenuation associated with host rocks (ANSTO, 2008 and 2008b). This modelling also applied PHREEQC to assess the migration of constituents. Modelling for those operations show negligible pH, sulphate, uranium and other elements plumes after periods of less than 500 years within 5 km of the point of discharge.

9.8 Summary

A risk register was prepared for the in-pit TSF which was supported by quantitative modelling of the fate and transport of groundwater. It is acknowledged that risk assessments can be subjective, and the majority of risks identified were assessed as being high.

Based on the quantitative assessment of the fate and transport of groundwater, the risks to stygofauna, down-gradient mines, existing abstractive groundwater use, and waterways whilst assigned as being high, have a limited likelihood of occurring.

Implementation of a number of measures, including an adaptive groundwater monitoring program, whilst not a mitigation measure itself, is required to verify the quantitative modelling undertaken, provide information to support the implementation of mitigation measures, and provide confidence to regulators that best practice is being applied.

10. Assessment of Impacts / Response to ESD Requirements

10.1 Lines of Evidence

There a number of lines of evidence to suggest that the use of the Princess Pit as a TSF would have acceptable environmental impacts. A discussion of these lines of evidence is provided in this section.

Geochemical Fixation

The formation of the uranium deposit is controlled by the redox conditions within the groundwater system. Oxidative conditions promote uranium mobility, whereas reductive conditions tend to fix uranium. These conditions have not only resulted in the formation of the MRUP deposit, however other mineral deposits have been formed in the same palaeochannels to the south.

The aquifers have high concentrations of organic material (refer Table 5). Drainage of tailings liquor above the water table has a high likelihood of intersecting carbonaceous and ligneous sediments. Due to their organic carbon contents, these materials provide a natural means of retaining free uranium, rendering it immobile by means of adsorption and precipitation.

Density contrasts exist between the hypersaline groundwater within the aquifers underlying the Princess Pit TSF, and the tailings water. The density contrast would promote the plume to be maintained in the upper parts of the saturated zone water column, which in turn increases the likelihood of any plume:

- increased contact time with carbonaceous and ligneous sediments within the lithological profile.
- The plume flowing through lower permeability sediments (the coarser grained sediments / thicker, cleaner sands are located within the basal parts of the palaeochannel).

To quantify the potential for geochemical fixation, the PHREEQC geochemical model was applied to predict changes in key parameters in groundwater, e.g. pH, U, Zn and Cu, over a distance of 12,000 m from the tailings pit. Attenuation processes have been modelled within a one dimensional advection-dispersion module in PHREEQC, and ten predictive scenarios were assessed, considering variations in the source loading, aquifer organic material, and aquifer cation exchange capacity.

After an advective groundwater movement of 12,000 m, it is predicted that natural geochemical mechanisms within the aquifer will attenuate the leachate plume in relatively close proximity to the tailings pit. The attenuation is primarily attributable to adsorption of protons and metals onto clay exchange sites and OM binding sites.

Interaction between the leachate and groundwater is predicted to result in the formation of the lead phosphate minerals pyromorphite and plumbogummite and the slight dissolution of the aluminium sulphate mineral jurbanite. No zinc minerals are predicted to form since the initial groundwater environment is not sufficiently reducing to form ZnS (based on available data). Cuprous ferrite ($CuFeO_2$) and the uranium minerals coffinite and uraninite are predicted to occur in groundwater under existing conditions and predicted to remain in saturated form.

When the initial uranium concentration in groundwater is 0 mg/L, the clay exchange and OM binding sites are dominated by the major cations (sodium, calcium and magnesium). As the leachate migrates into groundwater, protons and cations from the leachate (including U(VI), Zn and Cu) exchange with the sodium on the clay exchange sites and the calcium and magnesium on the OM surface binding sites. However, when the initial uranium concentration in groundwater is higher, uranyl ions held onto OM binding sites are released as protons and metal ions from the leachate interact with the groundwater resulting in an increase in the uranium concentration in groundwater (refer Figure 32).

The potential for an increase in uranium concentration down-gradient of the tailings pit requires further investigation and can be refined with more information regarding the spatial variability of pH, redox conditions, OM content and uranium concentrations in groundwater.

Low Value Groundwater Resource

The groundwater environment within the Tertiary age palaeochannel system is a low quality resource based on a number of factors:

- Groundwater levels are deep and therefore beyond reasonable access by the vegetation
- Groundwater quality is poor, and generally over 20,000 mg/L TDS. This significantly limits its application for stock-watering, and is generally too saline for vegetation.
- Stygofauna and troglofauna have not been identified in the proposed area of the Ambassador-Princess operations (Mulga Rock East).

Aquifer Injection

Groundwater seepage from dewatering activities is to be re-injected into the aquifer down-gradient of the Princess Pit TSF. Whilst this may be a relatively short-term activity, i.e. 10 to 15 years, it would create a water table mounding and a hydraulic control on groundwater flow. The influence of mounding may extend longer than this period, owing to the time for water level recovery, and the low recharge rates in the aquifer.

Other Sites

Literature review of Insitu Leach mining at other sites, e.g. 4-Mile deposit in South Australia suggests that plume transport distances in aquifers devoid of organic matter and characterised by much higher hydraulic conductivities are less than 5 km (<1,000 years) based upon dilution and aquifer – water reactions.

11. Conclusions

The target deposits (Ambassador, Emperor, Princess and Shogun) lie in a structurally controlled palaeochannel characterised by a sedimentary sequence of Quaternary-age sediments, overlying Neogene/Palaeogene-age sediments, overlying Permian basement rock. These sediments are of fluviatile – lacustrine origin and compromise a sequence of interbedded sandstone, claystone, lignite and minor conglomerate. The piezometric surface generally correlates with redox front between the reduced carbonaceous lignite and overlying, oxidised clays.

The lithology of these Eocene sediments, i.e. lignite and ligneous clays and sands, suggest that they are not highly transmissive and potentially confine the underlying coarse-grained sand sequences. Groundwater flow appears to consistent with the meandering of the palaeochannel, flowing in a general south westerly direction across Princess and Ambassador Pits at a gradient of approximately 0.002. Groundwater is generally acidic (pH 3 to 8) and highly saline (approximates 20,000 mg/L TDS) with low dissolved trace metal concentrations. ORP sampling data present mildly reducing to oxidising aquifer conditions inconsistent with an expected reducing environment supporting the formation of uranium deposits. The data possibly results from aerating sampling techniques and is not considered reliable.

The proposal to disposal of ore processing wastes to a mine void (Princess Pit) provides a number of benefits to the operations in terms of long-term management of dust emissions and run-off, however there are concerns that use of the Princess Pit would result in unacceptable impacts to the groundwater environment. To quantitatively assess these impacts, geochemical modelling was undertaken to assess the fate and transport of the uranium, and other contaminants of concern in groundwater. Additional analytical groundwater modelling was undertaken to assess the sensitivity of the inputs into the quantitative analysis.

There are a number of lines of evidence to suggest that the risks associated with using the Princess Pit as a TSF are acceptable:

- Over a period of 10,000 years, it is predicted that natural geochemical mechanisms within the aquifer will attenuate the leachate plume in relatively close proximity to the tailings pit. The attenuation is primarily attributable to adsorption of protons and metals onto clay exchange sites and OM binding sites.
- Conservative advective-dispersive groundwater flow modelling indicates, that under a variety of source loadings (continuous, 100 year, 200 year and 1,000 year pulse), concentrations of uranium at the site boundary, based on an initial input of 0.028 mg/L would have attenuated to 0.007 mg/L (or less). Modelling adopting retardation results in significantly retarded and attenuate concentrations. However it is noted that this was based on literature and not site specific testing.
- There are no permanent surface water bodies present onsite.
- Identified potential receptors such as Queen Victoria Spring Nature Reserve and Ponton Creek are unlikely to be impacted based on a) interpreted disconnection from groundwater, and b) separation distance from the site.
- The land has limited commercial use, supporting gold and uranium mining and possibly broad acre livestock grazing, however it is predominantly unused.
- Based on its salinity, groundwater has limited application for abstractive use. It is unsuitable for potable use, irrigation or livestock. Treatment, e.g. desalination, would be required for such purposes.

- Native vegetation is unlikely to be groundwater-dependent given their shallow rooting depths relative to the depth to groundwater at the Princess Pit.
- The geology and groundwater conditions at Mulga Rock indicate a low potential for the presence of stygofauna within the project area (Rockwater, 2015).

To address the uncertainties with the analysis, and to provide greater confidence to regulators, a number of recommendations are made regarding the establishment of a groundwater monitoring program for the Princess Pit TSF and better characterisation of aquifer hydraulic parameters.

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13. Limitations

This report: has been prepared by GHD for Vimy Resources Limited and *may only be used and relied on by Vimy Resources Limited for the purpose agreed between GHD and the Vimy Resources Limited as set out in Section 4 of this report.*

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14. Glossary of Hydrogeological Terms

Term	Definition
Annulus	The space between the rising main and the casing, or between the casing and the wall of the well.
Anisotropic	Having some physical property that varies with direction.
Aquifer	A geologic formation, a group of formations or part of a formation that is water bearing. A geological formation or structure that stores and transmits water to wells, springs and seeps.
Aquifer, perched	Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.
Aquifer System	A body of permeable or relatively permeable materials that functions regionally as a water yielding unit. It comprises two or more permeable units separated by at least locally by confining units that impede groundwater movement.
Aquifer Test	A test undertaken to determine the hydraulic properties of an aquifer. It involves the withdrawal of measured quantities of water from or the addition of water to a well and the measurement of resulting changes in aquifer pressure.
Aquitard	A saturated by poorly permeable bed that impeded groundwater water movement and does not yield water freely to wells, but which may transmit appreciable water to or from adjacent aquifers.
Artesian Well	A well deriving uts water from a confined aquifer in which the water level stands above the ground surface; synonymous with flowing artesian wells.
ASR	Aquifer Storage and Recovery is the re-injection of water (typically potable or semi-potable) back into an aquifer for later recovery and use
ASS	Acid Sulphate Soil (refer to PASS)
AASS	Actual Acid Sulphate Soil
Available Drawdown	The difference between the standing water level and the pump intake (i.e. the amount of water above a pump prior to pumping).
Baseflow	Also called drought flow, groundwater recession flow, low flow, and sustained or fair-weather runoff), is the portion of streamflow that comes from "the sum of deep subsurface flow and delayed shallow subsurface flow"
Beneficial Use	A use of the environment or any element of the environment which is conducive to public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from the effects of waste discharges, emissions or deposits
Boundary	A lateral discontinuity or change in the aquifer resulting in a significant change in hydraulic conductivity, storativity, or recharge.
Capillary fringe	The zone at the bottom of a vadose zone where groundwater is drawn upward by capillary force.
Confined Aquifer	A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations. Confined groundwater is generally subject to pressure greater than atmosphere.
Development	The act of repairing damage to the formation caused by drilling procedures and increasing the porosity and permeability of the materials surrounding the intake portion of a well.
Delayed Yield	Gravity drainage of water from interstices in the unsaturated zone, which may occur more slowly than the lowering of the water table in an unconfined or semi-confined aquifer. The effect becomes negligible as the pumping period increases.
Discharge	The volume of water pumped or flowing from a well per unit of time, expressed in litres per second.
Drawdown	The distance between the static water level and the surface of the cone of depression
Evaporation	In groundwater terms, evaporation is the loss of water from the water table to the atmosphere.

Term	Definition
Evapotranspiration	Loss of water from a land area through transpiration of plants and evaporation from the soil
Freshwater / saline interface	The contact between two groundwaters of varying salinity, typically occurring near coastal regions, but can occur in terrestrial environments. The flow is governed by density flow processes, and the contact described as a mixing zone. Saline intrusion is when the movement of salt water occurs into a body of fresh water. It can occur in either surface water or groundwater basins.
GDE	Groundwater Dependent Ecosystem – Ecosystems that require a supply of groundwater (either directly or indirectly) to maintain their current structure (special composition) and function (for example, rates of carbon fixation).
GIS	Graphical Information System
Grouting	The operation by which grout is placed between the casing and sides of a well bore (annulus) to a predetermined height above the bottom of the well. This secures the casing in place and excludes water and other fluids from the well bore.
Groundwater Flow System	Groundwater flow is defined as the "…part of streamflow that has infiltrated the ground, has entered the phreatic zone, and has been discharged into a stream channel as spring or seepage water". Flow is driven by hydraulic gradients,
Head	Energy contained in a water mass, produced by elevation, pressure or velocity
Head Loss	That part of head energy which is lost because of friction as water flows
Heterogeneous	Non uniform in structure or composition throughout.
Homogeneous	Uniform in structure or composition throughout
Hydraulic Conductivity	The rate at which water at the prevailing kinematic viscosity will move under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow, expressed in metres per day. NOTE: This definition assumes medium in which the pores are completely filled with water.
Hydraulic Gradient	The rate of change in total head per unit of distance of flow in a given direction.
Hydrogeologic	Those factors that deal with subsurface waters and related geologic aspects of surface waters.
Interference	The condition occurring when the area of influence of a water well comes into contact with or overlaps that of a neighbouring well, as when two wells are pumping from the same aquifer or are located near each other.
Isotropic	Said of a medium whose properties are the same in all directions.
Leachate	The liquid that has percolated through solid waste and dissolved soluble components.
Lost Circulation	The result of drilling fluid escaping from a borehole into the formation by way of crevices or porous media.
MAR	Managed Aquifer Recharge
Monitoring Bore	Refer Observation bore
Numerical Model	A groundwater model is a (computer) program for the calculation of groundwater flow and level. Some groundwater models include (chemical) quality aspects of the groundwater. Groundwater models may be used to predict the effects of hydrological changes (like groundwater abstraction or irrigation developments) on the behaviour of the aquifer and are often named groundwater simulation models. As the computations in mathematical groundwater models are based on groundwater flow equations, which are differential equations that can often be solved only by approximate methods using a numerical analysis, these models are also called mathematical, numerical, or computational groundwater models.
Observation Bore	A well drilled in a selected location for the purpose of observing parameters such as water levels and pressure changes.
Partial Penetration	The condition of the intake portion of the wellbeing less than the full thickness of the aquifer.

Term	Definition
PASS	Potential Acid Sulphate Soil (and ASS). Acid Sulphate soils are naturally occurring soils, sediments or organic substrates (e.g. peat) that are formed under waterlogged conditions. These soils contain iron Sulphide minerals (predominantly as the mineral pyrite) or their oxidation products. When oxidised they can generate acidic (aggressive) groundwater
Permeability	The property of capacity of a porous rock, sediment or soil for transmitting a fluid, it is a measure of the relative ease of fluid flow under unequal pressure.
Piezometer	A pipe in which the elevation of the water level or potentiometric surface can be determined. The pipe is sealed along its length and open to water flow at the bottom.
Potentiometric surface	A surface that represents the standing or total hydraulic head. NOTES: 1. In an aquifer system, it represents the levels to which water will rise in tightly cased wells. 2. The water table is the potentiometric surface of an unconfined aquifer.
Pump column	That part of the rising main from a pump within the well.
Recovery	The difference between the observed water level during the recovery period after cessation of pumping and the water level measured immediately before pumping stopped.
Residual drawdown	The difference between the observed water level during the recovery period following pumping and the pre-pumping water level.
Semi-confined (or leaky) aquifer	An aquifer confined by a layer of moderate permeability (aquitard) that allows vertical leakage of water into or out of the aquifer.
Specific Capacity	The rate of discharge of a water well per unit of drawdown. IT varies with duration of discharge.
Specific Yield	The ration of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.
Spring	A spring — also known as a rising or resurgence — is a component of the hydrosphere. Specifically, it is any natural situation where water flows to the surface of the earth from underground. Thus, a spring is a site where the aquifer surface meets the ground surface.
Static Water Level or Standing Water Level	The level of water in a well that is not being affected by withdrawal of groundwater.
Static head	The height, relative to an arbitrary reference level, of a column of water that can be supported by the static pressure of the aquifer at a given point.
Steady State conditions	A numerical (or analytical) model in which model stresses do not vary over time. A steady state model is run until the modelled region is in equilibrium and no more changes in potentiometric head are calculated. Steady state conditions can often be modelled under long term transient conditions.
Storage Coefficient / Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. Note: 1. In an unconfined aquifer, it is normally referred to as specific yield. 2. In confined aquifers, it may be referred to as storage coefficient.
Stratigraphy	The study of rock / soil strata, especially of their distribution, deposition and age.
Submersible Pump	A water pump with the motor and pump assembly located below ground at the bottom of the well column. A pump which is designed to operate under water. Usually these are electrical centrifugal pumps and have the electrical motor enclosed in a waterproof casing.
Throughflow	Throughflow is the ‘horizontal’ flow of groundwater through a saturated aquifer.
Transmissivity	The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient.
Transient conditions	Typically applied in the context of a numerical model in which the model stresses (inflows and outflows) and aquifer head vary over time.

Term	Definition
Transpiration	The process by which water is absorbed by plants, usually through the roots, is evaporated in to the atmosphere from the plant surface.
Unconfined Aquifer	An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.
Vadose Zone	The zone containing water under pressure less than that of the atmosphere including soil water, intermediate vadose water and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is the water table.
Water table	The water table is the level at which the groundwater pressure is equal to atmospheric pressure. It may be conveniently visualized as the 'surface' of the subsurface materials that are saturated with groundwater in a given vicinity. However, saturated conditions may extend above the water table as surface tension holds water in some pores below atmospheric pressure
Well Yield	The volume of water discharged from a well. Usually measured in litres per second or ML/day.

Appendices

Appendix A – Neighbouring Bore Information

Table 21 Summary of bore construction and location data for neighbouring bores

Bore	GDA94 z55)		Distance from Lease Boundary (approx. km)	Location in relation to Mulga Project	Catchment	Site Purpose	Groundwater Area	Groundwater Subarea	Drilled Depth (m)	Screened Interval (m)	Date Drilled
	Easting	Northing									
20079170	488061	6674680	85	West	Raeside-Ponton	Livestock	Goldfields	Raeside	-	-	2/01/1900
20079171	478026	6680445	95	West	Raeside-Ponton		Goldfields	Raeside	18.29	-	2/01/1900
20079456	536357	6603112	96	South	Raeside-Ponton		Goldfields	Rebecca	4.27	-	2/01/1900
20079457	536357	6603112	96	South	Raeside-Ponton		Goldfields	Rebecca	4.27	-	2/01/1900
20079458	537512	6602545	98	South	Raeside-Ponton		Goldfields	Rebecca	5.49	-	2/01/1900
20079459	543698	6603865	92	South	Raeside-Ponton		Goldfields	Rebecca	48.46	-	30/06/1962
20079460	542927	6600218	96	South	Raeside-Ponton		Goldfields	Rebecca	36.58	-	2/01/1900
20079461	535200	6603070	97	South	Raeside-Ponton		Goldfields	Rebecca	10.97	-	2/01/1900
20079610	561909	6691610	1.7 Lease 3900219	East of Emperor	Lake Carey	Observation	Goldfields	Minigwal	67	44.2 to ??	12/11/84
20079611	559343	6693475	0.8 Lease 3900876	North of Emperor	Lake Carey	Observation	Goldfields	Minigwal	74.5	-	21/11/84
20080288	646430	6613490	110	South-east	Lake Carey		Nullarbor	Nullarbor	45.72	58.5 to 62.2	2/01/1900
20080289	646590	6612198	110	South-east	Lake Carey		Nullarbor	Nullarbor	44.2	?? to 70.5	2/01/1900
20080290	647609	6612307	110	South-east	Lake Carey		Nullarbor	Nullarbor	45.72	-	2/01/1900
20080291	648604	6619182	110	South-east	Lake Carey		Nullarbor	Nullarbor	78.03	-	2/01/1900
23022464	602455	6729646	58	North east	Lake Carey	Exploration	Goldfields	Minigwal	28	-	1/08/2000
23022465	602470	6729643	60	North east	Lake Carey	Exploration	Goldfields	Minigwal	190	-	4/08/2000
23022466	614890	6728018	62	North east	Lake Carey	Exploration	Goldfields	Minigwal	295	-	11/08/2000
23023840	644431	6613397	110	South-east	Lake Carey		Nullarbor	Nullarbor	N/A	N/A	N/A

Note: Dark shading indicates that these wells are [possibly within the site area

Table 22 Summary of Water Level and Quality Data for Neighbouring Bores

Bore ID	Water Level Data		Water Quality Data					
	Date	Water Level	Date	Conductivity (µS/cm)	pH	TDS (mg/L)	Water supply (m^3/day)	Aquifer
20079170	N/A	N/A	01/01/1900	N/A	N/A	5000	N/A	Unknown
20079171	N/A	N/A	01/01/1900	N/A	N/A	11440	N/A	Unknown
20079459	N/A	N/A		N/A	N/A	8000	N/A	Unknown
20079610	12/11/1984	30.2		N/A	N/A	59100	15	Unknown
20079611	21/11/1984	27.9		N/A	N/A	89300	980	Unknown
20080289	01/01/1900	41.15	01/01/1900	N/A	N/A	N/A	21.8	Unknown
20080291	01/01/1900	45.72	01/01/1900	N/A	N/A	N/A	32.7	Unknown
23022466	11/08/2000	105.94		N/A	N/A	5300	N/A	Unknown
23023840	N/A	N/A		600	8.1	N/A	N/A	Unknown

