9.5 Hydrological Processes and Inland Water Quality (Groundwater)

9.5.1 EPA Objective

The EPA's objective with regards to hydrological processes for groundwater is:

- To maintain the hydrological regimes of groundwater so that existing and potential uses, including ecosystem maintenance, are protected.

The EPA's objective with regards to inland water quality for groundwater is:

- To maintain the quality of groundwater and biota so that the environmental values, both ecological and social are protected.

9.5.2 Relevant Legislation and Policy

The DoW draft guideline on the management of water in mining in Western Australian (DoW 2012) provides guidance on water management issues that need to be considered by mining projects and the type of information the department may require as part of the licence assessment process.

In WA, the DoW issues licenses and permits under the *Rights in Water and Irrigation Act 1914* (RIWI Act) that protect the State's water resources and promotes the sustainable and efficient use of water. Cameco will apply for a 5C licence to take water under the RIWI Act.

The DoW has also released a state-wide Environmental Water Provisions Policy (Water and Rivers Commission 2000). The primary objective of this policy is to provide for the protection of water dependent ecosystems whilst allowing for the management of water resources for their sustainable use and development to meet the needs of current and future users. It outlines the guiding principles to be followed by DoW when making decisions related to the provision of water to the environment.

The ANZECC and the ARMCANZ have developed the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000). The objective of these guidelines is to provide a national framework for the protection of water bodies from contamination as part of Australia's NWQMS. The scope of the documents includes a set of actions currently in practice all over Australia, and recommendations on how to implement or adapt new strategies to any groundwater body localities.

9.5.3 Studies and Investigations

9.5.3.1 Overview

The required work relating to groundwater is outlined in the ESD under Hydrological Processes / Inland Waters Environmental Quality (Appendix A1).

The hydrogeology of the proposed development area and catchment has been extensively studied since the early 1960s. The understanding of the groundwater regime and the assessment of potential groundwater impacts presented in this chapter is based on the knowledge gained from these previous studies and on other detailed work undertaken by Cameco. Essentially, the previous studies undertaken were used to develop a conceptual hydrogeological model and a numerical groundwater flow model (URS 2011). Cameco adapted this model to simulate the groundwater behaviour under the proposed operating conditions. Cameco also undertook further studies (concentrations of contaminants that could be released in solute [referred to as 'source terms'] of tailings and mine waste that would be generated) and modelling (solute transport modelling) to simulate the likely movement of contaminants in the groundwater over time following mine closure.

An independent external consultant has undertaken a review of the groundwater modelling undertaken by Cameco. A copy of the review is provided as Appendix I3.

The DoW has advised in writing (email dated 29th April 2015) that the work presented by Cameco to assess groundwater impacts meets the requirements of a H3 level of assessment as outlined in DoW Operational Policy No. 5.12 (DoW, 2009).

A summary of key studies used to inform this assessment is provided below.

9.5.3.2 Previous studies

Slot 1 mining trial

In 1972, WMC conducted an extensive trial mining operation, referred to as the Slot 1 trial, to support a pilot scale metallurgical testing program. This trial provided 'real' data for understanding of the mining site's underlying hydrogeological regime, the required dewatering rate and the water table drawdown in the surrounding area.

The Slot 1 excavation had dimensions of 457 m [l] x 46 m [w] x 9.1 m [d]. Dewatering, via excavated trenches, was undertaken to determine the upper limit of groundwater abstraction required to dewater the slot. During the mining trial, transient groundwater levels within the main water bearing aquifer in the catchment area (calcrete and transition calcrete successions) were measured in numerous mineral exploration monitoring wells. This trial enabled the assessment of the local aquifer responses to groundwater abstraction over a period of 98 days. The results of this trial were used subsequently to construct and calibrate the numerical groundwater flow model (URS, 2011).

Groundwater studies prior to 2009

In the early 1970s and 1980s numerous groundwater investigations were commissioned for the Yeelirrie Catchment. These studies included groundwater level monitoring, groundwater quality analyses, hydrogeological investigations and water supply studies.