Note: N/A not available

Appendix B – Groundwater Risk Register

Risk No.	Hazard	Pathway	Description of consequences	Long term / short term	Initial Risks			Uncertainty	Mitigation Measures	Revised Risks			Comments
					Consequence	Likelihood	Risk Rating			Consequence	Likelihood	Risk Rating	
GW01	Uranium & heavy metals	Introduced through tailings leachate	Migration of uranium occurs such that concentrations at the lease boundary are above background concentrations	Long term	*Catastrophic*	*Rare*	*High*	High	Natural processes with aqufier.	*Catastrophic*	*Rare*	*High*	1. Implement a monitoring program 2. Undertake geochemical and fate and transport modelling (as documented in report) Confirm analytical inputs (column testing)
GW02	Uranium & heavy metals	Introduced through tailings leachate	Rate of migration in the unsaturated zone leads to breakthrough into neighbouring Ambassador Pit during its mining	Short term	*Moderate*	*Possible*	*High*		Interception of leachate / segregation from dewatering circuit	*Moderate*	*Possible*	*High*	
GW03	Uranium & heavy metals	Introduced through tailings leachate, but migration facilitated by improperly abandoned exploration boreholes, or poor monitoring bore construction practices	Rate of migration is increased through preferred pathways such as abandoned exploration holes, leading to offsite effects.	Long term	*Minor*	*Possible*	*Medium*	Low	Grouting of exploration boreholes around Princess Pit. Application of the NUDLC (2012) minimum construction requirements.	*Minor*	*Possible*	*Medium*	Presence of unconsolidated sediments, small diameter bores, localised impacts only.
GW04	Uranium & heavy metals	Introduced through tailings leachate	Rate of migration is increased through preferred pathways such as faulting	Long term	*Minor*	*Unlikely*	*Low*	High		*Minor*	*Unlikely*	*Low*	Faults inferred, and within plastic sediments.
GW05	Uranium & heavy metals	Introduced through tailings leachate	Migration of uranium (and metals) is such that concentration exceed guidelines at discharging waterway	Long term	*Catastrophi*	*Rare*	*High*	High	Implementation of monitoring program to confirm results to quantitative monitoring	*Catastrophi*	*Rare*	*High*	Groundwater discharge to waterways not present on or near lease boundary.
GW06	Uranium & heavy metals	Introduced through tailings leachate	Migration of uranium (and metals) is such that concentrations have adverse effect on stygofauna	Long term	*Catastrophi*	*Rare*	*High*	Medium	Implementation of monitoring program to confirm results to quantitative monitoring	*Catastrophi*	*Rare*	*High*	Stygofauna not identified.
GW07	Uranium & heavy metals	Introduced through tailings leachate	Migration of uranium (and metals) is such that concentration exceed guidelines for livestock watering (or industrial use) in neighbouring bore	Long term	*Catastrophic*	*Rare*	*High*	High	Consultation with landholder / bore owner	*Catastrophic*	*Rare*	*High*	Vimy advises that only one operating bore on lease which supplies water to Ashanti Gold JV. Bore controlled by Vimy. Bore audit confirmed, however available information (and groundwater quality) suggests negligible use)
GW08	Uranium & heavy metals	Introduced through tailings leachate	Migration of uranium (and metals) is such that concentration reaches down-gradient mines	Long term	*Insignificant*	*Rare*	*Low*	Low		*Insignificant*	*Rare*	*Low*	Travel times and migration distances do not make this credible.
GW09	Uranium & heavy metals	Level of tailings close to (capillary) or above biogenic zone in Miocene sediments	Migration of uranium (and metals) is such that concentrations have adverse effect on stygofauna	Long term	*Moderate*	*Rare*	*Medium*	High	Design of TSF storage levels & monitoring of filling.	*Insignificant*	*Rare*	*Low*	Multiple bores thoughout the lease have charactersied the biogenic zone. Undertake prior to construction / TSF filling.
GW10	Integrity of aquitards	Mining to depths that result in thinning of aquitards or exposing the basal coarse sand aqufier	Reduced pathway for migration of uranium (and metals).	Long term	*Catastrophi*	*Rare*	*High*	High	Control of mining depths. Backfilling with fine grained materials.	*Catastrophi*	*Rare*	*High*	Needs to occur down-gradient of the Princess Pit.
GW11	Integrity of aquitards	Re-injection of water recovered from dewatering operations is injected above fracture gradients.	Creating pathways for uranium (and metals) to interact with the deeper basal coarse sand aquifer.	Long Term	*Insignifican*	*Rare*	*Low*	High	Monitoring of injection pressures.	*Minor*	*Rare*	*Low*	Re-injection borefield is located down-gradeint of the TSF. Modelling suggests that it is too remote to interaction with any leachate plume emanating from the in-pit TSF.

Appendix C – Groundwater Monitoring Program

Groundwater Monitoring Plan (GMP)

Scope

The purpose of a GMP is to describe the means by which the operator would aim to prevent, manage and control, or minimise the groundwater impacts associated with the Princess Pit TSF. The GMP would involve the establishment of a groundwater monitoring network and monitoring program with the objective of informing the existing conceptual understanding of groundwater systems around the TSF. This additional groundwater monitoring information will be available prior to the commencement of construction. An outline plan has been provided in this Report to document the minimum requirements of a GMP.

This Plan should be reviewed following the completion of additional groundwater monitoring so that specific information can be supplied (for example, bore identification, aquifer monitored).

Works (drilling, sampling, testing, gauging and monitoring) undertaken as part of the GMP will also further improve the hydrogeological understanding of the groundwater environment at Princess Pit TSF, and therefore possibly the build and calibration of a predictive numerical groundwater model. This model would be used to quantify impacts and assess the requirement for, and effectiveness of variation mitigation measures that have been proposed.

Objectives

The objective of the GMP will be to minimise the impact on groundwater and associated ecosystems during and post construction.

The targets are to avoid or minimise the impact on groundwater quality, as measured at the lease boundary.

Authorisation and approval

The GMP would be approved by the relevant referral agencies, for example, DER, EPA.

Monitoring Program components

Groundwater level

The GMP will provide reasonable spatial coverage of the study area, but also in the vertical perspective. This includes:

- operational monitoring bores installed as part of previous groundwater investigations;
- targeted locations / or installed as part of additional groundwater investigations; and;
- existing private bores (following audit), for example, stock bores, could be incorporated into the monitoring network following a review of their construction and condition.

This will be achieved through a groundwater observation bore network. The network will include:

- monitoring bores constructed to the minimum standards (NUDLC 2012);
- nested monitoring bores, i.e. monitoring of multiple aquifers within specific parts of the study area;

- monitoring bores to be surveyed (level to m AHD and location); and
- monitoring bores which are:
  - of known construction;
  - maintained in operational conditions;
  - kept secure from unauthorised access; and
  - clearly identified on the bore casing or headworks.

A preliminary monitoring network has been established throughout the site, however based on the information made available to GHD, the level of information regarding bore construction, intervals being monitored and seals, is variable.

As part of establishing the monitoring network would also allow for additional investigations. These could include aquifer testing (for example, slug tests to determine aquifer hydraulic conductivities, pumping tests to assess aquifer behaviour and determine aquifer transmissivity and storage coefficients), geophysical logging (for example, conductivity profiling), soil quality characterisation (for example, organic content, adsorptive capacities).

The frequency of groundwater level monitoring would vary between the pre-, during, and post operation phases of the project. A base monthly frequency would be adopted for the monitoring network prior to construction, however the frequency (and included bores) would be tailored to specific objectives within the study area during the construction phase.

Groundwater quality

Groundwater samples would be collected from monitoring bores. Groundwater monitoring would be in accordance with EPA guidelines, e.g. ANZECC/ARMCANZ (2000). Analytes to be incorporated into the monitoring program would include major cations and anions, organic and inorganic constituents and physical parameters (pH, TDS, ORP).

Similarly to groundwater level monitoring, the frequency of groundwater quality monitoring would vary between the pre-, during, and post construction phases of the project. A base quarterly frequency would be adopted for the monitoring network prior to TSF construction, however the frequency (and Sampling and Analytical Program) would be tailored to specific objectives within the study area during the construction phase.

The analytical program would consider the ANZECC/ARMCANZ (2000) water quality guidelines, and any identified naturally elevated constituent concentrations.

To confirm the presence or otherwise of stygofauna (organisms living within the groundwater environment), episodes of sampling would be included as part of the initial sampling events.

QA/QC

The GMP would include a quality assurance/quality control (QA/QC) program as part of its field procedures, based on relevant Australian Standards (Standards Australia 2005) and industry common practice. The QA/QC program undertaken could include the following:

- implementation of standard procedures including sampling equipment decontamination between sampling points;
- field measurement of groundwater quality parameters and purging records;
- field equipment calibration records
- preservation of samples with ice during transport from the field to the laboratory;
- use of laboratories certified by the National Association of Testing Authorities (NATA);
- transportation of samples with accompanying chain of custody (COC) documentation;

- collection of blind and split duplicate samples and calculated review of Relative Percent difference (RPDs);
- comparison of field and analytical data;
- compliance with sample holding times; and
- review of internal analysis of QC and laboratory duplicates.

Bore condition

The proponent would be responsible for maintaining operational monitoring bores. This would include periodical inspection, and repair or re-survey where required, of monitoring bores. Maintenance would be prompted from visual inspection and assessment during a site visit, but also where anomalous monitoring results (for example, water level or groundwater quality) are noted.

Data storage

Monitoring data would be stored (and backed-up) in a digital format, which facilitates simple information handling and transfer. Monitoring data would include:

- water levels;
- sampling purge details;
- metering data;
- field and laboratory water quality;
- bore condition; and
- QA/QC records (instrument calibration, laboratory program).
- Digital records of bore construction and location would also be maintained.

Reporting

Periodical reviews would be undertaken, with the review having the objective to interpret the data to determine:

- trends:
  - water level, quality and flow behaviour;
  - comparison against predicted water level trends and the radius of influence estimations;
- recommendations regarding improvements or refinements to the monitoring system, for example, network, frequencies, analytical scope;
- review of monitoring procedures, data collection and quality, training;
- collation and reporting for management and administration review;
- data distribution, for example, regulators, community groups, public access, education and further research.

Quantification of groundwater impacts

The proposed groundwater monitoring works will improve groundwater knowledge and support numerical groundwater modelling. This will in turn support quantification of the potential identified impacts arising from the various aspects of the proposed Princess Pit TSF.

The monitoring would assess the effectiveness of mitigation measures, establish trigger levels for intervention and assess the effectiveness of contingency measures.

Trigger levels

Triggers for management response are required to enable intervention to protect the study area biodiversity. This would likely comprise a tiered approach, with the amount of intervention increasing with the risk of adverse impact.

Groundwater quality triggers would be established based on maintaining the baseline groundwater quality. The groundwater baseline would be established through a pre-construction phase monitoring program, taking into consideration the ANZECC & ARMCANZ (2000) water quality guidelines and any identified naturally elevated constituent concentrations.

The groundwater level baseline would be established through a pre-construction phase monitoring program, however the establishment of groundwater level triggers would be based on a number of factors given the seasonal variability and climate influences on groundwater. Groundwater level triggers could be established to determine interventions.

As previously noted, some of the effects on ecological systems resulting from groundwater events may be more subtle and less easily determined. In some cases the response may not be immediate and may occur over a number of seasons. Where the GMP identifies changes to groundwater levels or quality, a trigger action could be to initiate additional ecological investigations. These investigations would include the collection of flora, vegetation and habitat structural information and fauna community data, to determine whether such groundwater changes translate into an impact on the assemblages and condition of site biodiversity.

Response plan and contingencies

The Response and Contingencies Plan, should a trigger level be reached, may include the following elements noted below. In addition to implementing appropriate responses, notification and reporting to other agencies may be required.

Changes to groundwater quality

Changes to groundwater quality would prompt trigger actions and some may include:

- re-testing or repeat monitoring as a QA/QC check;
- hydrogeological review;
- bore performance testing;
- geophysical testing; and/or,
- sampling of other nearby monitoring bores.

Considerable intervention may be deemed necessary resulting in the need for site specific groundwater investigations. For example, additional drilling to characterise plumes, installation of injection bores/extraction bores, groundwater/water treatments, recharge treatments, ecological stress investigations, and possibly groundwater remediation.

Appendix D – Geochemical Modelling

Geochemical Modelling

Modelling Approach

Geochemical modelling has been undertaken to investigate the fate and transport of COPC (Contaminants of Primary Concern) into the receiving aquifer. Geochemical modelling software PHREEQC (Parkhurst and Appelo, 1999) was used to establish the speciation and saturation of aqueous species and predict geochemical changes in groundwater quality that may occur in response to proposed emplacement of tailings.

PHREEQC is industry standard software for carrying out low temperature aqueous geochemical calculations. The database *wateq4f.dat* (Ball and Nordstrom, 1991) was used to define thermodynamic data for aqueous species and gas and mineral phases. This database contains a sufficient amount of thermodynamic data for potential contaminants of concern, defines the exchange species and is anecdotally preferred over MINTEQ by David Parkhurst, the co-developer of PHREEQC.

The following assumptions have been made:

- All reactions are instantaneous and at equilibrium.
- The system is closed with respect to CO_2.

Initial Solutions

The water quality data used to define the initial solutions of leachate and groundwater are provided in Table 23. The number of data points used to calculate average values for each parameter are also indicated in Table 23. Note that metal concentrations are reported for total metals for both leachate and groundwater.

Leachate water quality was determined from a review of the results of the Australian Standard Leaching Procedure (ASLP) tests undertaken by ANTSO (2015) to characterise the leachate predicted to occur from tailings materials. It is important to acknowledge that the ASLP data represents the worst case scenario as the large solid to solution ratio (i.e. 1:20) avoids the common ion effect and favours the forward dissolution reaction from solid to aqueous phase. In reality, a ratio of 1:<0.01 is likely to occur which has the tendency to restrict the release of metals and metalloids into the surrounding soil. In addition, the chemistry adopted for modelling was based on the higher (in the case of pH, the lower) of the results of the two bulk tests leached using the synthetic site water sample and two bulk tests leached using the MilliQ water (ANTSO, 2015). The highest concentrations were adopted so that a worst case scenario would be represented in the geochemical modelling.

Groundwater quality was determined from a review of historical data obtained from a number of bores at Mulga Rock. The chemistry adopted for modelling was generally based on an average of the combined dataset from 2009 to 2015.

Table 23 Water quality data for initial solutions

Parameter	Units	DoH (2006) non-potable groundwater	ANZECC & ARMCANZ (2000) Long-term irrigation water	Leachate		Groundwater	
				Count	Worst Case	Count	Average
pH	pH units	-	-	4	2.64	396	5.0
pE	pE units	-	-	4	9.6	106	2.2
Aluminium	mg/L	2	5	4	6	7	2.5
Arsenic	mg/L	0.07	0.1	4	0.1	1	0.03
Barium	mg/L	7	-	4	0.35	12	0.053
Calcium	mg/L	-	-	4	147	60	213
Cadmium	mg/L	0.02	0.01	4	0.24	14	0.027
Chloride	mg/L	-	-	4	3,000	60	5,326
Cobalt	mg/L			4	2.2	12	0.83
Copper	mg/L	20	0.2	4	6	5	3.1
Chromium	mg/L			4	0.08	8	0.012
Iron	mg/L	3	0.2	4	10	7	9.3
Lead	mg/L	0.1	2	4	7.7	7	0.59
Magnesium	mg/L	-	-	4	224	60	344
Manganese	mg/L	5	0.2	4	0.09	12	1.3
Nickel	mg/L	0.2	0.2	4	6.6	60	0.25
Potassium	mg/L	-	-	4	97	60	134
Selenium	mg/L	0.1	0.02	4	0.1	5	0.026
Silicon	mg/L	-	-	4	31	30	18.5
Sodium	mg/L	-	-	4	2,124	60	2,967
Strontium	mg/L	-	-	4	2.3	20	6.5
Sulphur	mg/L	-	-	4	369	60	1,205
Uranium	mg/L	0.2	0.01	4	0.14	6	0.028
Zinc	mg/L	30	2	4	10.3	51	0.79

The equilibrium or disequilibrium of the initial solutions were checked using PHREEQC to validate the equilibrium assumption. The equilibrium assumption is normally validated when all potential mineral phases are in solution or there is equilibrium between the solid and aqueous phases (saturation) since precipitation is a kinetic process.

The water chemistry reported in Table 23 was input into PHREEQC, with each sample being defined as a separate SOLUTION. For both the leachate and groundwater, PHREEQC predicted that iron oxides and hydroxides would be precipitating (such as hematite and goethite), as well as various aluminosilicate and sulphate minerals (including barite) within the groundwater.

Therefore, based on the water chemistry data the initial solutions are not at equilibrium. However, since this assessment is concerned primarily with predicting geochemical conditions over a large time scale it is not considered that the disequilibrium of the initial solutions will affect the results of this assessment and the equilibrium assumption is considered to remain valid.

Based on initial solution calculations, PHREEQC predicts that existing uranium in groundwater is primarily in the U(VI) form since the redox conditions are not sufficiently reducing (based on available groundwater data). Therefore, it is not considered that U(VI) from the tailings that may migrate to groundwater in the future will immobilise via reduction and precipitation processes.

Model Construction and Inputs

PHREEQC was used to carry out geochemical calculations of the following leachate attenuation mechanisms:

- Dilution;
- Mineral phase precipitation and dissolution;
- Cation exchange; and
- Adsorption onto organic matter (OM).

Calculations were undertaken within a one dimensional advective-dispersive transport module.

Dilution

Mixing of leachate and groundwater occurs as a result of dispersion within the aquifer, resulting in dilution of the leachate. The TRANSPORT module uses the longitudinal dispersivity values from Table 27 to calculate mixing ratios as the leachate migrates through the aquifer.

Precipitation and dissolution

As part of mixing calculations, PHREEQC calculates the saturation index of each mineral phase to determine whether mineral phases are saturated (i.e. precipitating) or unsaturated. The pH and redox conditions are key solution properties that determine speciation and saturated indices. Thermodynamic data from the database *wateq4f.dat* has been used in these calculations.

Cation exchange

PHREEQC uses the EXCHANGE module to model the adsorption of cations from the aqueous phase onto permanently charged clay mineral exchange sites. Exchange reactions between exchange site X^- and most of the common cations are included in the *wateq4f.dat* database. The following supplementary exchange reaction (adapted from McKinley *et al*, 1995) was included for U(VI):

$UO_2^{+2} + 2X^- = UO_2X_2$

log k 0.3

Cation exchange capacities (CEC) for the clay exchange site of 5 and 25 milliequivalents (meq) per 100 g (meq/100 g) were modelled. These values were in the range reported by Vimy (< 5 to 66 meq/100g) for 21 sediment samples collected at depths of 38 to 56.5 m below ground level, averaging around 27 meq/100g (Appendix G). An aquifer clay content of 25% and effective porosity of 0.2 was adopted to calculate the moles of exchange sites.

Surface adsorption/complexation

The SURFACE module has been used to model adsorption or complexation of ions onto variably charged OM surfaces. Reaction constants for the complexation of cations onto OM binding sites are not included in the *wateq4f.dat* database and no constants for complexation onto lignite could be found in literature. However, a number of reaction constants for cation complexes on humic acid are reported in Tipping et al (2011) and were adopted for this assessment. The code defining the surface binding sites is shown in Figure 23.

```
SURFACE_MASTER_SPECIES
    H_a            H_aH

SURFACE_SPECIES
H_aH = H_aH                      log_k   0
H_aH = H_a- + H+                 log_k  -4.1
H_aH + Ag+ = H_aAg + H+          log_k 1.5
H_aH + Al+3 = H_aAl+2 + H+       log_k 2.67
H_aH + Ca+2 = H_aCa+ + H+        log_k 1.19
H_aH + Cd+2 = H_aCd+ + H+        log_k 1.61
H_aH + Cu+2 = H_aCu+ + H+        log_k 2.54
H_aH + Mg+2 = H_aMg+ + H+        log_k 0.98
H_aH + Mn+2 = H_aMn+ + H+        log_k 2.21
H_aH + Ni+2 = H_aNi+ + H+        log_k 1.6
H_aH + Pb+2 = H_aPb+ + H+        log_k 2.39
H_aH + Sr+2 = H_aSr+ + H+        log_k 1.49
H_aH + UO2+2 = H_aUO2+ + H+      log_k 2.64
H_aH + Zn+2 = H_aZn+ + H+        log_k 1.87
```

Figure 23 Surface Binding code

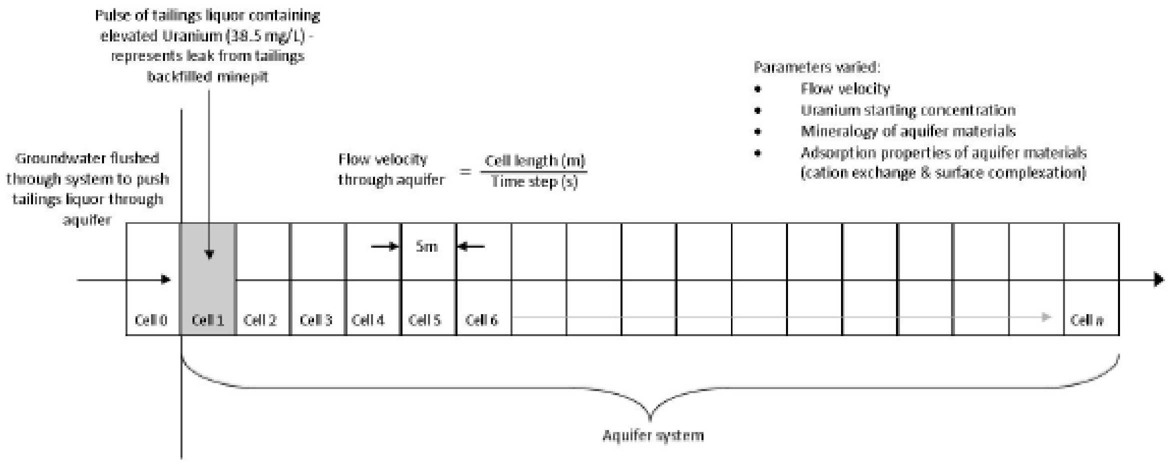
A binding site density of 7.1 meq/g for humic acids (PHREEQC user guide, example 19b) and aquifer OM contents of 1% and 20% have been adopted for modelling. These OM contents are generally consistent with the total carbon contents of the ore, analysed to range between 6 and 25% (Soil Water, 2015).

Thermodynamic data from Dzombak and Morel (1990), included in the *wateq4f.dat* database, was used to model cation adsorption onto variably charged amorphous iron oxide surfaces. Various simulations were undertaken to compare contaminant attenuation by OM surfaces and iron oxide surfaces. Strong iron oxide binding sites were found to function similarly to OM in terms of attenuation of potential contaminants of concern while the weak binding sites provided limited attenuation. Based on this analysis, only OM surfaces have been adopted in the geochemical modelling and have been used to represent combined attenuation from both OM surfaces and strong iron oxide surface binding sites.

Advective-dispersive transport

The attenuation mechanisms were run within the TRANSPORT module. The one dimensional transport path was divided into 120 cells of length 100 m for a total flow path of 12,000 m (approximate flow distance from Princess Pit to southern lease boundary, therefore used as 'point of compliance').

Models were run over 146 shifts, with each shift representing the time for groundwater to travel 100 m under advection only (based on the weighted average rate from Table 30). Results from shift 146 therefore predict geochemical conditions within each cell after 10,000 years. A longitudinal dispersivity of 25 m was adopted (Table 27). The 'worst case' leachate chemistry (Table 23) was used to define SOLUTION 0 while the average groundwater chemistry (Table 23) was used to define the SOLUTION 1-120 for the first time step as shown below.



Modelling Scenarios

A total of ten scenarios were modelled as summarised in Table 24. The initial uranium concentration in groundwater has been varied to assess the potential effect of the initial adsorbed uranium concentration on attenuation mechanisms.

For Scenarios 1 to 4, the initial uranium concentration in groundwater is 0 mg/L and therefore there is no uranium initially adsorbed to the clay exchange sites or OM binding sites. Lower uranium concentrations in groundwater are more likely to exist further away from the ore zone, however it was necessary to run these scenarios as part of the uncertainty analysis. The initial groundwater uranium concentration adopted for Scenarios 5 to 8 is the average concentration from Table 23.

Most scenarios were run under a continuous source boundary condition. Under the continuous source condition, leaching from the tailings pit is assumed to occur at constant source concentrations over the full modelling period of 10,000 years. This condition does not consider the reduction in leachate concentrations over time and therefore models a greater contaminant load that what will actually be introduced into the aquifer. Scenarios 5a and 8a were run using a constant source concentration over a 'pulse' of 100 to 200 years as discussed in Appendix E.

Table 24 Details of each modelling scenario

Scenario	Initial Uranium in Groundwater (mg/L)	Source Condition	Organic Material (%)	CEC (meq/100g)
1	0	Continuous	1	5
2	0	Continuous	1	25
3	0	Continuous	20	5
4	0	Continuous	20	25
5	0.028	Continuous	1	5
5a	0.028	Pulse	1	5
6	0.028	Continuous	1	25
7	0.028	Continuous	20	5
8	0.028	Continuous	20	25
8a	0.028	Pulse	20	25

Results

Predicted pH and concentrations of dissolved aluminium, barium, cadmium, copper, iron, nickel, lead, uranium and zinc after 10,000 years are shown in Figure 24 to Figure 33 below. Results are shown for those parameters for which worst case leachate concentrations exceed average groundwater concentrations (Table 23) and sufficient thermodynamic data are available.

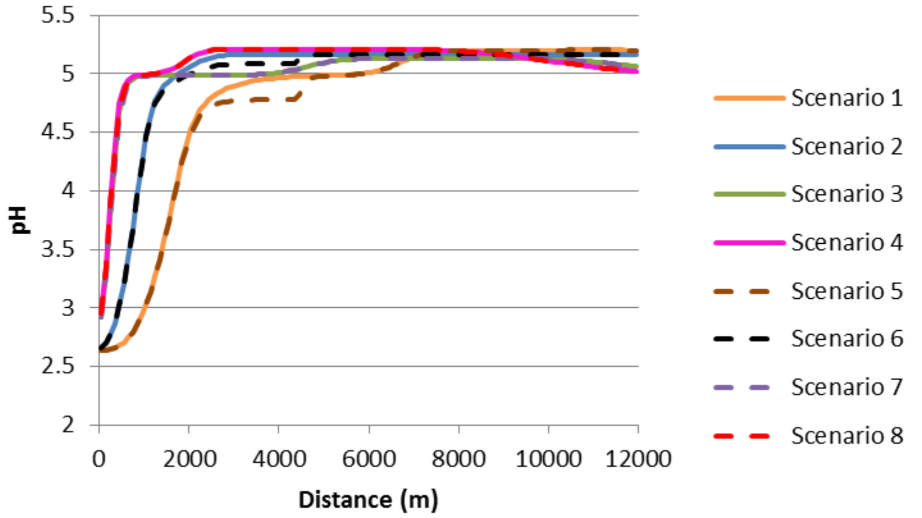


Figure 24 Predicted pH from source after 10,000 years

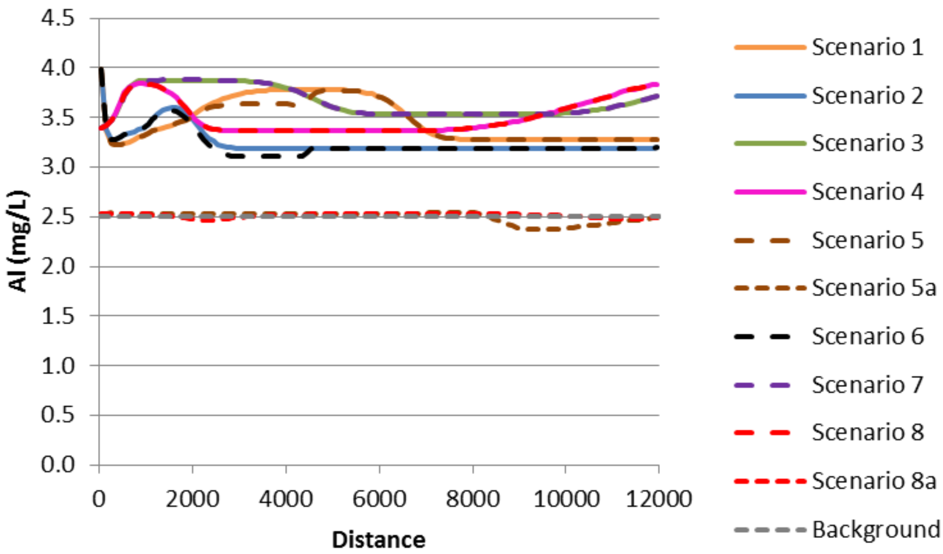


Figure 25 Predicted Al concentration from source after 10,000 years

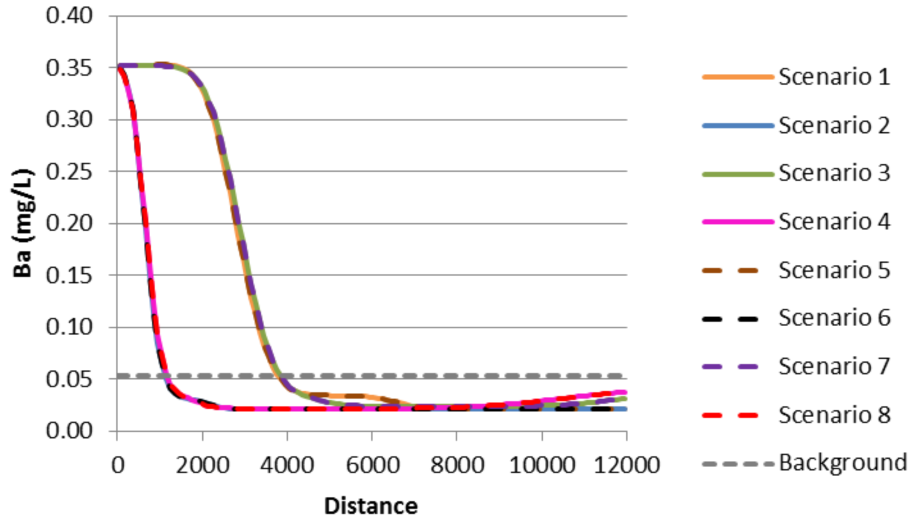


Figure 26 Predicted Ba concentration from source after 10,000 years

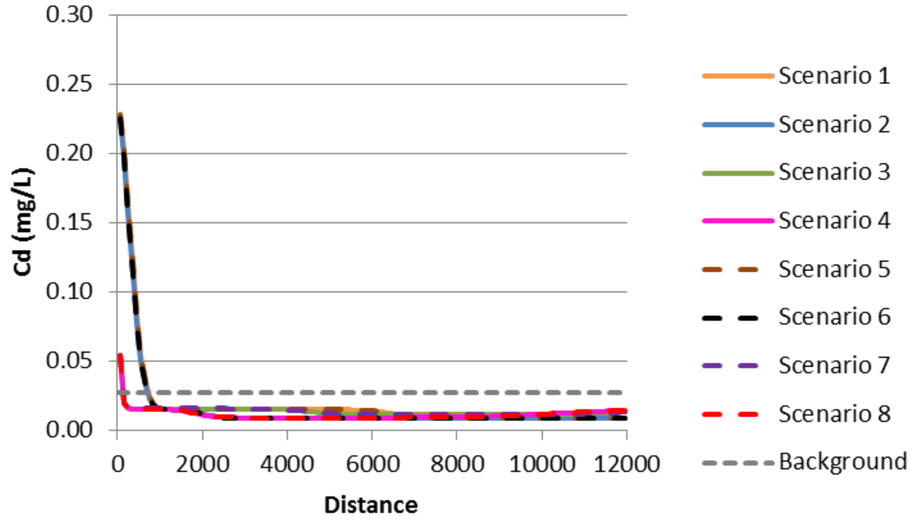


Figure 27 Predicted Cd concentration from source after 10,000 years

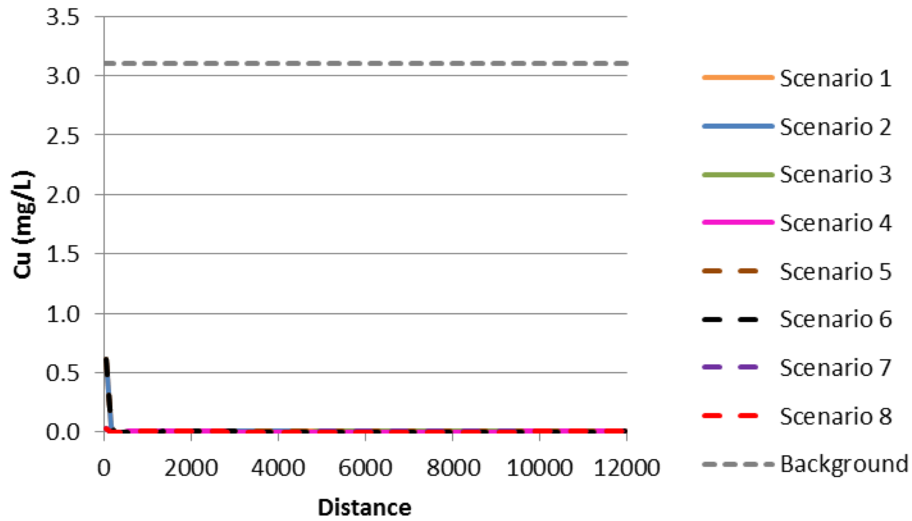


Figure 28 Predicted Cu concentration from source after 10,000 years

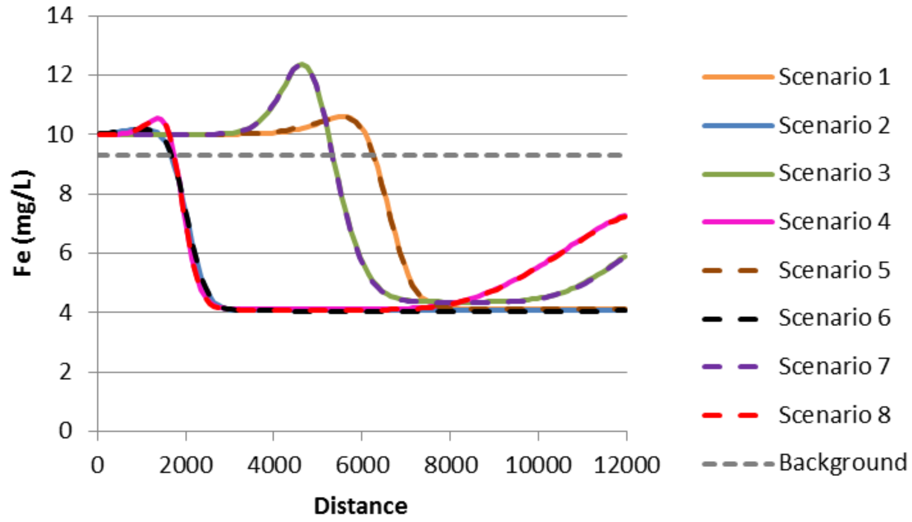


Figure 29 Predicted Fe concentration from source after 10,000 years

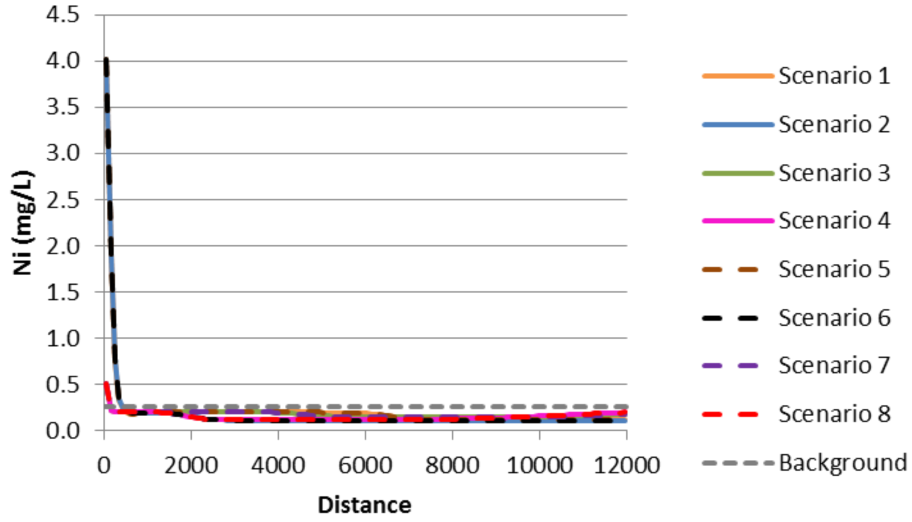


Figure 30 Predicted Ni concentration from source after 10,000 years

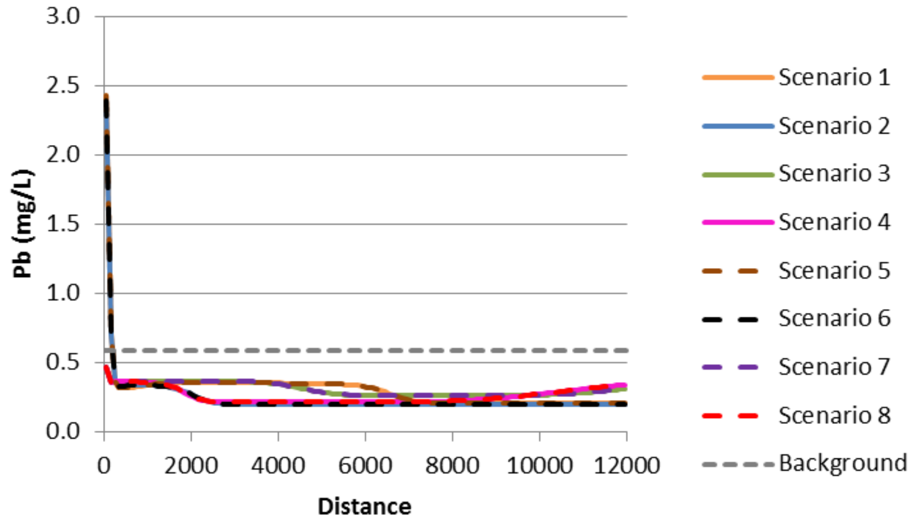
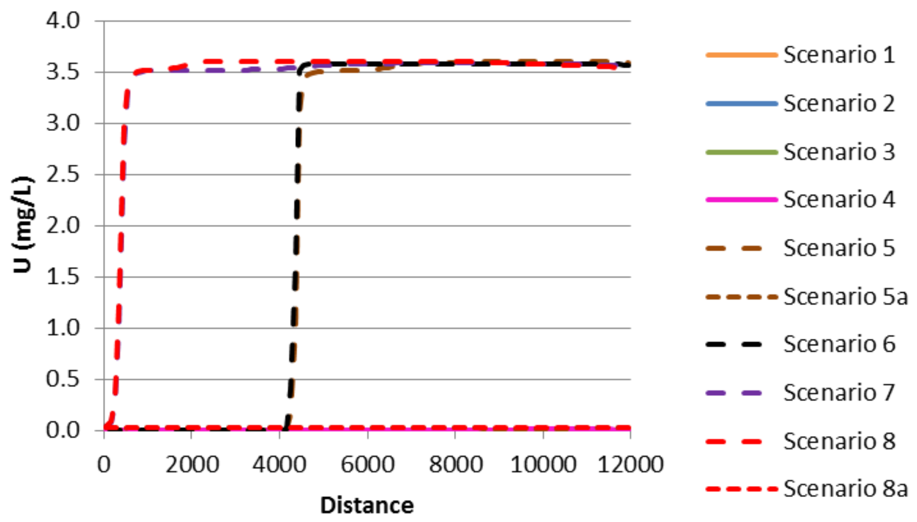


Figure 31 Predicted Pb concentration from source after 10,000 years



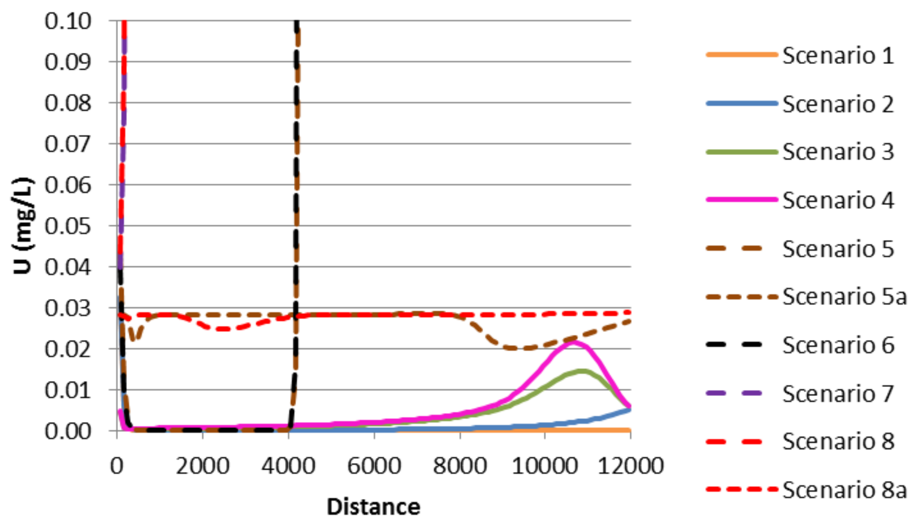


Figure 32 Predicted U concentration from source after 10,000 years (second figure is a zoomed in section of the first, only showing concentrations between 0 and 0.1 mg/L)

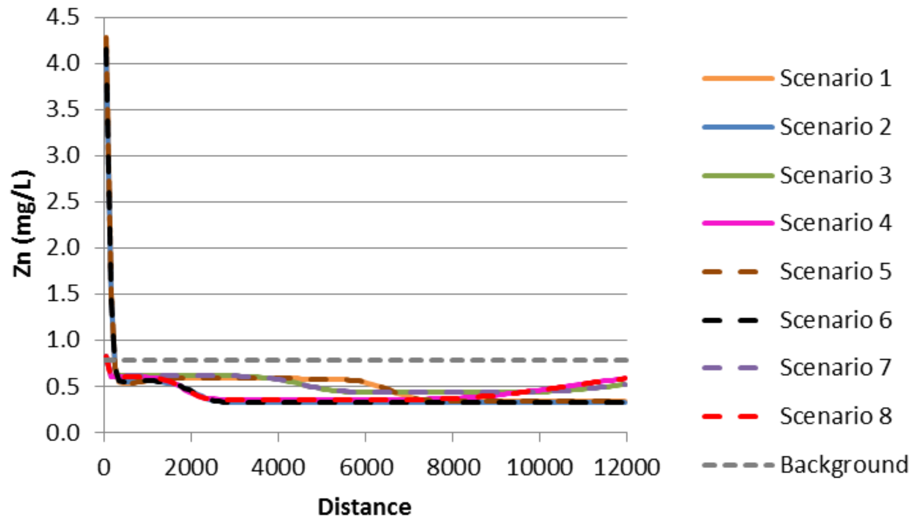


Figure 33 Predicted Zn concentration from source after 10,000 years

As shown in Figure 24, groundwater pH is predicted to be below 5 up to a distance of 700 m (for the scenarios with the higher proportion of OM) to approximately 4,500 m from the source after 10,000 years based on the worst case continuous source conditions. Groundwater pH at a distance of 12,000 m is not predicted to be affected after 10,000 years based on continuous source conditions. Under the pulse source condition, groundwater pH is predicted to be at background levels (pH 5) after 10,000 years.