The key reports reviewed and prepared as part of the baseline studies include the following:

- Australian Groundwater Consultants Pty Ltd. (1972): A preliminary study of water supply that included a census of 22 wells in the Yeelirrie Catchment, providing information on depths, groundwater levels and salinity and catchment lithology.
- Western Mining Corporation (1978): A report that included investigating groundwater contours and groundwater quality. The groundwater quality data are sourced from 26 windmills, 25 geological exploration wells, and two deep groundwater wells.
- Australian Groundwater Consultants Pty Ltd. (1981): A comprehensive study of water supply options to inform feasibility of supply, inclusive of site investigations to indicate aquifer storage, hydraulic characteristics and groundwater quality within selected potential source areas.
- Australian Groundwater Consultants Pty Ltd. (1982): This study assessed the effects of mine dewatering on regional groundwater levels. A numerical groundwater model was used to predict the cumulative impacts of concurrent pit dewatering and process water supply abstractions together with the disposal of excess groundwater at times when the pit dewatering exceeds process supply demands. In addition, a solute transport model was used to estimate transient variations in salinity of the process water supply sources during the proposed development.
- AGC Woodward-Clyde Pty Limited (1996): This report presents geological cross-sections of the Yeelirrie Palaeochannel and the findings of groundwater exploration drilling and aquifer testing investigations from the early 1970s to the 1990s to develop process water supplies for the Mt Keith Operation.
- Stentiford and Berry (2008): Annual production and monitoring report for the Albion Downs Wellfield, approximately 50 km south east of the Project Area, the period 1 July 2006 to 30 June 2007. The report hosts historical abstraction, groundwater level data, groundwater quality data and an assessment of source performance.

- URS (2011): Report on a conceptual hydrogeological model which, in turn, formed the basis for developing a numerical groundwater flow model.
- Cameco (2015): Report completed by Cameco hydrologists on the amended hydrogeological model. (Appendix I1)

Development of Yeelirrie Catchment Model

In 2009 and 2010, BHPB commissioned several groundwater related field investigation programs in support of establishing a conceptual hydrogeological model which, in turn, formed the basis for developing a numerical groundwater flow model, termed the Yeelirrie Catchment Model (URS, 2011). The fieldwork conducted included:

- Construction and monitoring of groundwater monitoring wells:
  - 143 single groundwater monitoring wells;
  - seven multi-level monitoring wells (typically three monitoring wells were completed in a single borehole at each of the multi-level sites);
  - eight test production wells;
  - 95 wells for characterising stygofauna; and
  - 77 wells for troglofauna characterisation.
- Pumping tests:
  - Short-term pumping tests (50 monitoring wells) and longer term tests (eight test production wells) were conducted to obtain an estimate of the hydraulic conductivity and transmissivity of the various hydrostratigraphic units at the site.
- Laboratory test
  - conducted on eight undisturbed core samples from the clayey alluvium to determine the vertical hydraulic conductivity.
- Groundwater quality:
  - data were collected from 215 sampling sites;
  - groundwater was analyzed for major ions, metals (dissolved and total), nutrients and radiochemicals.

9.5.3.3 Studies undertaken by Cameco

Cameco Model

Cameco developed a numerical model (the Cameco Model) to model groundwater flow (drawdown and recovery) and solute transport movement from the TSF (Numerical Groundwater Flow and Solute Transport Model of the Yeelirrie Uranium Deposit (Cameco, 2015a) presented in Appendix I1).

The development of the Cameco Model was based on the Yeelirrie Model but was modified (to consider the mining and processing rates, and groundwater abstraction locations proposed by Cameco) and expanded to include solute transport modelling.

The groundwater flow and solute transport modelling report:

- presents the characteristics of the baseline hydrogeological environment;
- assesses water supply options;
- provides a water balance for the proposal;
- evaluates the impacts of abstracting groundwater to meet Project water demand;
- presents the predicted extent and magnitude of groundwater drawdown; and
- outlines the simulated impact on the environment of solute transport of selected constituents of concern (COC) originating from the tailings (determined in the Source Terms analysis described below).