For all scenarios, dissolved barium, cadmium, copper, iron, lead and zinc concentrations are predicted to be below initial average groundwater concentrations at a distance of 12,000 m after 10,000 years based on continuous source conditions. Dissolved copper, lead and zinc concentrations are only predicted to exceed initial groundwater concentrations up to a distance of 250 m from the source. Dissolved cadmium, barium and iron concentrations are predicted to exceed the initial groundwater concentration up to 650 m, 4,000 m and 6,250 m from the source respectively after 10,000 years.

As shown in Figure 25, the dissolved aluminium concentration is predicted to exceed the initial concentration in groundwater after 10,000 years along the entire groundwater flow path up to 12,000 m from the source for all continuous source condition scenarios. This is due primarily to insufficient adsorption of aluminium onto exchange and OM sites as the leachate migrates through the aquifer. Under pulse source conditions (Scenarios 5a and 8a), the dissolved aluminium concentration in groundwater is predicted to be consistently at or below the initial concentration in groundwater.

The predicted dissolved uranium concentration in groundwater for each scenario is shown in Figure 32. For the continuous source condition scenarios with an initial uranium concentration in groundwater of 0 mg/L (Scenarios 1 to 4), the uranium concentration is predicted to remain below 0.02 mg/L after 10,000 years. However, when the initial uranium concentration in groundwater is higher and consistent with the average existing groundwater concentration of 0.028 mg/L (Scenarios 5 to 8), the model predicts that there will be a release of uranium from OM binding sites and the concentration of uranium in groundwater will increase to approximately 3.5 mg/L. This increase occurs along the entire flow path under the worst case continuous source scenario. Under pulse source conditions however (Scenarios 5a and 8a), dissolved uranium in groundwater is predicted to be consistently at or below the initial concentration in groundwater (0.028 mg/L).

Discussion

The PHREEQC geochemical model has been used to predict changes in key parameters in groundwater (pH, Al, Ba, Cd, Cu, Fe, Ni, Pb, U, Zn) over a distance of 12,000 m from the proposed tailings pit. Attenuation processes have been modelled within a one dimensional advection-dispersion module. Ten scenarios have been modelled to address uncertainty of input parameters.

After 10,000 years, it is predicted that natural geochemical mechanisms within the aquifer will attenuate most contaminants within the leachate plume in relatively close proximity (i.e. within approximately 700 m) to the tailings pit. This is the case under the extreme worst case condition of a continuous source condition, demonstrating the capacity of the aquifer to naturally attenuate the leachate. The attenuation is primarily attributable to adsorption of protons and metals onto OM binding sites (and potentially amorphous iron oxide surfaces), noting that the influence of redox conditions on uranium attenuation is minor in the geochemical model since the existing groundwater environment was not found to be sufficiently reducing to immobilise (by reduction and precipitation) oxidised uranium from the tailings pit.

Interaction between the leachate and groundwater is predicted to result in the formation of the lead phosphate minerals pyromorphite and plumbogummite and the slight dissolution of the aluminium sulphate mineral jurbanite. No zinc minerals are predicted to form since the initial groundwater environment is not sufficiently reducing to form ZnS (based on available data). Cuprous ferrite ($CuFeO_2$), barite and the uranium minerals coffinite and uraninite are predicted to occur in groundwater under existing conditions and predicted to remain in saturated form.

The geochemical assessment has identified aluminium and uranium as potential contaminants of concern, however this is only the case under the extreme worst case condition of a continuous source input.

When the initial uranium concentration in groundwater is 0 mg/L, the clay exchange and OM binding sites are dominated by the major cations (sodium, calcium and magnesium). As the leachate migrates into groundwater, protons and metal cations from the leachate exchange with the sodium on the clay exchange sites and the calcium and magnesium on the OM surface binding sites. However, when the initial uranium concentration in groundwater is higher, uranyl ions held onto OM binding sites are released as protons and metal ions from the leachate interact with the groundwater resulting in an increase in the uranium concentration in groundwater (as shown in Figure 32). When the pulse of leachate input to groundwater is limited to 100-200 years, any increase in the uranium concentration in groundwater would be localised (i.e. a few hundred metres from the pit), however under the worst case scenario of continuous source conditions over 10,000 years an increase in uranium concentration further down gradient of the tailings pit is predicted. It is considered that this is an overly conservative assessment of down gradient uranium concentrations (based on a continuous source input over 10,000 years) and therefore does not warrant further investigation.

Appendix E – Analytical Groundwater Fate and Transport Modelling

Model Selection & Limitations

Transport in Groundwater

There are a number of processes that influence the fate and transport of constituents in groundwater and a summary has been provided in Table 25.

Table 25 Groundwater Transport Processes

Process	Description	Dependencies	Effect
Advection	Movement of solute by bulk ground-water movement. i.e. movement of mass entrained in flow.	Dependent on aquifer properties, mainly hydraulic conductivity and effective porosity, and hydraulic gradient. Independent of contaminant properties.	Main mechanism driving contaminant movement in the subsurface.
Dispersion (hydraulic or mechanical)	Fluid mixing due to ground-water movement and aquifer heterogeneities, i.e. variations in groundwater velocities.	Dependent on aquifer properties and scale of observation. Independent of contaminant properties. The degree of spreading associated with hydraulic dispersion depends solely upon the distance travelled due to advective transport, not the time taken to traverse the pathway, i.e. if the water does not move, the mass does not spread.	Causes longitudinal, transverse, and vertical spreading of the plume. Reduces solute concentration.
Diffusion	Spreading and dilution of contaminant due to molecular diffusion, i.e. random, molecular processes of Brownian motion	Dependent on contaminant properties and concentration gradients. Described by Fick's Laws. Molecular diffusion is not a function of groundwater movement – it can happen in both still and moving dissolved plumes	Diffusion of contaminant from areas of relatively high concentration to areas of relatively low concentration. Generally unimportant relative to dispersion at most ground-water flow velocities.
Sorption	Reaction between aquifer matrix and solute whereby compounds become sorbed to organic carbon or clay minerals. Sorption reactions tend to be rapid approaching equilibrium in minutes or hours.	Dependent on aquifer matrix properties (organic carbon and clay mineral content, bulk density, specific surface area, and porosity) and contaminant properties (solubility, hydrophobicity, octanol-water partitioning coefficient).	Tends to reduce apparent solute transport velocity and remove solutes from the ground water via sorption to the aquifer matrix. If a solute does not sorb at all to the aquifer mineral grains as it flows, the average rate of solute transport can be estimated directly from the (average linear) groundwater flow velocity. When a solute does sorb significantly, its migration is slower than the groundwater flow.

Process	Description	Dependencies	Effect
Recharge (Simple Dilution)	Movement of water across the water table into the saturated zone.	Dependent on aquifer matrix properties, depth to ground water, surface water interactions, and climate.	Causes dilution of the contaminant plume and may replenish electron acceptor concentrations, especially dissolved oxygen. This is not relevant over the long term for the constituents at MRUP.
Bio-degradation	Microbially mediated oxidation-reduction reactions that degrade contaminants.	Dependent on ground-water geochemistry, microbial population and contaminant properties. Biodegradation can occur under aerobic and/or anaerobic conditions.	May ultimately result in complete degradation of contaminants. Typically the most important process acting to truly reduce contaminant mass.
Volatilization	Volatilization of contaminants dissolved in ground water into the vapor phase (soil gas).	Dependent on the chemical's vapor pressure and Henry's Law constant.	Removes contaminants from ground water and transfers them to soil gas. This is not relevant to the constituents at MRUP.
Abiotic Degradation	Chemical transformations that degrade contaminants without microbial facilitation; only halogenated compounds are subject to these mechanisms in the ground-water environment.	Dependent on contaminant properties and ground-water geochemistry.	Can result in partial or complete degradation of contaminants. Rates typically much slower than for biodegradation. This is not relevant to the constituents at MRUP.
Partitioning from NAPL	Partitioning from NAPL into ground water. NAPL plumes, whether mobile or residual, tend to act as a continuing source of ground-water contamination.	Dependent on aquifer matrix and contaminant properties. as well as ground-water mass flux through or past NAPL plume.	Dissolution of contaminants from NAPL represents the primary source of dissolved contamination in ground water. This is not relevant to the constituents at MRUP.

Modelling Conceptualisation

In order to apply a broad screening approach to the fate and transport, some simplifications of the complex palaeochannel hydrogeology has been undertaken. A schematic concept of the modelling approach has been shown in Figure 34. It shows the completed in-pit TSF (either Princess Pit or the subsequent Ambassador Pit if required).

The facility is to be capped as part of the closure and rehabilitation. Capping would minimise the infiltration of rainfall and thus potential for additional dissolution and leachate generation from the tailings. Permeability studies of the tailings indicates that the materials are of low permeability, and that a low permeability crust would form due to evaporative drying.

The mass load to the aquifer from the in-pit TSF source is the liquor draining from the saturated tailings. The leachate would have concentrations as informed through the ASLP testing undertaken.

In the hydrogeological conceptualisation there were two identified pathways for the migration of leachate:

- Vertical drainage of tailings liquors from the in-pit TSF.
  This is expected to the dominant and most probable pathway. Leachate draining vertically through the sediments underlying the pit and migrating along the coarser grained lenses within the palaeochannel under regional hydraulic gradients.
  This is considered the highest risk for migration of leachate from the pit.

- Leachate draining from tailings deposited above the water table could migrate laterally through permeable beds.
  It is understood from modelling of the tailings permeability (Soil Water 2015) that lateral migration with the tailings would form a minor component of the drainage.
  Migration rates from the tailings into the adjoining unsaturated materials is expected to be slow owing to the unsaturated conditions. It should be noted that any lateral seepage in the unsaturated zone would be well below the biogenic zone, and overlie carbonaceous materials with the palaeochannel.

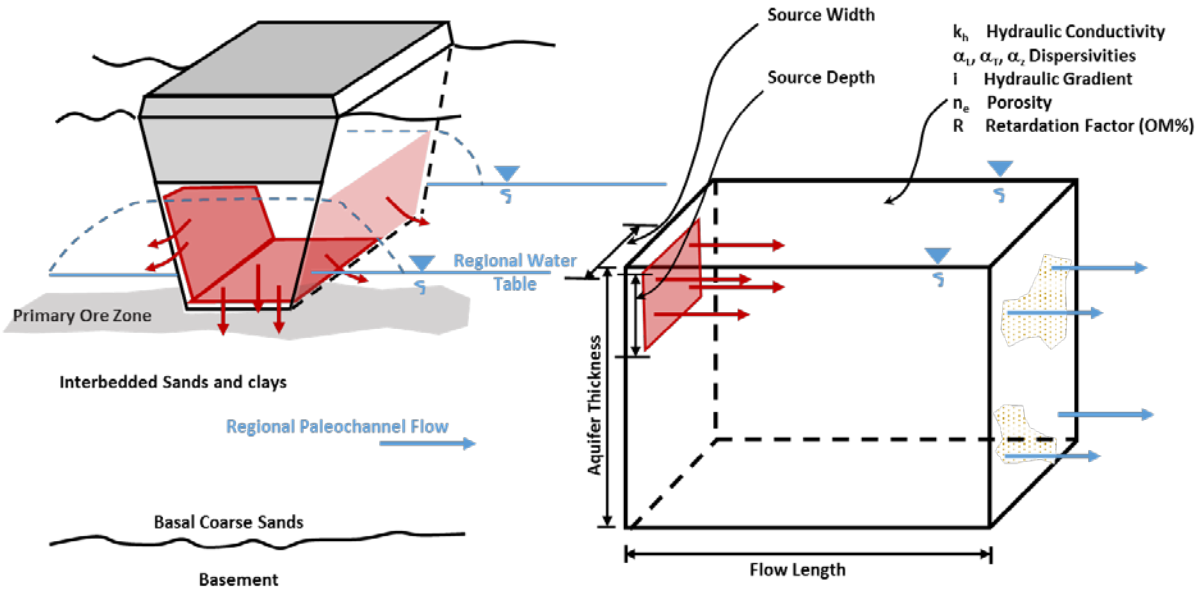


Figure 34 Conceptual schematic of modelling process

There are a number of factors relating to the simplification that result in the analytical modelling approach having embedded conservatism.

There modelling approach adopted by GHD does not consider processes occurring within the tails themselves, e.g. binding to carbonaceous material, or retardation at the regional water table interface, e.g. liquors encountering strongly reducing conditions, and these are discussed in the geochemical assessment. These are process that would tend to retard and fix leachate materials.

The modelling removes the influence of faults and does consider the influence of density differences between the tailings leachate and the saline to hypersaline regional groundwater. These are processes that would increase retardation and fixation.

The modelling assumes that the leachable component directly interacts with the aquifer, i.e. concentrations are introduced in the aquifer with no allowance for geological material properties, such as vertical hydraulic conductivities of the tailings, that would retard vertical migration towards the more permeable basal parts of the palaeochannel aquifer.

Model Selection

To model the fate of a particular dissolved species in groundwater, a number of analytical screening tools have been developed, e.g. Bioscreen (Newell *et al* 1996), AT123D (Yeh 1981), AT123D-AT (Tetratech, 2014). Srinivasan *et al* (1987), and Cecan and Schnieker (2010) suggests that Bioscreen tends to significantly underestimate contaminant mobility owing to the use of the Domenico (1987) solution and therefore preference was given to closed form analytical solvers, i.e. AT123D-AT).

Estimation of Analytical Modelling Inputs

Hydraulic Gradient

Rockwater (2013) estimated an average hydraulic gradient of 0.0022. GHD also undertook an interpretation of hydraulic gradients at the Princes Pit, which indicated an average hydraulic gradient of 0.002 (refer Section 6.3.2) which is comparable with previous interpretations.

Flow Length / Distance to Receptor / Boundaries

The distance between the Princess Pit and the lease boundary of 12 km has been applied as 'point of compliance'.

In general terms, the water level at the Princess Pit is 40 m, palaeochannel thickness of 100 m, and 10 m to 30 m of ore could be mined. An average aquifer thickness of 30 m is considered reasonable. A nominal palaeochannel aquifer width of 6 km has been adopted. Given the low transverse dispersivity, it is unlikely that aquifer lateral boundaries would influence migration.

Hydraulic Conductivity

The characterisation of site-specific aquifer hydraulic properties is limited, with quantification skewed to the more transmissive beds of the palaeochannel, or the primary ore zone. The beds adjacent to the zones of mineralisation tend to be fine grained and ligneous and therefore hydraulic conductivities are likely to be on the lower end of ranges, e.g. 0.1 m/day. The basal sand sequences tend to be highly transmissive, e.g. 1 m/day to over 10 m/day and the intervening interbedded sands and clays somewhere between these two extremes.

In determining a representative hydraulic conductivity, a number of factors need to be considered:

- The limited characterisation of aquifer hydraulic parameters (in both the spatial and vertical sense);
- The ore body is interpreted to be of low permeability, but would be removed by the mining process;
- The tailings materials are very fine grained and expected to have a low permeability (0.1 m/day or less)
- The more transmissive layers form the basal parts of the sedimentary sequence, but are separated by interbedded clays, and have denser (hypersaline) groundwater relative to the tailings.

To address uncertainty with the analytical modelling, sensitivity of this input parameter has been assessed. Two modelling conceptualisations were applied:

Scenario 1 – Probable

This scenario assumes that the density contrast between the highly saline native groundwater, and lower salinity tailings liquors results in retarding the vertical migration of the liquor to deeper parts of the palaeochannel system. Under this scenario, tailings liquors would be migrating laterally through lower permeability clay and sand beds.

To determine a representative hydraulic conductivity, it has been assumed that there is a 15 m saturated palaeochannel aquifer underlying the in-pit TSF, which comprises equal proportions of clay (0.001 m/day), sand (5 m/day) and clay sand mixtures (0.1 m/day). This results in a weighted average horizontal conductivity of 0.7 m/day.

Scenario 2 – Worst Case / Unlikely

This scenario assumes the primary ore zone is mined out in the Pits, and that no density contrast exists between the tailings liquor and the native groundwater. Under this scenario, tailings liquors could migrate to deeper intervals of the aquifer.

To determine a representative hydraulic conductivity, it has been assumed that there is 30 m of saturated palaeochannel aquifer underlying the in-pit TSF which comprises 50% sand (clean) and 50% sandy clays / clayey sands material. A weighted average horizontal of 2 m/day is estimated based on hydraulic conductivities of 1 m/day and 10 m/day for the sands and sand – clay mixtures respectively.

These two hydraulic conductivity scenarios are shown schematically in Figure 35.

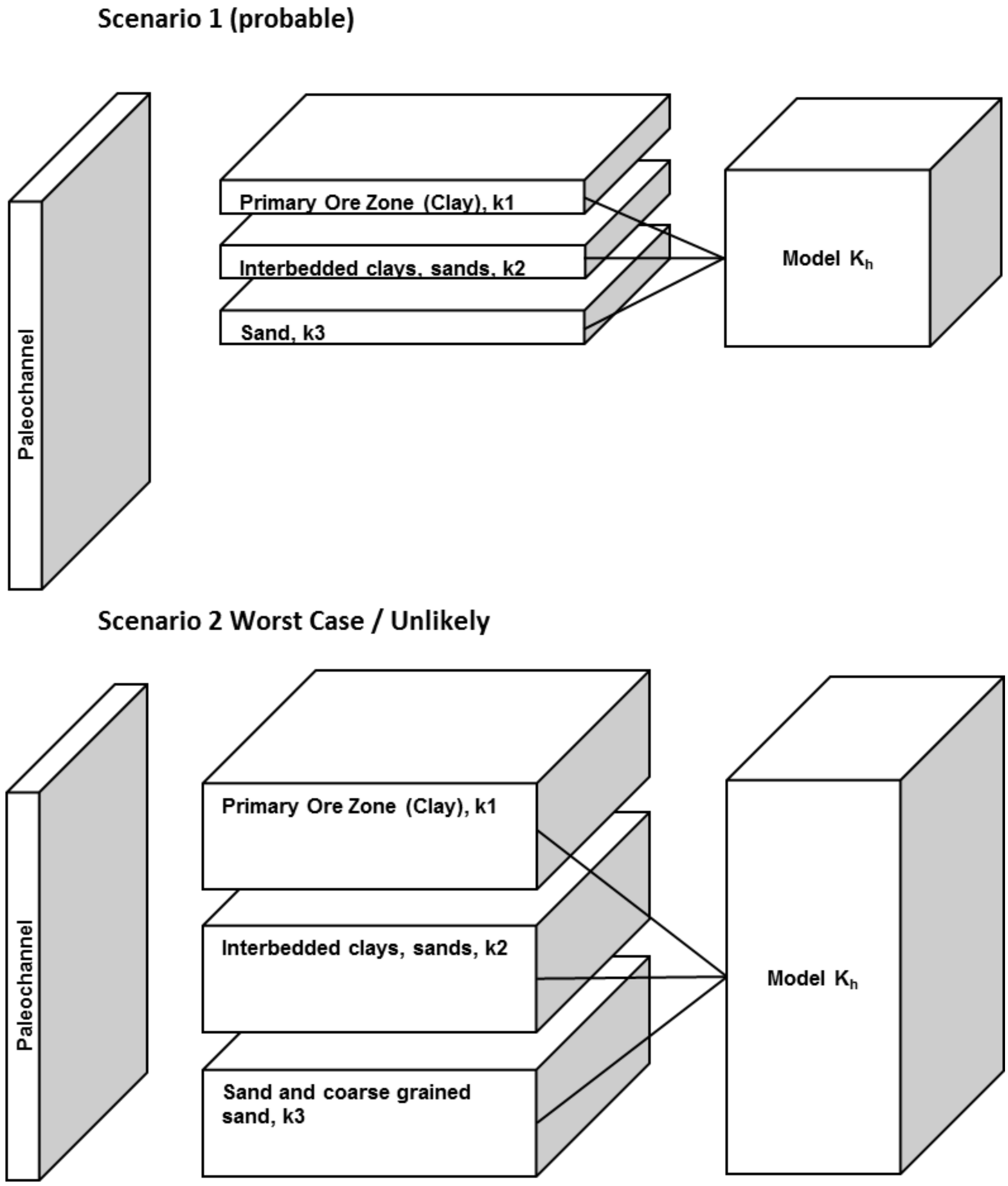


Figure 35 Representation of conductivity scenarios

Both of the above scenarios have some conservatism attached to them, as each involves horizontal conductivities of multiple beds being bulked together. It is noted that vertical hydraulic conductivities, whilst not characterised at MRUP are commonly assumed to be 1/10 of horizontal hydraulic conductivities, i.e. vertical migration between beds is likely to be low. This implies that longer timeframes are required for liquors to migrate vertically towards the deeper, coarser grained lenses within the palaeochannel, on the assumption that mining depths do not extend to the main basal sequence of the palaeochannel, i.e. shortened migration pathways to the more transmissive sequences within the palaeochannel.

Aquifer Bulk Density and Porosity

Aquifer material bulk densities and aquifer porosities are available from literature and ranges have been summarised in Table 26. An average of 1,500 kg/m^3 and effective porosity of 0.2 has been adopted for the analysis for consistency with the modelling completed by Rockwater (2015), which applied specific yields of 0.05 (clay) to 0.2 (sand) (refer Table 11).