Cameco has used a conservative approach to modelling the groundwater flow and solute transport, including:

Groundwater flow modelling

- using a water supply demand which is 26% more than required for the Project;
- assuming a low (10%) recovery of water from tailings and processing;
- using low abstraction intensity from the wellfield; and
- making no allowance for harvesting of rainfall and runoff;

Solute Transport Modelling

- determining site specific distribution coefficients for the various subsurface mediums (ability of the medium to attenuate a contaminant) and conducting sensitivity analyses to understand the effect on transport and
- increasing the source terms by 20%.

Further detail on the methodology and assumptions is presented in Cameco (2015a) in Appendix I1.

Source Terms

Cameco also undertook a detailed analysis of the source terms of the tailings and stockpiled materials (Cameco 2015b). This work built upon previously commissioned work that included a geochemical assessment of tailings and mine waste (SRK Consulting, 2011a) and an assessment to determine the tailings' and mine waste's source terms (SRK Consulting, 2011b). SRK Consulting's work included chemical characterisation of Yeelirrie materials and laboratory leach tests. The source terms were then applied in the solute transport modelling described above to simulate the potential impacts to the groundwater over time following project closure. The steps involved in developing the source terms were as follows:

1. A review of a SysCAD process model with a production rate of 2.4 million tonnes of ore per year. The process model provided geochemical information of the tailings discharge slurry.
2. A review of the tailings aging data from the SRK Consulting investigations. Statistical parameters of the tailings aging data in conjunction with geochemical modelling predictions were used to determine the tailings source terms.
3. The sensitivity of the source terms was investigated by varying the pH and redox potential. Evaporation and the resulting effects on salinity and constituent porewater concentrations were also modelled.

Geochemical modelling using the software program Geochemist's Workbench was then undertaken using thermodynamic data held in various databases.

Further detail on the methodology for this study is presented in Cameco (2015b) in Appendix I2.

TSF design and management

Cameco has also prepared a report for the Yeelirrie TSF design and management (Cameco, 2015c; Appendix D) which is relevant to the management of impacts on groundwater.

9.5.4 Existing Environment

9.5.4.1 Physical setting

The Yeelirrie uranium deposit occurs in the Cenozoic aged drainage channel of a wide, flat and long drainage valley (Yeelirrie Catchment) flanked by granitic breakaways of low topographic relief; including the Barr Smith Range to the north-east and the Montague Range to the west.

The drainage channel is incised into the crystalline, Archaean aged basement rocks of the northern Yilgarn Craton.

The valley has a northwest to southeast orientation. The valley floor has an elevation of about 500 mAHD, while the breakaways are 50 to 100 m higher. In the vicinity of the deposit, the valley is 25 to 30 km wide. From the Yeelirrie deposit, the valley extends at least 50 km to the north-west and approximately 80 km to the southeast, where it joins the Lake Miranda basin at 460 mAHD.

Regionally there are a number of important features that relate to the groundwater regime in the Yeelirrie Catchment. These include the Yeelirrie and Albion Downs Playas and the Albion Downs Wellfield. The Yeelirrie and Albion Downs Playas are small playa lakes that exist in topographic depressions in the lower reaches of the catchment. They are located on or adjacent to the channel axis approximately 20 km and 30 km south east of the Project Area, between the Yeelirrie deposit and Lake Miranda. The Albion Downs Wellfield is described in Section 9.5.4.5.

The climate in the Yeelirrie catchment area is classified as arid with a variable temporal and spatial rainfall distribution. The average annual rainfall of 239 mm is overwhelmed by the large evaporation rates that exist in the area. The Wiluna BoM Station No. 013012 (1957 to 1985) (the closest official site to Yeelirrie) recorded an average pan evaporation rate of 2,412 mm a year.

9.5.4.2 Aquifer systems

The aquifer systems within the Yeelirrie Catchment have been determined based on a conceptual hydrogeological model developed by URS (2011). The interpreted hydrostratigraphical setting is shown in Table 9-43.

Calcrete Aquifers

The calcrete deposits form the most significant water table (unconfined) aquifers in the central valley areas of the region, with transmissivity enhanced by karstic secondary porosity characteristics. Well yields in calcrete are known to be widely variable, due to the karst development. Yields at Depot Springs (located 75 km south from the Project) ranged from 300 to 5,000 kL/day in massive and strongly karstic calcrete (WMC, 1978).

Alluvial Aquifers

The majority of the alluvial aquifers occur between the base of the carbonated clay-quartz unit and above the unconformity marker horizon (Table 9-43). The alluvial sediments commonly form an unconfined water table aquifer with a saturated thickness from 5 to 15 m. Typically, the water table is comparatively shallow at depths of 2 to 10 m beneath the valley-floor and foot-slope areas. Water yields of 50 to 330 kL/day occur within the Albion Downs Wellfield downstream of Yeelirrie.

Basal Palaeochannel Sand Aquifer (Woolubar Sandstone)

The basal sands form important regional aquifers capable of providing substantial groundwater supplies. Based on aquifer tests the hydraulic conductivity of this aquifer is in the range of 1 to 40 m/day (average 10 m/day).

Archaean Basement

Basement rocks within the Yeelirrie Catchment are typically considered to have a low transmissivity, consistent with assessments made in other similar geological settings. Weathered and fractured fault/shear zones may be associated with localised aquifer zones but these zones would have relatively a low transmissivity. The weathered granite is interpreted to form a hydraulic link between the Early Tertiary sediments and the near surface alluvial/calcrete aquifers. Fresh granite forms the base of the groundwater flow system within the Yeelirrie Catchment.

Table 9-43: Regional and Yeelirrie Catchment Stratigraphy

Hydrostratigraphic Unit		Potential Aquifer Description	
		Storage Characteristics	Broad Lithology
Quaternary/Recent Superficial Formations			
Hard Pan		Unconfined	Loam and Hard Pan
Calcrete			Calcrete
			Transitional Calcrete
			Carbonated Clay-Quartz
Alluvium		Unconfined to Semi-Confined	Sandstone
			Sandy Alluvium
			Clayey Alluvium
Early-Tertiary Successions – Yeelirrie Palaeochannel			
Upper Channel	Unconformity Marker Bed	Confined	Ferricrete/Desiccated Clay
	Carbonaceous Marker Bed		Dark Grey Clay
	Upper Palaeochannel Sands		Palaeochannel Sand
Lower Channel	Perkolilli Shale		Lacustrine Clay
	Wollubar Sandstone		Palaeochannel Sand
Archaean - Yilgarn Shield			
Weathered Bedrock		Confined	Granite, Greenstone and Dolerite
Fresh Bedrock		Confined Fractured Rock	Granite, Greenstone and Dolerite

Units considered potential aquifers

Source: Cameco (2015a) after URS (2011)

9.5.4.3 Groundwater levels

Baseline (pre-development) water table elevations were reported by URS (2011).

The interpreted water table topography closely reflects the land surface topography. Groundwater is predicted to move from the catchment divides towards the valley floor areas and then in a general southeast direction towards the Yeelirrie Playa, Albion Downs Playa and Lake Miranda. With elevations ranging from 530 to 610 mAHD, the groundwater levels are the highest in the northwest (headwaters) of the Yeelirrie catchment. Down-gradient, across the deposit, it ranges from 490 to 492 mAHD and is about 480 mAHD at the Yeelirrie Homestead. In the vicinity of Miranda Lake the water table is about 460 mAHD. Along the valley floor the hydraulic gradients are flat, reflecting the high transmissivity of the calcrete and sandy alluvium aquifers.