Table 26 Aquifer Bulk Density and Porosity

Material	Density (kg/m^3)	Effective Porosity (-)
Clay	1,400 to 2,200	0.01 to 0.2
Sand	1,180 to 1,580	0.1 to 0.3 (fine) 0.15 to 0.3 (medium) 0.2 to 0.35 (coarse)
Silt	1,290 to 1,800	0.01 to 0.3
Sandstone		0.005 – 0.1

Hydrodynamic Dispersion

Selection of dispersivity values is problematic given that it is impracticable to measure dispersion in the field. Estimates of dispersivity are based on the contaminant plume length (which pre-mining is unknown). Dispersivities can be informed through column scale laboratory tests.

A number of empirical relationships, based on scale have been determined as shown in Figure 36, and the adopted hydrodynamic dispersions are summarised in Table 27, based on distance to the point of compliance of 12 km. To address uncertainty with the analytical modelling, sensitivity of this input parameter has been assessed.

Table 27 Adopted Dispersions

Direction	Source	Dispersivity (m)
Longitudinal (α_L)	Based on Xu & Eckstein (1995)	25
Transverse (α_T)	0.1 to 0.3 x longitudinal dispersivity (Gelhar *et al*, 1992)	2.5
Vertical (α_V)	Very low (EPA 1996) 0.025 to 0.1 x longitudinal dispersivity (EPA 1986)	0.1

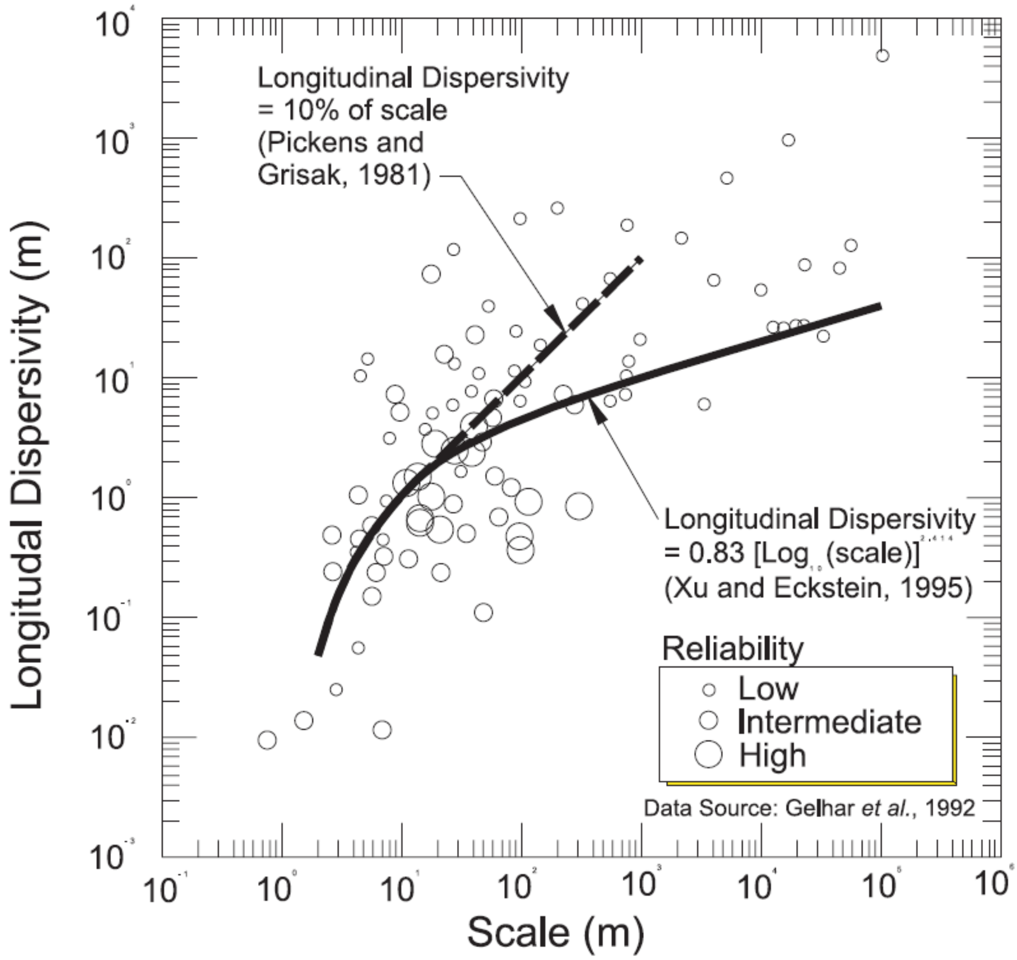


Figure 36 Empirical Determination of Dispersivity

Adsorption and Distribution Co-efficients

The influence of adsorption is described by a retardation co-efficient, which can be defined as follows:

$R = 1 + \frac{\rho_b K_d}{n_e}$ where

R = Retardation co-efficient

K_d = Contaminant soil water distribution co-efficient
where K_d = K_{oc} (octanol – water partition co-efficient) x f_{oc} (fraction organic content)

ρ_b = bulk density of the aquifer

Uranium

The distribution co-efficient (K_d) of uranium and its daughter products is determined from adsorption and desorption testing, i.e. quantified in the laboratory using batch or column tests. In the absence of such data, distribution coefficients were taken from literature, specifically for sites that were measured under similar conditions geological conditions as the MRUP.

The US EPA & US DOE (1999) compiled a review of uranium distribution coefficients from a variety of studies undertaken in differing geologic environments. These studies indicated that pH and dissolved carbonate concentrations are the two most important factors influencing the adsorption behaviour of U(VI).

Uranium K_d values show a trend as a function of pH and this pH-dependent behaviour is considered to be related to the pH-dependent surface charge properties of the soil minerals and complex aqueous speciation of dissolved U(VI) (US EPA & US DOE, 1999). The USE EPA & US DOE (1999) generated a look-up table for the range of estimated minimum and maximum K_d values for uranium which has been reproduced as Table 28. To address uncertainty with the analytical modelling, sensitivity of this input parameter has been assessed. The pH of the leachate is estimated to be approximately 3 pH units (ANSTO 2015a).

Table 28 Uranium Distribution Coefficients

pH	3	4	5	6	7	8	9	10
Minimum	<1	0.4	25	100	63	0.4	<1	<1
Maximum	32	5,000	160,000	1,000,000	630,000	250,000	7,900	5

Source: US EPA & US DOE (1999)

Note:
1. All K_d = mL/g. 1 mL/g = 0.001 m^3/kg
2. For K_d values at non-integer pH values, especially given the rapid changes in uranium adsorption observed at pH values less than 5 and greater than 8, a linear relationship between each adjacent pair of pH-Kd values should be assumed.
3. US EPA & US DOE (1999) note that in compiling literature values, those from organic rich materials K_d = 33 mL/g to 39 mL/g.

Estimation of the Source Load

The geochemical assessment has identified uranium as potential contaminant of concern, however this is only the case under the extreme worst case condition of a continuous source input. For the purposes of the groundwater transport modelling, U has been assessed.

Once the resource has been exhausted, and groundwater dewatering finished, the tailings in the Princess Pit TSF would be mostly located above the water table. The water entrained within the leachate would drain under gravity, as the tailings consolidate under their own weight. This time dependent compression is consolidation. The time required for consolidation is inversely proportional to the vertical conductivity, and directly proportional to the thickness of the consolidating sediments. This assumes that the sediments comprising the walls of the Princess Pit are of lower permeability than the tailings themselves, i.e. will promote drainage.

The total volume of leach that could be derived from the Princess Pit TSF, assuming instantaneous deposition, can be determined from the size of the pit, and the moisture content of the tailings. The approximate dimensions of the Princess Pit are summarised in Table 13.

The tailings would be pumped to the Princess Pit TSF as a slurry. As the tailings are deposited, some liquids would be lost through evaporation, some would be trapped or retained by the tailings, and the remainder is expected to drain from the TSF, as discussed previously, either vertically towards the groundwater table (most probable pathway), or laterally through permeable pit walls. It is proposed to cap the Princess Pit TSF upon the completion of mining. Whilst over the long term a capping may deform, potentially enabling ponding of surface, however infiltrating rainfall would still need to penetrate the consolidated, low permeability tailings in order to generate leachate. The analytical modelling does not account for recharge.

To determine the leachate loads to groundwater, it was assumed that the leachable concentration, based on the ASLP testing completed by ANSTO (2015a), represented the load to groundwater, i.e. what was leachable from the tailings would directly access the groundwater environment. The contaminant of concern that was assessed is summarised in Table 29.

Table 29 Contaminants of Concern

Analyte	Leachable Concentration (mg/L)
Uranium	0.14

Three cases were assessed for the source loading:

- Case 1 (continuous loading)
  A continuous load equal to the leachable concentration (i.e. extending over 10,000 years). This is conservative (over estimates contaminant loads) as it assumes that mass is not lost from the tails within the Princess Pit TSF.
- Case 2 (Time varying loading pulse)
  A load equal to the leachable concentration, extending over 100 years (refer Figure 37). This assumes that leachate from the Princess Pit TSF would drain and be exhausted over 100 years. At the time of reporting, the consolidation of the TSF had not been determined, however a pulse or slug is considered a more reasonable estimation of the leachate behaviour relative to a continuous source. A 200 year and 500 year pulse were also modelled to assess the sensitivity.
- Case 3 (exponentially decaying pulse)
  A load equal to the leachable concentration would exponentially decay with a half life of 100, 200 and 500 years respectively, with the various half lives applied to assess sensitivity to this source loading..

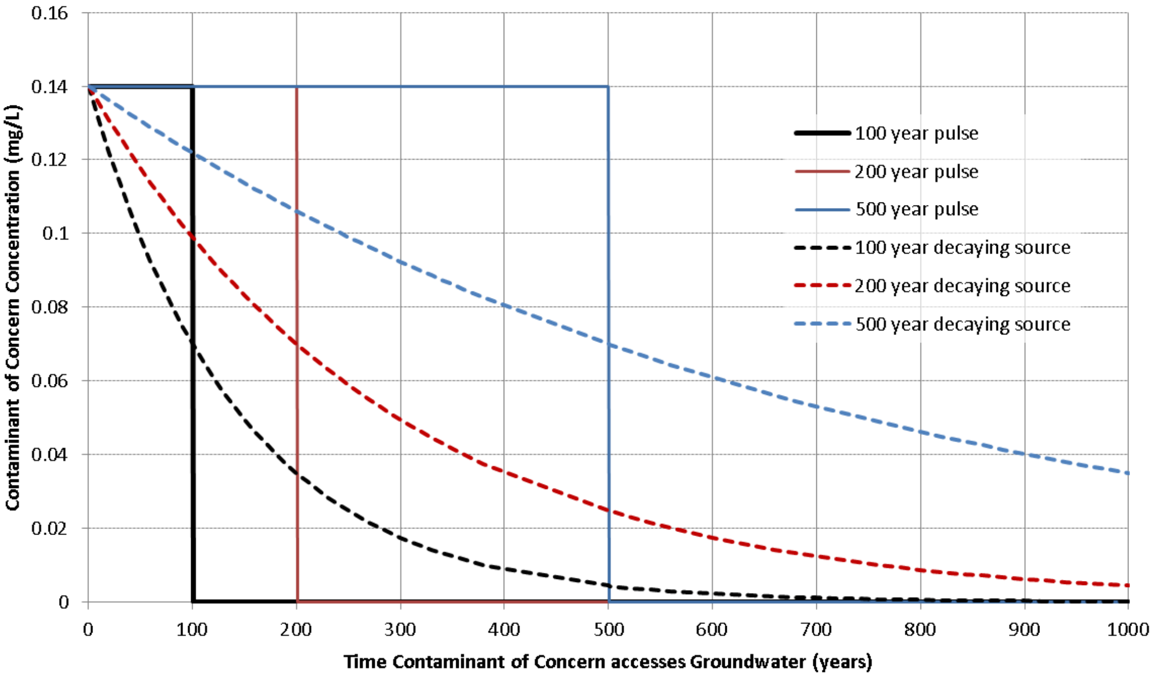


Figure 37 Modelled Source Load Boundary Conditions

For Scenario 1, both the aquifer and the source were assumed to be 15 m thick, with the source being 250 m x 20 m plane normal to the groundwater flow direction. For Scenario 2, the load source was assumed to form a 250 m x 20 m plane normal to the groundwater flow direction. The plane was located in the upper 20 m of the 30 m thick aquifer.

Scenario modelling

Simplistic Advective Transport

An absolute worst case analysis is to conceptualise the palaeochannel as:

- An isotropic, homogeneous aquifer;
- A single material (all aquifers bulked together);
- Faulting is ignored

- The aquifer is infinitely extensive along the length of flow
- Constituents of concern migrate under advection, with:
  - no hydrodynamic dispersion,
  - no retardation through adsorption; and
  - ignoring any redox processes that may precipitate mobile constituents

An estimate of the advective transport of constituents in groundwater has been summarised in Table 30 for a range of aquifer hydraulic conductivities. GHD estimated an average hydraulic gradient of 0.002. Flatter hydraulic gradients shorten the transport distance (over the same time period).

Table 30 Distance Travelled from Source (m)

	Aquifer material	Low (sandy clays, clay)	Weighted Average (Scenario 1)	Medium (fine sands, clayey sands)	Weighted Average (Scenario 2)	High (sands)
	Hydraulic Conductivity (m/day)	0.1	0.7	1	2	10
	Hydraulic Gradient	0.002	0.002	0.002	0.002	0.002
Distance travelled in year (m)	After 1 year	0.07	0.5	0.7	1.5	7.3
	After 1000 years	73	511	730	1,460	7,300
	After 10,000 years	730	5110	7,300	14,600	73,000

Note: Weighted average defined in Appendix G.

With increasing aquifer permeability, and time, the migration distance of contaminants of concern increases. Four hydraulic conductivities have been applied, which range from 0.1 m/day through to 10 m/day. The 10 m/day is considered representative of permeable sands in the thick, coarse grained sequences of the palaeochannel. The low rage hydraulic conductivity estimate of 0.1 m/day was adopted for numerical modelling (Rockwater, 2014), however it is relatively conservative (permeable) based on published hydraulic conductivity ranges for the primary ore zone which is clayey (refer Table 11 and Table 12).

Under scenario 1, the density contrasts that retain any draining liquors draining from the TSF to the upper parts of the saturated palaeochannel, migration distances of less than 5 km are predicted.

Under scenario 2, where density is ignored, and the tailings liquor migrates to the basal, coarse grained sands of the palaeochannel, groundwater could travel upwards of 70 km after 10,000 years. This latter scenario should be considered theoretical rather than realistic, based on the gross simplifications of the advective transport model. Furthermore it assumes that Princess Pit TSF leachate is in direct hydraulic connection, laterally extensive and not truncated by faults of facies changes / lensing.

Advective Transport with Hydrodynamic Dispersion

Analytical modelling was undertaken to determine the effect of dispersive processes on groundwater migration, and to quantify the contaminant of concern concentrations at the MRUP boundary, approximately 12 km distant from the Princess Pit TSF.

This modelling made the following assumptions:

- Groundwater flow is steady, i.e. it is not influenced by groundwater injection, abstraction during the modelling period
- Flow is uniform (no fluid density controls)

- Sorption is assumed to be instantaneous and reversible (and governed by a linear isotherm)
- The aquifer is free of contaminants, i.e. not remobilising constituents
- Mass is not lost through the upper (water table) and lower (base of aquifer) boundaries.
- Molecular diffusion has been ignored.

A summary of the results from the dispersive transport has been provided in the following figures for the two scenarios:

- Figure 38 Dispersive Transport (continuos source)
- Figure 39 Dispersive Transport (100 year pulse)
- Figure 40 Dispersive Transport (200 year pulse)
- Figure 41 Dispersive Transport (500 year pulse)
- Figure 42 Dispersive Transport (100 year decaying source)
- Figure 43 Dispersive Transport (200 year decaying source)
- Figure 44 Dispersive Transport (500 year decaying source)

Each plot shows the centreline of the plume, and the upper elevation of the plume (note the deeper parts of the plume are retarded by lower vertical dispersivities). It is noted that some numerical instability occurs with the larger time steps, i.e. 5,000 years and 10,000 years.

Scenario 1	Scenario 2

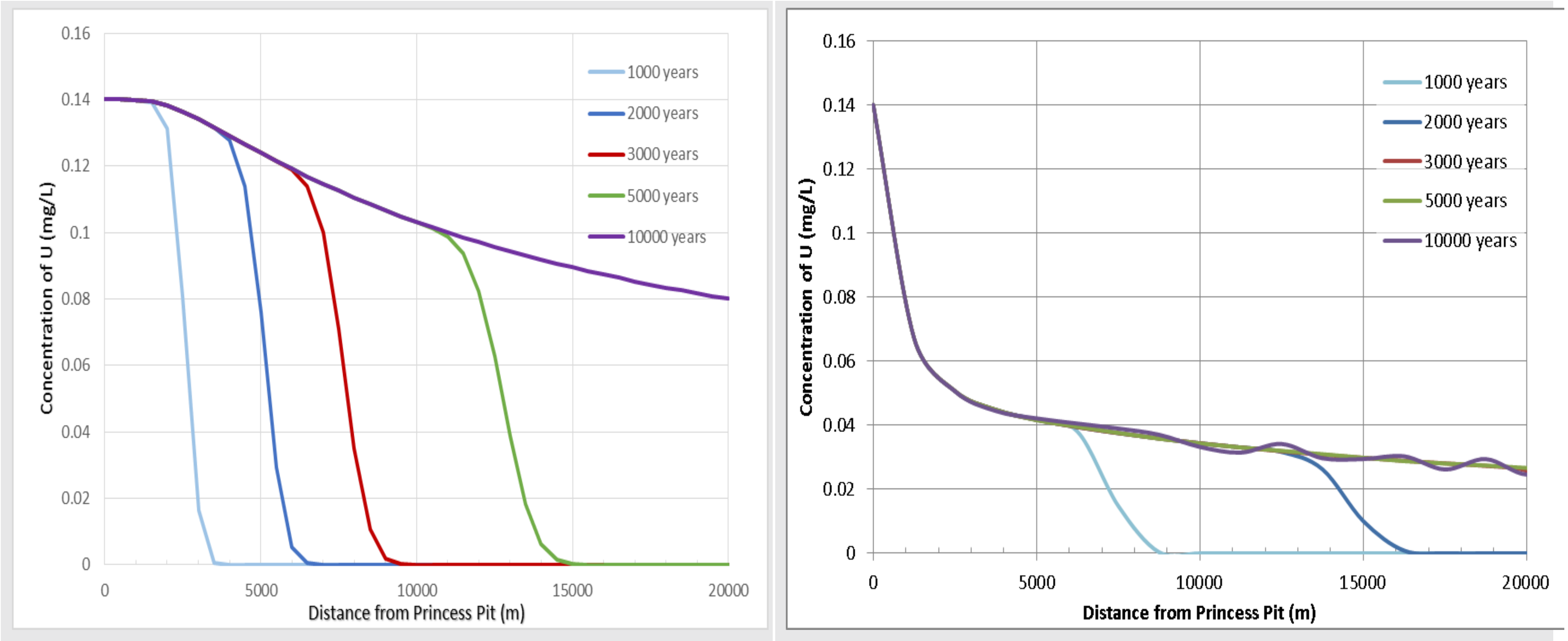


Figure 38 Dispersive Transport (continuos source)

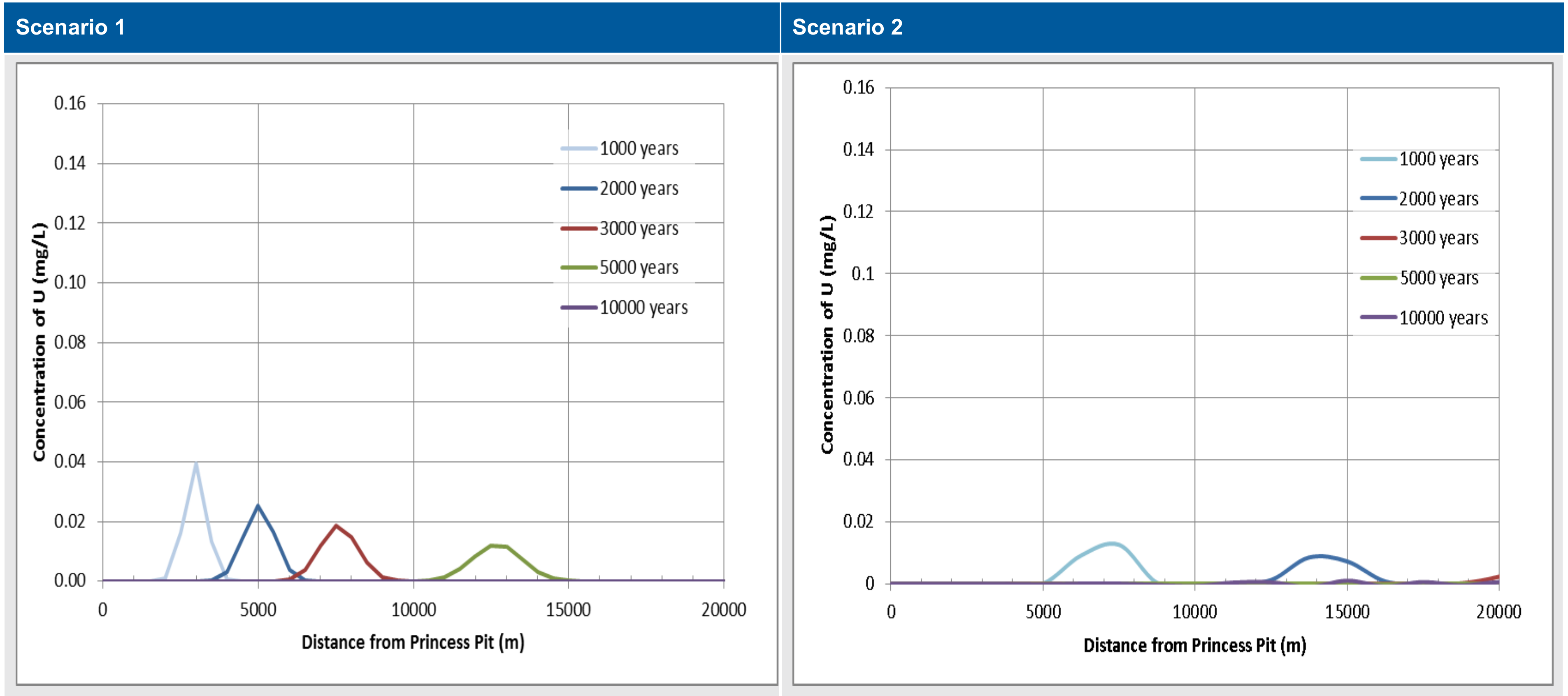


Figure 39 Dispersive Transport (100 year pulse)