The greatest depths to the water table are found in the headwater area of the catchment and along the flanks. In these areas the depth to the water table ranges from 10 to 20 m below ground surface and locally is greater than 20 m. Along the valley floor, the depth to the water table is typically less than 5 m. Within the area of the deposit the depth to the water table is in the 3 to 5 m range. Regional groundwater level data also show that the range of water level fluctuations is less than 0.2 m with no evidence of seasonality fluctuations.

Interpreted pre-development water table elevations are shown in Figure 9-34.

Water fluxes within the Yeelirrie Catchment are likely to be complex and variable. A simplified interpretation of the system of recharge and discharge is that recharges occur in the breakaways and in the flanks for the catchments via directed infiltration, while discharges occur from the playas and lakes through evaporation and/or transpiration processes. As a result of the concurrent occurrence of several processes, the water table salt concentrations sporadically increase and decrease down the valley in response to reoccurring discharge and recharge occurrences.

Surface runoff occasionally occurs within the Yeelirrie Catchment following intense rainfall. Sheet runoff from the upper margins of the catchments flows to the central drainage line and generates ephemeral stream flow. Typically, the stream flow terminates in playas (including clay pans). Water may remain on the larger clay pans and playas for several weeks after large rainfall events, however groundwater recharge is not understood to occur at these locations due to the underlying clay which prevents infiltration.

9.5.4.4 Groundwater quality

The geochemical characteristics of the groundwater in the catchment have evolved over geologic time due to processes including:

- precipitation;
- runoff and ponding of runoff;
- infiltration of precipitation and runoff;
- geochemical interactions between infiltrating water and the sediments through which the water flows;
- groundwater flow patterns (recharge and discharge areas, as developed over time); and
- evaporation and evapotranspiration.

Reported groundwater quality data (URS, 2011) indicate:

- Groundwater in the Yeelirrie catchment typically is of the sodium-chloride (Na-Cl) type.
- Areas with low total dissolved solids (TDS), which is suitable for the beneficial use ‘stock watering’ under the ANZECC guidelines, coincide with zones where the depth to the water table is the deepest. These areas represent the weathered granite, clayey and sandy alluviums along the flanks of the valley floor.
- High TDS groundwater is found along the valley floor, in areas where the water table is at shallow depth.
- The quality of shallow groundwater in the area of the Yeelirrie deposit is highly variable. The average and standard deviation of the TDS in the eastern part of the deposit (32,700 ± 14,900 mg/L) is higher than in the western part (15,800 ± 10,300 mg/L).
- Within the palaeochannel aquifer low TDS water (average 3,800 mg/L) is found west of the deposit but increases eastward to 87,400 mg/L near the Albion Downs wellfield.
- Dissolved uranium is present in all of the hydrostratigraphical units. Overall, the concentration ranges from less than detection limit (<0.001 mg/L) to 2.4 mg/L. Within the deposit the average is 0.29 mg/L (± 0.32 mg/L) and in the palaeochannel sediments it is 0.74 mg/L (± 0.69 mg/L).
- The dissolved vanadium concentration is typically less than the detection limit (0.01 mg/L).
- Bromide is present in significant concentrations (up to tens of milligrams per litre) in all hydrostratigraphical units.