Scenario 1	Scenario 2

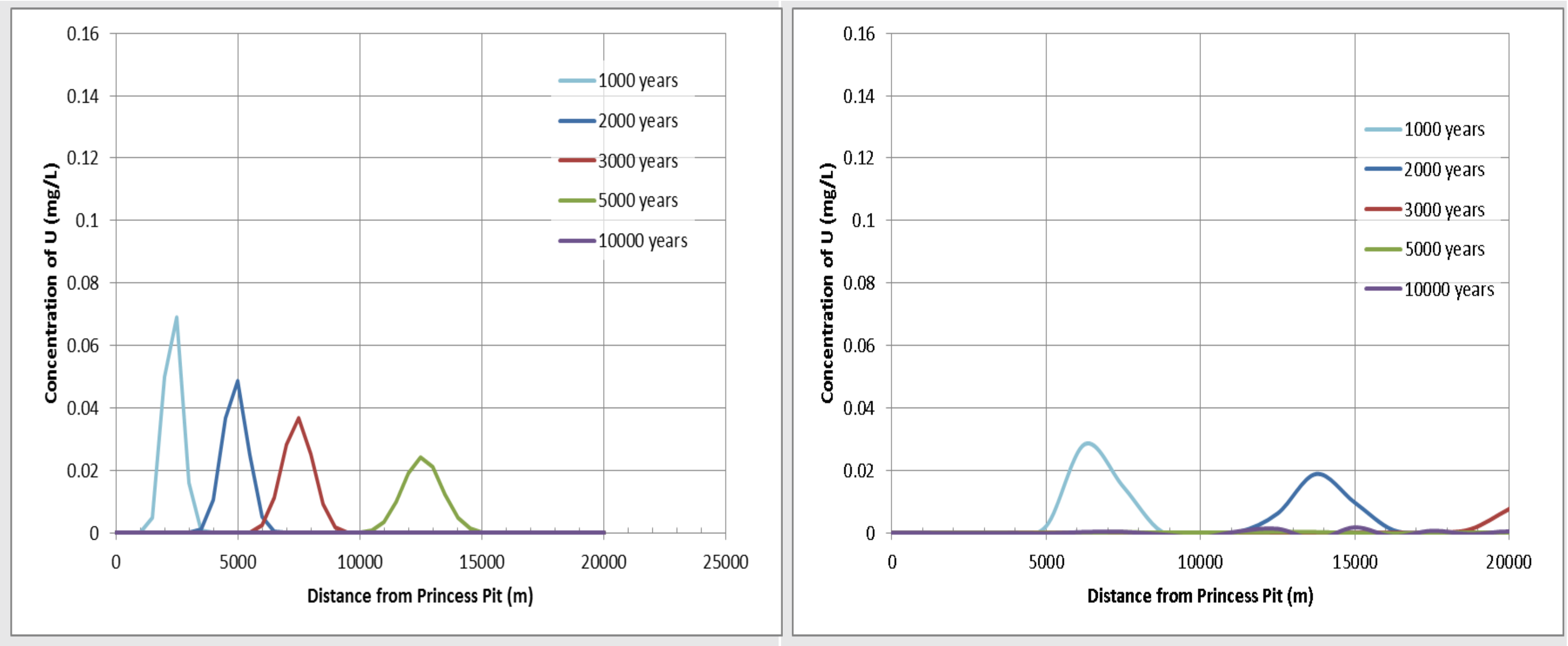


Figure 40 Dispersive Transport (200 year pulse)

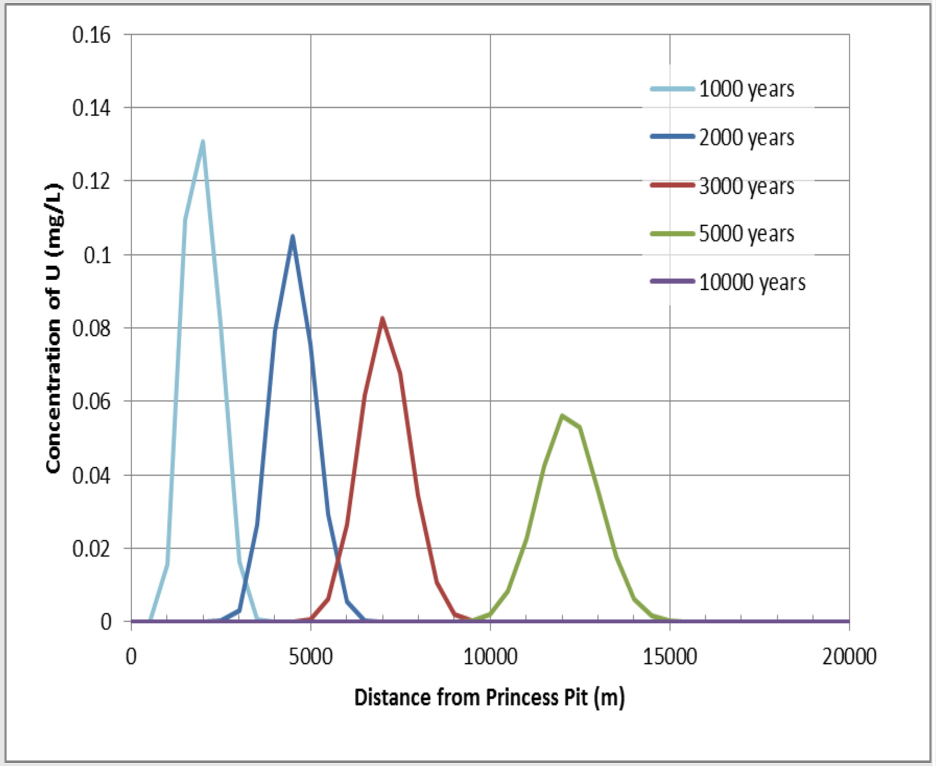
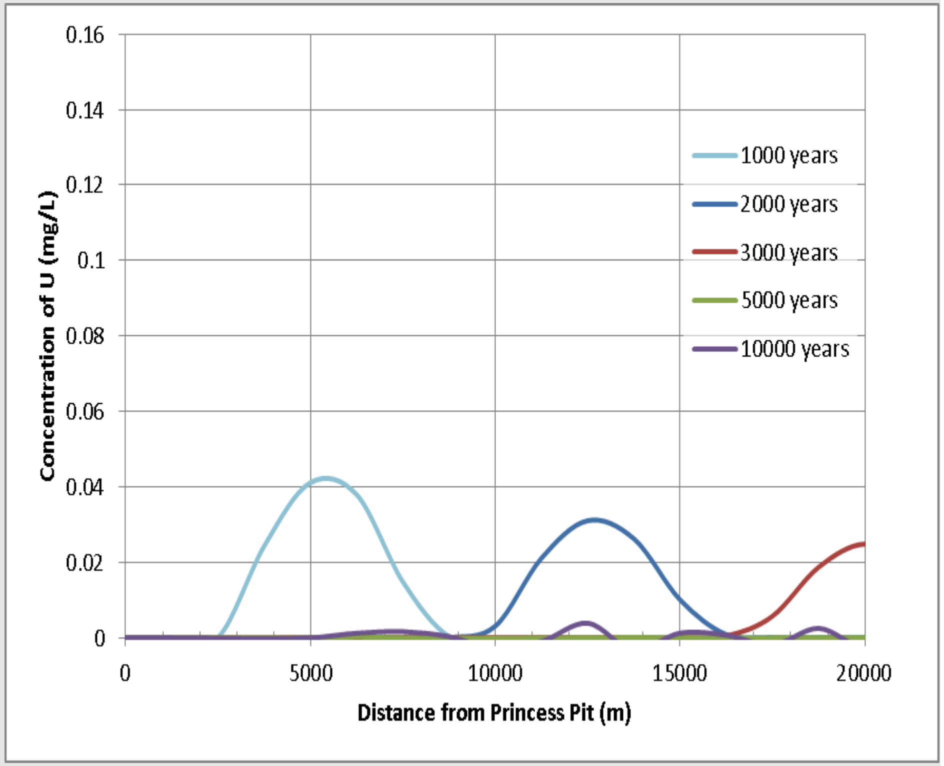
Scenario 1	Scenario 2
	

Figure 41 Dispersive Transport (500 year pulse)

Scenario 1	Scenario 2

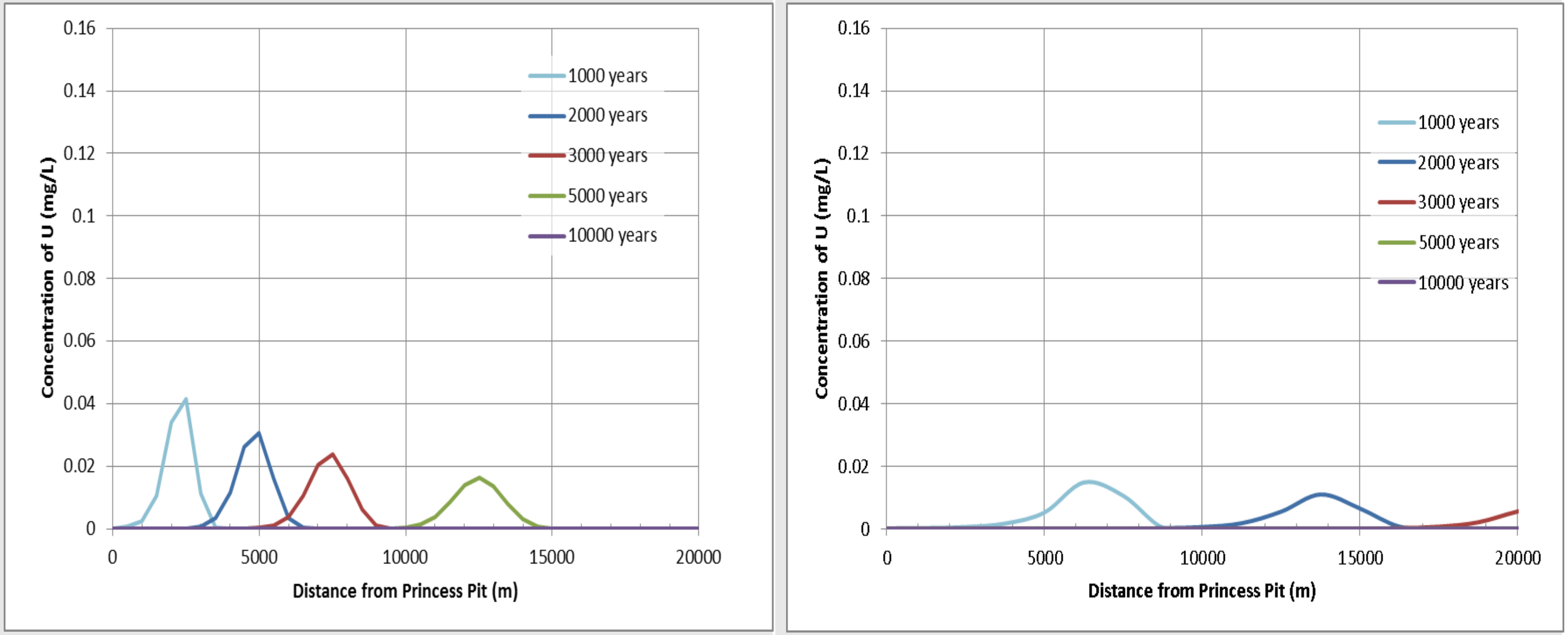
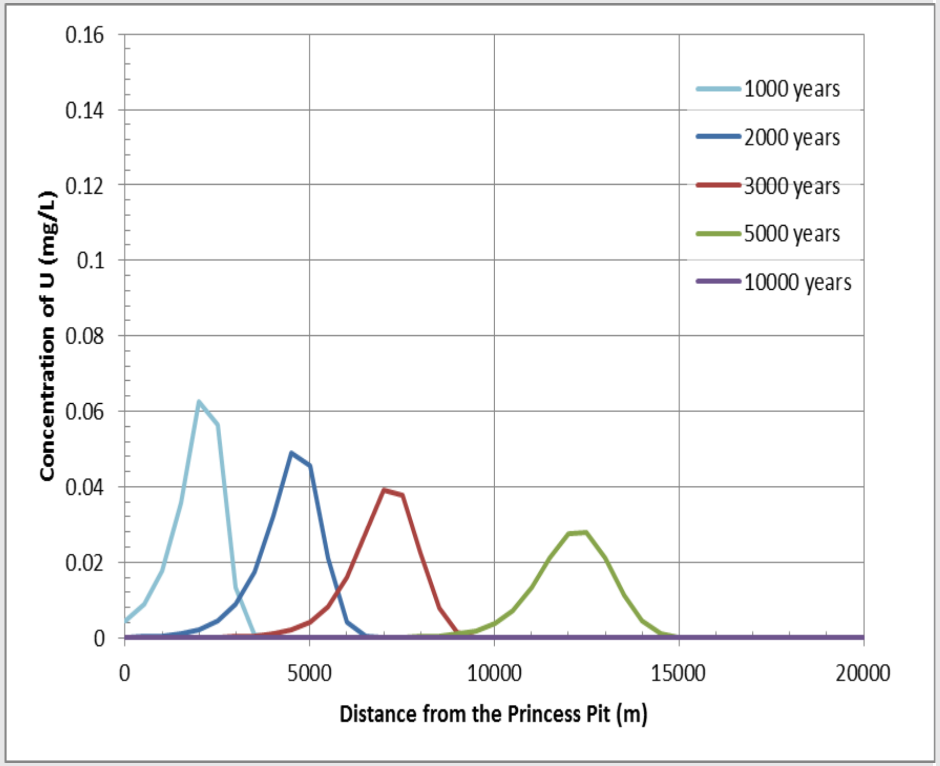


Figure 42 Dispersive Transport (100 year decaying source)

Scenario 1



Scenario 2

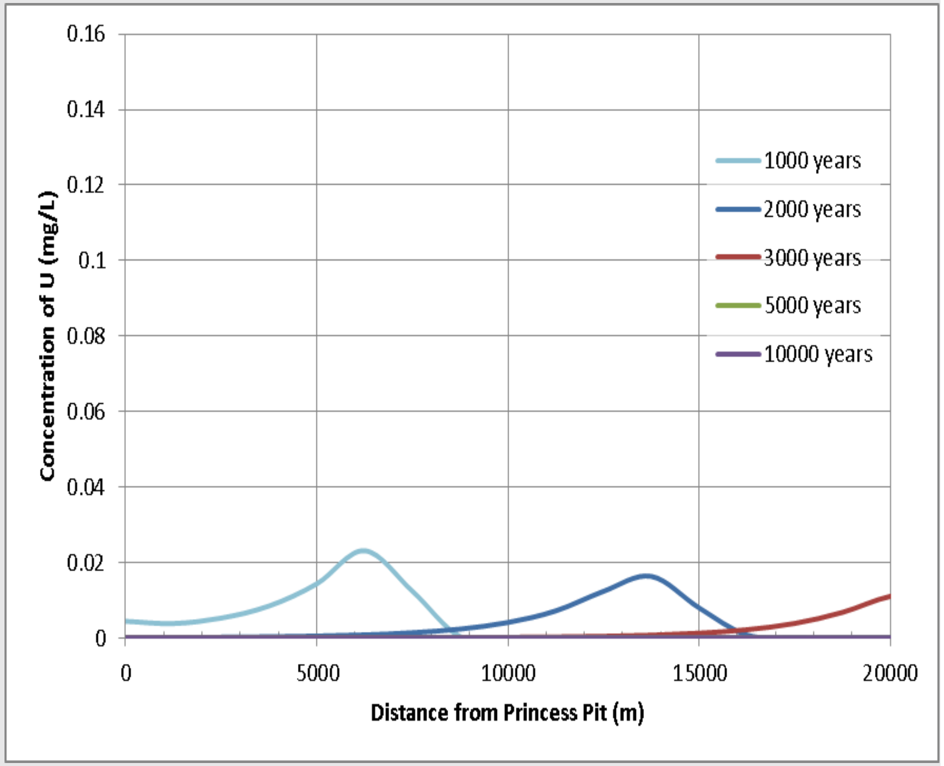


Figure 43 Dispersive Transport (200 year decaying source)

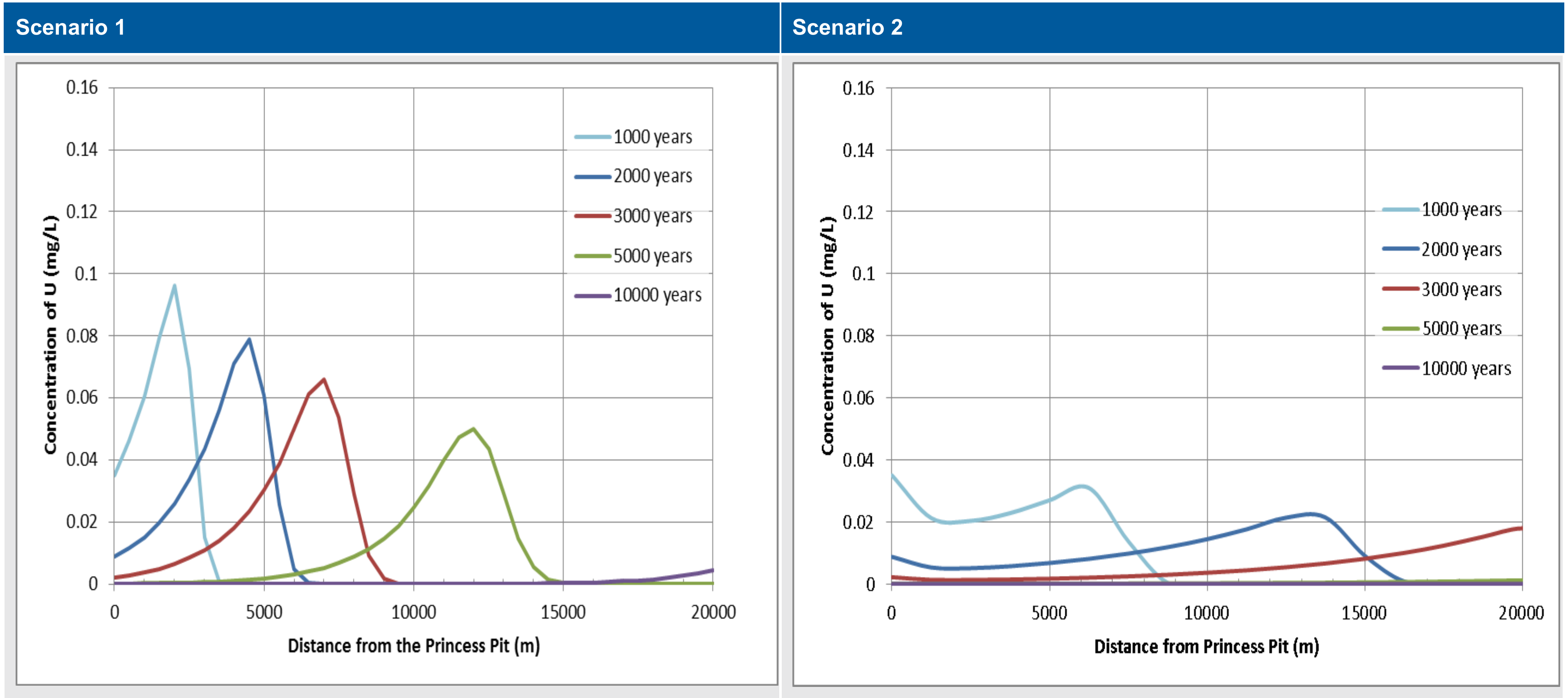


Figure 44 Dispersive Transport (500 year decaying source)

Concentrations at the lease boundary are summarised in Table 31 for the various pulse durations for the two scenarios. As the analytical model assumes that the background concentration in the aquifer is zero, the concentrations reported in Table 31 therefore represent concentrations above the background concentration within the aquifer.

The continuous and longer pulses result in more tailings liquors entering the aquifer and therefore concentration of uranium are greater down-gradient of the in-pit TSF. Under scenario 1 it takes approximately 5000 years for the concentrations to breakthrough at the lease boundary (approximately 12 km distance from the source). This time is more than halved under the less likely scenario 2, which has a much higher advective groundwater flow rate.

Under a variety of source loadings, excluding the continuous source, concentrations of uranium travel up to 25 km from the site, but the hydrodynamic dispersion has significantly reduced concentrations. Note that none of these model runs have incorporated retardation, i.e. the influence of carbonaceous materials within the aquifer.

Table 31 Estimated Concentration at Point of Concern

Source Type	At Lease Boundary		After 10,000 years	
	Peak Concentration (mg/L)	Breakthrough Time (years)	Peak Concentration (mg/L)	Distance Travelled (m)
Scenario 1 (Bulked kh, upper part of palaeochannel)				
Continuous, 0.14 mg/L	0.1	Approx 5000 years	0.07	25,000
100 year pulse	0.01	Approx 5000 years	<0.01	25,000
200 year pulse	0.025	Approx 5000 years	0.01	25,000
500 year pulse	0.05	Approx 5000 years	0.03	25,000
100 year decay	0.015	Approx 5000 years	<0.01	25,000
200 year decay	0.03	Approx 5000 years	0.015	25,000
500 year decay	0.04	Approx 5000 years	0.03	25,000
Scenario 2 (Bulked kh, upper and basal part of palaeochannel)				
Continuous, 0.14 mg/L	0.03	Approx 2000 years	0.015	72,000 (1)
100 year pulse	0.01	Approx 2000 years	<0.01	72,000 (1)
200 year pulse	0.02	Approx 2000 years	<0.01	72,000 (1)
500 year pulse	0.03	Approx 2000 years	<0.01	72,000 (1)
100 year decay	0.01	Approx 2000 years	<0.01	72,000 (1)
200 year decay	0.017	Approx 2000 years	<0.01	72,000 (1)
500 year decay	0.022	Approx 2000 years	<0.01	72,000 (1)

Note:

4. Numerical instability noted.
5. All concentrations for top of plume (assuming 30 m aquifer thickness)
6. All based on k=2 m/day

Advective Transport with Adsorption

The geochemical modelling indicated that pH would initially start around 2.5, but increase, within a relatively short timeframe (approximately 2,000 years) towards 5 to 5.5. Based on this pH range, distribution coefficients could be between 1 and $1.6x10^5$. Adopting a distribution co-efficient for uranium of 36 mL/g (average of USE EPA & US DOE (1999) for organic rich materials), the effect of adsorption was estimated based on a low carbon content (1%) and high carbon content (20%) was determined for the 500 year pulse and a decaying source with a 500 year half-life.

The modelling of the 500 year pulse was repeated incorporating both hydrodynamic dispersion and adsorption. The results are shown in Figure 45 and Figure 46 for a high and low range of organic material for both scenarios.

Small proportions of organic material in the aquifer have a significant influence of the retardation of uranium. Under scenario 1, concentrations of uranium do not reach the lease boundary within 10,000 year timeframe. Under the higher hydraulic conductivity scenario 2, breakthrough beyond the lease boundary occurs after over 5,000 years, with concentrations estimated at less than 0.02 mg/L above background.

It should be considered the assignment of retardation is subjective and that a wide variation of the distribution coefficients. The analysis indicates that any permanent adsorption would significantly retard the migration of uranium, such that concentrations would have a limited likelihood of reaching the MRUP lease boundaries.

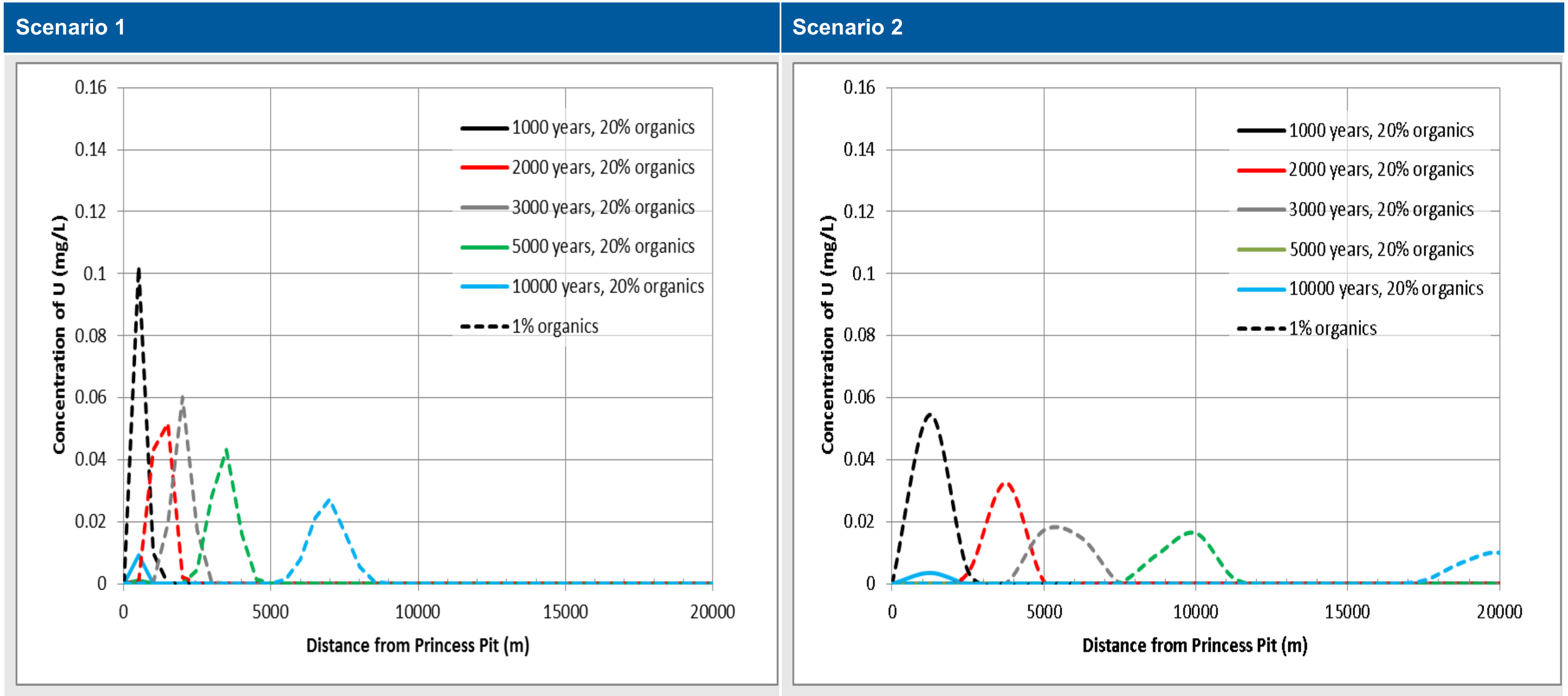


Figure 45 Dispersive and Retarded Transport (500 year pulse)

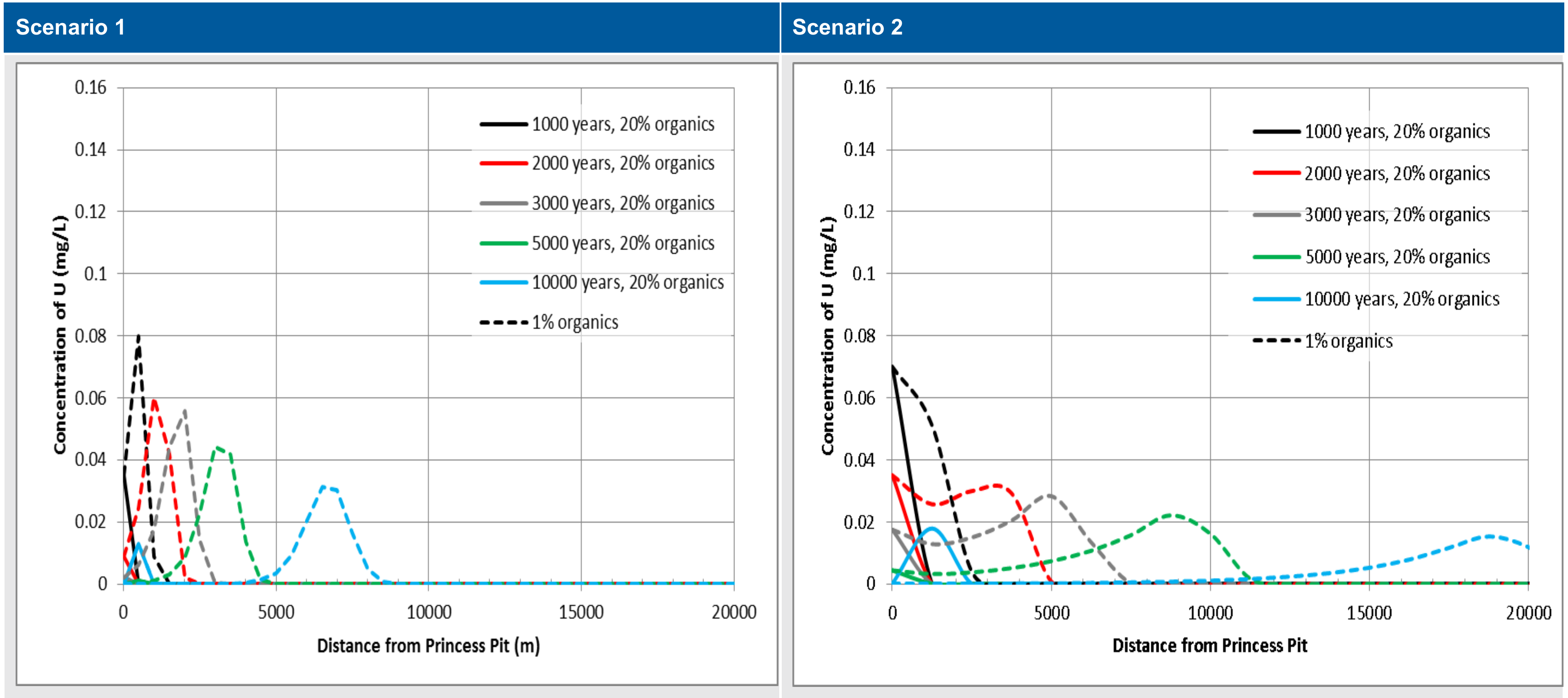


Figure 46 Dispersive and Retarded Transport (500 year decaying source)

Summary

0 examined the mixing processes between the tails leachate, and the native groundwaters. Fate and transport of the groundwater was undertaken, that considered the interactions between the various constituents within the groundwater, e.g. the influence of pH on the mobility of metals including uranium.

In this section the fate and transport of groundwater was assessed based on simpler mechanisms of transport relating to the hydraulic gradient, aquifer materials (hydraulic conductivity) and dispersive properties (e.g. velocity variations around aquifer mineral particles) that would act to dilute concentrations at increasing times and distances of travel from the Princess Pit TSF. These analytical processes ignore geochemical reactions which may increase the mobility, or conversely trap contaminants of concern within the aquifer.

A number of inputs into the analytical modelling could be derived from site specific data, such as concentrations (leachate testing), and hydraulic gradient (regional water level mapping), and a number of published literature values and relationships (e.g. dispersivities, material density and specific yields). The analytical approach is considered a reasonable screening approach to identify any significant issues which plume migration.

Key input uncertainties include the form of the source leachate load to the groundwater system, aquifer permeabilities and retardation. To address the uncertainties into the analytical inputs, sensitivity analysis was undertaken:

- A range of source loading rates to the aquifer were applied, which included a continuous load (considered too conservative as it assumes no loss of mass), 100 year, 200 year and 500 year drainage times represented as both a pulse, or decaying source.
- Modelling two hydraulic conductivity scenarios:
  - A probable scenario where a bulked horizontal hydraulic conductivity representing a 15 m zone of primary ore zone and underlying interbedded sands and clay sediments, i.e. hydraulic conductivity of 0.7 m/day. The basis of this scenario was that salinity contrasts between the process / tailings liquor, and saline native groundwater would restrict the vertical migration of any plume.
  - A worst case scenario where a bulked horizontal hydraulic conductivity representing both the ore zone and underlying interbedded sands and clays, and the basal, transmissive coarse grained sands, i.e. hydraulic conductivity of 2 m/day. This scenario ignores any density contrasts.

Modelling without any form of retardation of uranium, indicated that breakthrough at the lease boundary would occur within 5000 years under scenario 1. Hydrodynamic dispersion resulted in concentrations reducing by 50% or greater, depending upon the applied source load. Continuous sources, and long source pulses (or decaying half-lives) resulted in less reduction in concentrations. Pulses of 100 years resulted in concentrations at the lease boundary being 10% of that of the source.

Modelling with retardation (adsorption of metals to aquifer minerals) under scenario 1 suggests that the uranium plume would be significantly retarded, and would not reach the lease boundary after 10,000 years. The sensitivity was assessed based on a high (20%) and low (1%) organic content.

It is acknowledged that retardation and the assessment of adsorption based on literature results is subjective, and may not necessarily reflect the site-specific geochemical reactions occurring at the MRUP. The analysis is also sensitive to advective groundwater flow and therefore horizontal hydraulic conductivities of the aquifers underlying the Princess Pit TSF.

Further laboratory analysis, e.g. column testing, would be required to determine site specific adsorption coefficients, and verify the advective-retardation analytical modelling. However, it was the natural carbonaceous materials, and redox conditions that led to the formation of the deposit within the aquifer. Therefore these results should be considered in the context of the geochemical modelling also undertaken.

Appendix F – Radionuclide analyses in groundwater (Ambassador deposit and main palaeochannel)

Certificate of Analysis

REPORT №:	**15-0065-R1**
Issue date:	**25th February 2015**
Client:	**Vimy Resources**
Address:	Ground Floor 10 Richardson Street West Perth 6005
Contact:	Mr. Xavier Moreau
Telephone:	(08) 9389 2700
E-mail:	xmoreau@vimyresources.com.au; mwu@vimyresources.com.au
Client reference:	CoC dated 20th January 2015 and PO № 8591

SAMPLE DETAILS

Sample description or type:	Water
Number of samples received:	Four
Date received:	22nd January 2015
Analysis required:	a. Ra-226 and Pb-210 by High resolution gamma spectrometry b. Uranium-238 by activity conversion of elemental concentration c. Po-210 and Th-230 by alpha spectrometry

SGS AUSTRALIAN RADIATION SERVICES

Authorised signatory: S. Rutkowski

Name: **Mr. Stephen Rutkowski**

Position: Senior Health Physicist

Accreditation No. 16987
Accredited for compliance with ISO/IEC 17025

NATA
WORLD RECOGNISED ACCREDITATION

Important Note:
a. This report supersedes any previous reports with this reference number.
b. The results in this report apply to the sample(s) as received by SGS Australian Radiation Services
c. This report has been prepared and issued in accordance with NATA's accreditation requirements.

RESULTS:

Notes:

a) Radionuclide or gross radioactivity concentrations are expressed in becquerel per kilogram of sample as received or becquerel per litre of water sample unless otherwise specified. The becquerel (Bq) is the SI unit for activity and equals one nuclear transformation per second.
b) 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.
c) The reported uncertainty in each result is the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%.
d) Uranium-238 activity concentration is calculated from the uranium mass concentration using a conversion factor of 12.445 $Bq \cdot mg^{-1}$.
e) Thorium-232 activity concentration is calculated from the thorium mass concentration using a conversion factor of 4.046 $Bq \cdot mg^{-1}$.

A. Specific radionuclides

Test method: a. Preparation – ARS-SOP-AS301 – Preparation of liquid samples for measurement by high resolution gamma ray spectrometry.
b. Measurement – ARS-SOP-AS406 – Measurement by high resolution gamma ray spectrometry.

		Radionuclide Concentration		
		Naturally-occurring uranium (U-238) series		
Client Sample ID (ARS Lab. ID)	**Unit**	**Uranium-238**	**Radium-226**	**Lead-210**
RC1279 (15-0065-01)	$Bq \cdot L^{-1}$	< 0.02	2.01 ± 0.19	< 0.19
NND5030 (15-0065-02)	$Bq \cdot L^{-1}$	0.22 ± 0.02	1520 ± 110	< 6.1
NND5036 (15-0065-03)	$Bq \cdot L^{-1}$	1.5 ± 0.1	77.3 ± 5.5	1.06 ± 0.23
NND5040 (15-0065-04)	$Bq \cdot L^{-1}$	0.30 ± 0.02	13.9 ± 1.0	0.34 ± 0.10

B. Elemental concentrations:

Elemental concentration was determined by SGS Leeder Consulting, NATA Accredited Laboratory Number: 14429.

Test method: a. Preparation – MA-1400.WW.01 Metals
b. Measurement – MA-1400.WW.01 Metals

		Analyte
Client Sample ID (ARS Lab. ID)	**Unit**	**Uranium**
RC1279 (15-0065-01)	$mg \cdot L^{-1}$	< 0.001
NND5030 (15-0065-02)	$mg \cdot L^{-1}$	0.018 ± 0.001
NND5036 (15-0065-03)	$mg \cdot L^{-1}$	0.12 ± 0.01
NND5040 (15-0065-04)	$mg \cdot L^{-1}$	0.024 ± 0.002

C. Naturally occurring radionuclides by alpha spectrometry

Radionuclide concentrations by alpha spectrometry were determined by Institute of Environmental Science and Research Limited. IANZ accreditation number: 848

Test method: a. Preparation & measurement – Alpha spectrometry after radiochemical preparation.

		Radionuclide concentration	
Client Sample ID (ARS Lab. ID)	**Unit**	**Polonium-210**	**Thorium-230**
RC1279 (15-0065-01)	$Bq \cdot L^{-1}$	0.025 ± 0.013	0.021 ± 0.014
NND5030 (15-0065-02)	$Bq \cdot L^{-1}$	0.014 ± 0.010	0.277 ± 0.049
NND5036 (15-0065-03)	$Bq \cdot L^{-1}$	0.036 ± 0.016	2.56 ± 0.24
NND5040 (15-0065-04)	$Bq \cdot L^{-1}$	0.0105 ± 0.0089	0.271 ± 0.071

Certificate of Analysis

REPORT №:	**15-0193-R1**
Issue date:	**13th April 2015**
Client:	**Vimy Resources**
Address:	Ground Floor, 10 Richardson Street West Perth WA 6005
Contact:	Mr. Xavier Moreau
Telephone:	(08) 9389 2700
E-mail:	xmoreau@vimyresources.com.au; mwu@vimyresources.com.au
Client reference:	CoC dated 19th February 2015 and Project Reference: MULGA ROCK

SAMPLE DETAILS

Sample description or type:	Water
Number of samples received:	Three
Date received:	27th February 2015
Analysis required:	a. Naturally occurring radionuclides b. USEPA 6010 metal suite including U and Th

SGS AUSTRALIAN RADIATION SERVICES

Authorised signatory:	S. Rutkowski
Name:	**Mr. Stephen Rutkowski**
Position:	Senior Health Physicist

NATA WORLD RECOGNISED ACCREDITATION

Accreditation No. 16987
Accredited for compliance with ISO/IEC 17025

Important Note:

a. This report supersedes any previous reports with this reference number.
b. The results in this report apply to the sample(s) as received by SGS Australian Radiation Services
c. This report has been prepared and issued in accordance with NATA's accreditation requirements.

SGS Australian Radiation Services | PO Box 3103, Nunawading VIC 3131 7/25–37 Chapman Street Blackburn North VIC 3130
t +61 (0)3 9210 2000 f +61 (0)3 9899 6155 www.radiation.net.au www.sgs.com

Member of the SGS Group (SGS SA)

ABN 44 000 964 278

RESULTS:

Notes:

a) Radionuclide or gross radioactivity concentrations are expressed in becquerel per kilogram of dried solid sample or becquerel per litre of water sample unless otherwise specified. The becquerel (Bq) is the SI unit for activity and equals one nuclear transformation per second.
b) Metals and anions and other non-radiological parameters are expressed in milligram (mg) per kilogram of dried solid sample or milligram per litre of water sample unless otherwise specified.
c) 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.
d) The reported uncertainty in each result is the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%.
e) Uranium-238 activity concentration is calculated from the uranium mass concentration using a conversion factor of 12.445 $Bq{\cdot}mg^{-1}$.
f) Thorium-232 activity concentration is calculated from the thorium mass concentration using a conversion factor of 4.046 $Bq{\cdot}mg^{-1}$.

A. Specific radionuclides

Test method: a. Preparation – ARS-SOP-AS301 – Preparation of liquid samples for measurement by high resolution gamma ray spectrometry.
b. Measurement – ARS-SOP-AS406 – Measurement by high resolution gamma ray spectrometry.

		Radionuclide Concentration					
		Naturally-occurring uranium (U-238) series			***Naturally-occurring thorium (Th-232) series***		
Client Sample ID (ARS Lab. ID)	**Unit**	**Uranium-238**	**Radium-226**	**Lead-210**	**Thorium-232**	**Radium-228**	**Thorium-228**
BORE #1 (15-0193-01)	$Bq{\cdot}L^{-1}$	< 0.07	0.178 ± 0.022	< 0.15	< 0.03	0.351 ± 0.040	< 0.025
BORE #2 (15-0193-02)	$Bq{\cdot}L^{-1}$	< 0.13	1.28 ± 0.16	< 0.63	< 0.05	2.61 ± 0.31	< 0.097
BORE #3 (15-0193-03)	$Bq{\cdot}L^{-1}$	< 0.13	1.27 ± 0.12	< 0.54	< 0.05	2.68 ± 0.26	< 0.11

B. Elemental concentrations:

Elemental concentration was determined by SGS Perth Environmental, NATA Accredited Laboratory Number: 2562.