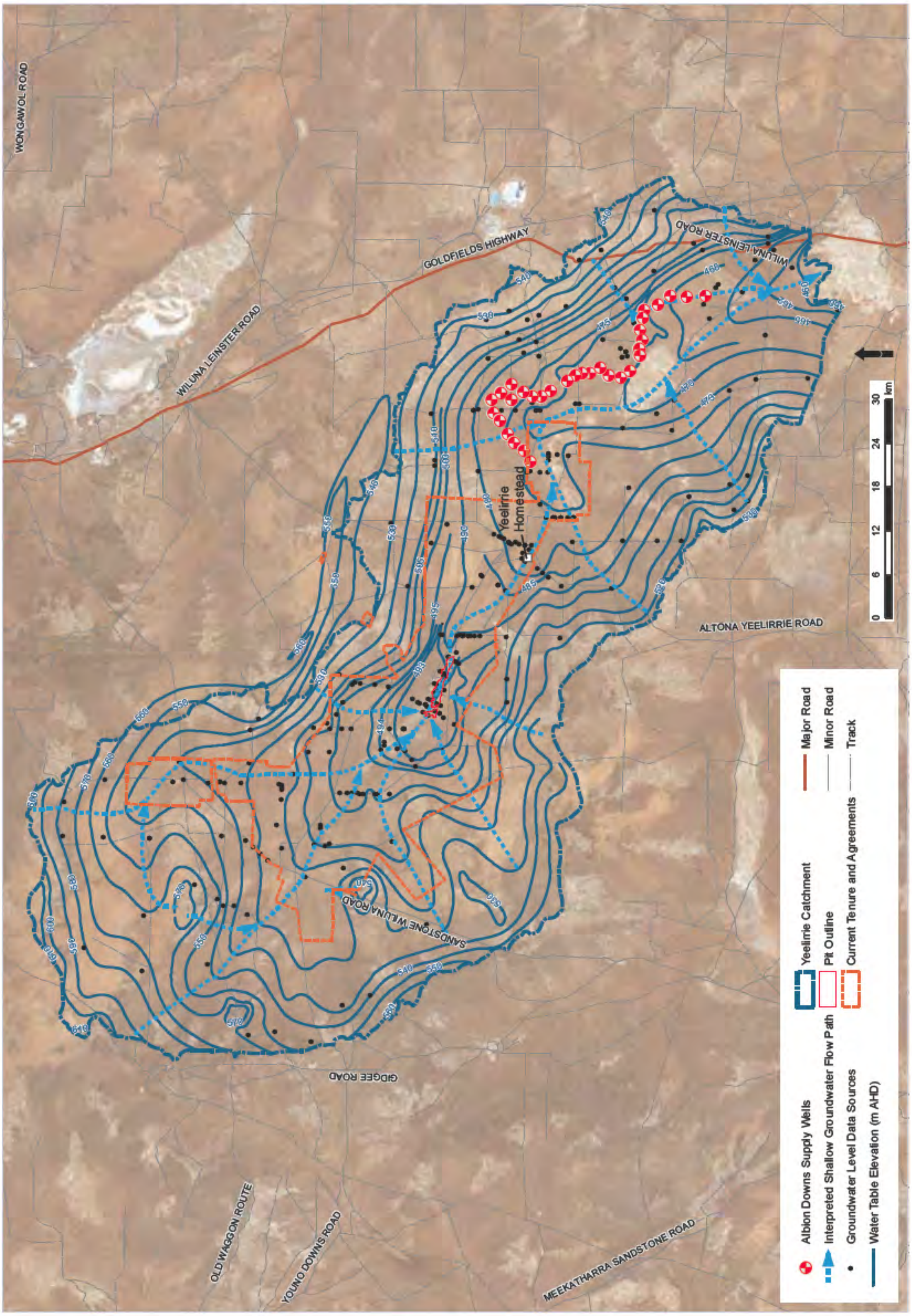

Figure 9-34: Interpreted pre-development water table elevations

9.5.4.5 Existing groundwater users

There are a significant number of existing groundwater bores (wells) in the region. These include pastoral wells, groundwater investigation and monitoring wells, and production wells related to the Albion Downs Wellfield.

The historical land use in the Yeelirrie Catchment has been fenced pastoral activities. URS (2011) noted that many of the pastoral wells have not been used in recent times. An exception is the Big Mill well which is used by the Yeelirrie Homestead (located approximately 10 km south east of the proposed mining lease area) as a water supply source. Farther away from the Yeelirrie deposit several pastoral wells related to the Albion Down pastoral lease are likely to be in use.