Test method: a. Preparation – AN311/AN312 Mercury
AN318/AN320 Trace metals
b. Measurement – AN311/AN312 Mercury
AN318/AN320 Trace metals

	Client Sample ID (ARS Lab. ID)		
Parameter	**BORE #1 (15-0193-01)**	**BORE #2 (15-0193-02)**	**BORE #3 (15-0193-03)**
Antimony	< 0.005	< 0.010	< 0.010
Arsenic	< 0.005	< 0.010	< 0.010
Barium	0.050	0.026	0.024
Beryllium	< 0.005	< 0.010	< 0.010
Boron	2.7	8.1	7.6
Cadmium	< 0.0005	< 0.0010	< 0.0010
Chromium	< 0.005	< 0.010	< 0.010
Cobalt	0.011	< 0.010	< 0.010
Copper	< 0.005	< 0.010	< 0.010
Lead	< 0.005	< 0.010	< 0.010
Manganese	0.15	1.2	1.2
Mercury	< 0.00005	0.00005	0.00012

Parameter	Client Sample ID (ARS Lab. ID)		
	BORE #1 (15-0193-01)	BORE #2 (15-0193-02)	BORE #3 (15-0193-03)
Molybdenum	< 0.005	< 0.010	< 0.010
Nickel	0.020	0.015	0.015
Selenium	< 0.005	0.019	0.018
Thorium	< 0.005	< 0.010	< 0.010
Tin	< 0.005	< 0.010	< 0.010
Uranium	< 0.005	< 0.010	< 0.010
Zinc	0.026	0.062	0.065

C. Naturally occurring radionuclides by alpha spectrometry

Radionuclide concentrations by alpha spectrometry were determined by Institute of Environmental Science and Research Limited, IANZ accreditation number: 848.

Test method: a. Preparation & measurement – Alpha spectrometry after radiochemical preparation.

		Radionuclide concentration	
Client Sample ID (ARS Lab. ID)	**Unit**	**Polonium-210**	**Thorium-230**
BORE #1 (15-0193-01)	$Bq \cdot L^{-1}$	0.0038 ± 0.0051	0.065 ± 0.031
BORE #2 (15-0193-02)	$Bq \cdot L^{-1}$	0.0090 ± 0.0071	0.0133 ± 0.0085
BORE #3 (15-0193-03)	$Bq \cdot L^{-1}$	0.0114 ± 0.0076	0.31 ± 0.11

Appendix G – Cation Exchange Capacity (CEC) of sediments downstream of proposed Ambassador and Princess operations

16 - 18 Hayden Court, Myaree, Western Australia 6154
PO Box 4023 Myaree BC, Western Australia 6960
Tel: +61 8 9317 2505 / Fax: +61 8 9317 4163
email: laboratory@mpl.com.au
www.envirolabservices.com.au
Envirolab Services (WA) Pty Ltd ABN 53 140 099 207

Part of the Envirolab Group

CERTIFICATE OF ANALYSIS 166253

Client:
Vimy Resources
Ground Floor, 10 Richardson Street
WA 6005

Attention: Xavier Moreau

Sample log in details:

Your Reference:	**VIMY Resources**
No. of samples:	8 Soil
Date samples received:	22/05/2015
Date completed instructions received:	22/05/2015
Location	

Analysis Details:
Please refer to the following pages for results, methodology summary and quality control data.
Samples were analysed as received from the client. Results relate specifically to the samples as received.
Results are reported on a dry weight basis for solids and on an as received basis for other matrices.
Please refer to the last page of this report for any comments relating to the results.

Report Details:

Date results requested by:	27/05/15
Date of Preliminary Report:	25/05 26/05
Issue Date:	27/05/15

Results Approved By:

Todd Lee
Laboratory Manager

ESP/CEC*						
Our Reference:	UNITS	166253-1	166253-2	166253-3	166253-4	166253-5
Your Reference	-------------	NNA5243	NNA5243	NNA5243	NNA5431	NNA5431
Depth	------------	43-43.5	45-45.5	49-49.5	48-48.5	51-51.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Calcium	mg/kg	75	230	270	3,200	1,500
Potassium	mg/kg	<50	<50	<50	160	180
Magnesium	mg/kg	<50	<50	63	2,000	1,100
Sodium	mg/kg	<50	<50	<50	930	990
Aluminium	mg/kg	<10	<10	<10	<10	<10
Exchangeable Ca*	meq/100g	<1	1	1	16	7
Exchangeable K*	meq/100g	<1	<1	<1	<1	<1
Exchangeable Mg*	meq/100g	<1	<1	<1	17	9
Exchangeable Na*	meq/100g	<1	<1	<1	4	4
Exchangeable Al*	meq/100g	<1	<1	<1	<1	<1
Cation Exchange Capacity*	meq/100g	<5	<5	<5	37	21

ESP/CEC*						
Our Reference:	UNITS	166253-6	166253-7	166253-8	166253-9	166253-10
Your Reference	-------------	NNA5431	NNA5433	NNA5433	NNA5433	NNA5441
Depth	------------	56-56.5	39-39.5	43-43.5	51-51.5	40-40.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Calcium	mg/kg	4,300	3,300	3,100	4,600	720
Potassium	mg/kg	250	290	120	360	190
Magnesium	mg/kg	2,800	2,700	140	3,400	450
Sodium	mg/kg	2,400	2,600	690	3,500	330
Aluminium	mg/kg	<10	<10	260	<10	<10
Exchangeable Ca*	meq/100g	21	17	16	23	4
Exchangeable K*	meq/100g	<1	<1	<1	<1	<1
Exchangeable Mg*	meq/100g	23	22	1	28	4
Exchangeable Na*	meq/100g	10	11	3	15	1
Exchangeable Al*	meq/100g	<1	<1	2	<1	<1
Cation Exchange Capacity*	meq/100g	55	50	22	66	9

ESP/CEC* Our Reference: Your Reference Depth Type of sample	UNITS ------------- ------------	166253-11 NNA5441 48-48.5 Soil	166253-12 NNA5441 50-50.5 Soil	166253-13 NNA5442 38-38.5 Soil	166253-14 NNA5442 42-42.5 Soil	166253-15 NNA5442 49-49.5 Soil
Calcium	mg/kg	1,000	900	2,100	3,400	3,800
Potassium	mg/kg	230	82	420	350	410
Magnesium	mg/kg	670	650	1,800	2,700	2,800
Sodium	mg/kg	350	1,000	2,100	3,400	3,100
Aluminium	mg/kg	<10	<10	<10	44	<10
Exchangeable Ca*	meq/100g	5	5	11	17	19
Exchangeable K*	meq/100g	<1	<1	1	<1	1
Exchangeable Mg*	meq/100g	5	5	14	22	23
Exchangeable Na*	meq/100g	2	5	9	15	13
Exchangeable Al*	meq/100g	<1	<1	<1	<1	<1
Cation Exchange Capacity*	meq/100g	12	14	35	54	57

ESP/CEC* Our Reference: Your Reference Depth Type of sample	UNITS ------------- ------------	166253-16 NNA5446 47-47.5 Soil	166253-17 NNA5446 51-51.5 Soil	166253-18 NNA5446 56-56.5 Soil	166253-19 NNA5451 36-36.5 Soil	166253-20 NNA5451 41-41.5 Soil
Calcium	mg/kg	4,100	630	980	1,200	4,100
Potassium	mg/kg	350	81	53	410	320
Magnesium	mg/kg	3,300	400	550	850	3,200
Sodium	mg/kg	3,000	730	790	690	2,900
Aluminium	mg/kg	15	<10	<10	<10	<10
Exchangeable Ca*	meq/100g	21	3	5	6	20
Exchangeable K*	meq/100g	<1	<1	<1	1	<1
Exchangeable Mg*	meq/100g	27	3	5	7	27
Exchangeable Na*	meq/100g	13	3	3	3	13
Exchangeable Al*	meq/100g	<1	<1	<1	<1	<1
Cation Exchange Capacity*	meq/100g	61	10	13	17	60

ESP/CEC*		
Our Reference:	UNITS	166253-21
Your Reference	-------------	NNA5451
Depth	------------	47-47.5
Type of sample		Soil
Calcium	mg/kg	760
Potassium	mg/kg	<50
Magnesium	mg/kg	390
Sodium	mg/kg	100
Aluminium	mg/kg	<10
Exchangeable Ca*	meq/100g	4
Exchangeable K*	meq/100g	<1
Exchangeable Mg*	meq/100g	3
Exchangeable Na*	meq/100g	<1
Exchangeable Al*	meq/100g	<1
Cation Exchange Capacity*	meq/100g	7

Acid Neutralisation Capacity*						
Our Reference:	UNITS	166253-1	166253-2	166253-3	166253-4	166253-5
Your Reference	-------------	NNA5243	NNA5243	NNA5243	NNA5431	NNA5431
Depth	------------	43-43.5	45-45.5	49-49.5	48-48.5	51-51.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date Prepared		22/05/2015	22/05/2015	22/05/2015	22/05/2015	22/05/2015
Date Analysed		25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Fizz Rating		0	0	0	0	0
ANC	kg H2SO4/tonne	4.2	2.2	1.4	<0.5	2.0
ANC	% CaCO3	0.4	0.2	0.1	<0.05	0.2

Acid Neutralisation Capacity*						
Our Reference:	UNITS	166253-6	166253-7	166253-8	166253-9	166253-10
Your Reference	-------------	NNA5431	NNA5433	NNA5433	NNA5433	NNA5441
Depth	------------	56-56.5	39-39.5	43-43.5	51-51.5	40-40.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date Prepared		22/05/2015	22/05/2015	22/05/2015	22/05/2015	22/05/2015
Date Analysed		25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Fizz Rating		0	0	0	0	0
ANC	kg H2SO4/tonne	<0.5	<0.5	<0.5	<0.5	3.8
ANC	% CaCO3	<0.05	<0.05	<0.05	<0.05	0.4

Acid Neutralisation Capacity*						
Our Reference:	UNITS	166253-11	166253-12	166253-13	166253-14	166253-15
Your Reference	-------------	NNA5441	NNA5441	NNA5442	NNA5442	NNA5442
Depth	------------	48-48.5	50-50.5	38-38.5	42-42.5	49-49.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date Prepared		22/05/2015	22/05/2015	22/05/2015	22/05/2015	22/05/2015
Date Analysed		25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Fizz Rating		0	0	0	0	0
ANC	kg H2SO4/tonne	<0.5	<0.5	2.9	2.8	6.8
ANC	% CaCO3	<0.05	<0.05	0.3	0.3	0.7

Acid Neutralisation Capacity*						
Our Reference:	UNITS	166253-16	166253-17	166253-18	166253-19	166253-20
Your Reference	-------------	NNA5446	NNA5446	NNA5446	NNA5451	NNA5451
Depth	------------	47-47.5	51-51.5	56-56.5	36-36.5	41-41.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date Prepared		22/05/2015	22/05/2015	22/05/2015	22/05/2015	22/05/2015
Date Analysed		25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Fizz Rating		0	0	0	0	0
ANC	kg H2SO4/tonne	3.4	6.1	<0.5	5.1	7.8
ANC	% CaCO3	0.3	0.6	<0.05	0.5	0.8

Acid Neutralisation Capacity*		
Our Reference:	UNITS	166253-21
Your Reference	-------------	NNA5451
Depth	------------	47-47.5
Type of sample		Soil
Date Prepared		22/05/2015
Date Analysed		25/05/2015
Fizz Rating		0
ANC	kg H2SO4/tonne	5.8
ANC	% CaCO3	0.6

Miscellaneous Inorg - soil						
Our Reference:	UNITS	166253-1	166253-2	166253-3	166253-4	166253-5
Your Reference	-------------	NNA5243	NNA5243	NNA5243	NNA5431	NNA5431
Depth	------------	43-43.5	45-45.5	49-49.5	48-48.5	51-51.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date prepared	-	25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Date analysed	-	27/05/2015	27/05/2015	27/05/2015	27/05/2015	27/05/2015
Anion Exchange Capacity*	$cmol_c/kg$	0.017	0.025	0.025	0.036	0.020

Miscellaneous Inorg - soil						
Our Reference:	UNITS	166253-6	166253-7	166253-8	166253-9	166253-10
Your Reference	-------------	NNA5431	NNA5433	NNA5433	NNA5433	NNA5441
Depth	------------	56-56.5	39-39.5	43-43.5	51-51.5	40-40.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date prepared	-	25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Date analysed	-	27/05/2015	27/05/2015	27/05/2015	27/05/2015	27/05/2015
Anion Exchange Capacity*	$cmol_c/kg$	<0.005	<0.005	0.042	0.014	0.034

Miscellaneous Inorg - soil						
Our Reference:	UNITS	166253-11	166253-12	166253-13	166253-14	166253-15
Your Reference	-------------	NNA5441	NNA5441	NNA5442	NNA5442	NNA5442
Depth	------------	48-48.5	50-50.5	38-38.5	42-42.5	49-49.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date prepared	-	25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Date analysed	-	27/05/2015	27/05/2015	27/05/2015	27/05/2015	27/05/2015
Anion Exchange Capacity*	$cmol_c/kg$	0.084	<0.005	0.025	0.013	0.017

Miscellaneous Inorg - soil						
Our Reference:	UNITS	166253-16	166253-17	166253-18	166253-19	166253-20
Your Reference	-------------	NNA5446	NNA5446	NNA5446	NNA5451	NNA5451
Depth	------------	47-47.5	51-51.5	56-56.5	36-36.5	41-41.5
Type of sample		Soil	Soil	Soil	Soil	Soil
Date prepared	-	25/05/2015	25/05/2015	25/05/2015	25/05/2015	25/05/2015
Date analysed	-	27/05/2015	27/05/2015	27/05/2015	27/05/2015	27/05/2015
Anion Exchange Capacity*	$cmol_c/kg$	0.006	0.022	0.031	0.090	<0.005

Miscellaneous Inorg - soil		
Our Reference:	UNITS	166253-21
Your Reference	-------------	NNA5451
Depth	------------	47-47.5
Type of sample		Soil
Date prepared	-	25/05/2015
Date analysed	-	27/05/2015
Anion Exchange Capacity*	$cmol_c/kg$	0.007

Method ID	Methodology Summary
METALS-020	Metals in soil and water by ICP-OES.
Metals-009	Preparation of sample for CEC.
AMD-001	Acid Mine Drainage determined by AMIRA International - Acid Rock Drainage Test Handbook.

QUALITY CONTROL ESP/CEC*	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD	Spike Sm#	Spike % Recovery
Calcium	mg/kg	50	METALS-020	<50	166253-1	75 || 77 || RPD: 3	LCS-1	106%
Potassium	mg/kg	50	METALS-020	<50	166253-1	<50 || <50	LCS-1	107%
Magnesium	mg/kg	50	METALS-020	<50	166253-1	<50 || <50	LCS-1	102%
Sodium	mg/kg	50	METALS-020	<50	166253-1	<50 || <50	LCS-1	96%
Aluminium	mg/kg	10	METALS-020	<10	166253-1	<10 || <10	LCS-1	106%
Exchangeable Ca*	meq/100 g	1	Metals-009	[NT]	166253-1	<1 || <1	[NR]	[NR]
Exchangeable K*	meq/100 g	1	Metals-009	[NT]	166253-1	<1 || <1	[NR]	[NR]
Exchangeable Mg*	meq/100 g	1	Metals-009	[NT]	166253-1	<1 || <1	[NR]	[NR]
Exchangeable Na*	meq/100 g	1	Metals-009	[NT]	166253-1	<1 || <1	[NR]	[NR]
Exchangeable Al*	meq/100 g	1	Metals-009	[NT]	166253-1	<1 || <1	[NR]	[NR]
Cation Exchange Capacity*	meq/100 g	5	Metals-009	[NT]	166253-1	<5 || <5	[NR]	[NR]

QUALITY CONTROL Acid Neutralisation Capacity*	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD
Date Prepared				[NT]	166253-1	22/05/2015 || 22/05/2015
Date Analysed				[NT]	166253-1	25/05/2015 || 25/05/2015
Fizz Rating			AMD-001	[NT]	166253-1	0 || 0
ANC	kg H2SO4/tonne	0.5	AMD-001	[NT]	166253-1	4.2 || 3.8 || RPD: 10
ANC	% CaCO3	0.05	AMD-001	[NT]	166253-1	0.4 || 0.4 || RPD: 0

QUALITY CONTROL Miscellaneous Inorg - soil	UNITS	PQL	METHOD	Blank	Duplicate Sm#	Duplicate results Base II Duplicate II %RPD
Date prepared	-			[NT]	166253-1	25/05/2015 || 25/05/2015
Date analysed	-			[NT]	166253-1	27/05/2015 || 27/05/2015
Anion Exchange Capacity*	$cmol_c$ /kg	0.005		[NT]	166253-1	0.017 || 0.017 || RPD: 0

QUALITY CONTROL ESP/CEC*	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Calcium	mg/kg	166253-11	1000 || 1000 || RPD: 0	166253-2	100%
Potassium	mg/kg	166253-11	230 || 220 || RPD: 4	166253-2	95%
Magnesium	mg/kg	166253-11	670 || 660 || RPD: 2	166253-2	96%
Sodium	mg/kg	166253-11	350 || 350 || RPD: 0	166253-2	90%
Aluminium	mg/kg	166253-11	<10 || <10	166253-2	100%
Exchangeable Ca*	meq/100 g	166253-11	5 || 5 || RPD: 0	[NR]	[NR]

QUALITY CONTROL ESP/CEC*	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD	Spike Sm#	Spike % Recovery
Exchangeable K*	meq/100 g	166253-11	<1 || <1	[NR]	[NR]
Exchangeable Mg*	meq/100 g	166253-11	5 || 5 || RPD: 0	[NR]	[NR]
Exchangeable Na*	meq/100 g	166253-11	2 || 2 || RPD: 0	[NR]	[NR]
Exchangeable Al*	meq/100 g	166253-11	<1 || <1	[NR]	[NR]
Cation Exchange Capacity*	meq/100 g	166253-11	12 || 12 || RPD: 0	[NR]	[NR]

QUALITY CONTROL Acid Neutralisation Capacity*	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD
Date Prepared		166253-11	22/05/2015 || 22/05/2015
Date Analysed		166253-11	25/05/2015 || 25/05/2015
Fizz Rating		166253-11	0 || 0
ANC	kg H2SO4/tonne	166253-11	<0.5 || <0.5
ANC	% CaCO3	166253-11	<0.05 || <0.05

QUALITY CONTROL Miscellaneous Inorg - soil	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD
Date prepared	-	166253-11	25/05/2015 || 25/05/2015
Date analysed	-	166253-11	27/05/2015 || 27/05/2015
Anion Exchange Capacity*	cmolc/kg	166253-11	0.084 || 0.086 || RPD: 2

QUALITY CONTROL Acid Neutralisation Capacity*	UNITS	Dup. Sm#	Duplicate Base + Duplicate + %RPD
Date Prepared		166253-21	22/05/2015 || 22/05/2015
Date Analysed		166253-21	25/05/2015 || 25/05/2015
Fizz Rating		166253-21	0 || 0
ANC	kg H2SO4/tonne	166253-21	5.8 || 6.2 || RPD: 7
ANC	% CaCO3	166253-21	0.6 || 0.6 || RPD: 0

Report Comments:

Anion Exchange Capacity - Analysis conducted as per Raymont & Lyons Method 15E1.

Definitions:

NT: Not tested NA: Test not required INS: Insufficient sample for this test PQL: Practical Quantitation Limit
<: Less than >: Greater than RPD: Relative Percent Difference LCS: Laboratory Control Sample
NS: Not Specified NEPM: National Environmental Protection Measure

Australian Drinking Water Guidelines recommend that Thermotolerant Coliform, Faecal Enterococci, & E.Coli levels are less than 1cfu/100mL. The recommended maximums are taken from "Australian Drinking Water Guidelines", published by NHMRC & ARMC 2011

Quality Control Definitions

Blank: This is the component of the analytical signal which is not derived from the sample but from reagents, glassware etc, can be determined by processing solvents and reagents in exactly the same manner as for samples.

Duplicate: This is the complete duplicate analysis of a sample from the process batch. If possible, the sample selected should be one where the analyte concentration is easily measurable.

Matrix Spike : A portion of the sample is spiked with a known concentration of target analyte. The purpose of the matrix spike is to monitor the performance of the analytical method used and to determine whether matrix interferences exist.

LCS (Laboratory Control Sample) : This comprises either a standard reference material or a control matrix (such as a blank sand or water) fortified with analytes representative of the analyte class. It is simply a check sample.

Surrogate Spike: Surrogates are known additions to each sample, blank, matrix spike and LCS in a batch, of compounds which are similar to the analyte of interest, however are not expected to be found in real samples.

Laboratory Acceptance Criteria

Duplicate sample and matrix spike recoveries may not be reported on smaller jobs, however, were analysed at a frequency to meet or exceed NEPM requirements. All samples are tested in batches of 20. The duplicate sample RPD and matrix spike recoveries for the batch were within the laboratory acceptance criteria.
Filters, swabs, wipes, tubes and badges will not have duplicate data as the whole sample is generally extracted during sample extraction.
Spikes for Physical and Aggregate Tests are not applicable.
For VOCs in water samples, three vials are required for duplicate or spike analysis.

Duplicates: <5xPQL - any RPD is acceptable; >5xPQL - 0-50% RPD is acceptable.
Matrix Spikes, LCS and Surrogate recoveries: Generally 70-130% for inorganics/metals; 60-140% for organics (+/-50% surrogates) and 10-140% for labile SVOCs (including labile surrogates), ultra trace organics and speciated phenols is acceptable.

In circumstances where no duplicate and/or sample spike has been reported at 1 in 10 and/or 1 in 20 samples respectively, the sample volume submitted was insufficient in order to satisfy laboratory QA/QC protocols.

When samples are received where certain analytes are outside of recommended technical holding times (THTs), the analysis has proceeded. Where analytes are on the verge of breaching THTs, every effort will be made to analyse within the THT or as soon as practicable.

GHD

180 Lonsdale Street
Melbourne, Victoria 3000
T: (03) 8687 8000   F: (03) 8687 8111   E: melmail@ghd.com.au

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A						5/6/2015
B						12/6/2015
0	A Barron S Gray T Anderson	R Virtue P Beck		R Virtue		19/6/2015

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