The Albion Downs Wellfield is located about 30 km east of the Yeelirrie deposit, and consists of 32 production wells, spaced about 1.6 km apart, stretching over a linear distance of approximately 51 km. The wellfield produces on average approximately 20,000 kL/day (about 7.5 GL/yr) for the BHP Billiton Nickel West Mt. Keith Operation.

9.5.5 Potential Impacts and Management

The Project will result in local and temporary changes to the groundwater regime in the Project Area. Without appropriate measures in place, proposed activities that are most likely to affect the groundwater regime are:

- Groundwater abstraction, mine pit dewatering and aquifer recharge, could potentially impact groundwater availability to groundwater dependent ecosystems (refer to Sections 9.1 and 9.2) and other groundwater users.
- Storage of ore and mine waste in stockpiles, and tailings in the TSF, could result in changes to water chemistry and contamination of the groundwater.
- Potential precipitation of solids due to mixing of groundwater chemistry during the re-injection process.

9.5.5.1 Project Water Balance

Methodology

Water is needed throughout each phase of the Project. The water need, or water demand, would be met by a supply of groundwater.

Water demand

The Project's total water demand is predominantly the amount of water required to process ore in the processing plant. Detailed process modelling of the processing plant has been undertaken to determine the volumes of water required to process a proposed 2.4 Mt/yr of ore using alkaline extraction to extract uranium from the ore. Water demand for vehicle washing and dust suppression (adopted from URS 2011) and for domestic use in the mine camp and administration facilities (estimated based on Cameco's previous experience) are also components of the total water demand calculation. The total water demand for the Project was presented in Section 6.6 and is estimaged on an average annualised basis to be approximately 8.7 ML/day.

Water supply

Groundwater would be sourced from the following:

- mining pit dewatering; and
- proposed water supply wellfields.

As described in Section 6, dewatering of the mine pit would need to be undertaken to allow the ore to be mined. The water sourced from this dewatering will meet the initial Project demand.

When ore processing commences in year four, the Project water demand exceeds the supply from dewatering and groundwater would be abstracted from the proposed wellfields.

Conversely, prior to the commencement of processing, the dewatering volumes will exceed the water demand and surplus water would be re-injected.

The groundwater supply wellfields were previously identified (URS 2011) and are located within and outside the Project Area and the Yeelirrie catchment. Figure 9-35 shows the locations of the proposed wellfields.

The proposed wellfields are:

- Western Brackish Wellfield; comprising wells that intercept the alluvium aquifer.
- Northern Brackish Wellfield; comprising wells that intercept the alluvium and weathered bedrock aquifers.
- Eastern Brackish Wellfield; comprising wells that intercept the alluvium and weathered bedrock aquifers, and
- Saline Wellfield; comprising wells that intercept the alluvium and Yeelirrie Palaeochannel aquifers, and wells that intercept the weathered bedrock aquifer.

The volume of groundwater that would be supplied from dewatering which was based on the previous work done at Yeelirrie was determined using a numerical groundwater flow model (Appendix I1).

Other (minor) sources of water supply would include:

- Reagents: Water naturally contained in the reagents. This source is included in the Water Balance for the processing water needs.
- Opportunistic rainfall runoff: Water collected from within the mine pit and disturbed areas. This water would be sporadically available and therefore cannot be quantified or consistently relied upon.
- The groundwater naturally contained in the mined ore would also offset processing water needs.

Water within the tailings would also be recycled from the TSF. This water would be available during the period that ore is milled, and will offset demand from the wellfields.

Total project water balance

The water demand modelling shows the indicative total demand for water is estimated to be in the order of 53.35 GL over the life of the project (Table 9-44). The indicative maximum total daily demand for water is estimated to be in the order of 8,724 kL. The results of the groundwater modelling predict that the total amount of water derived from dewatering would be 18.9 GL. The modelled volume of withdrawals from aquifers is 50.72 GL (Table 9-44).

Groundwater Reinjection

Prior to the commencement of the operation phase (operation of the processing mill in Year 4), dewatering would result in excess water for the project. When this occurs it is proposed to re-inject the excess water back into the underlying calcrete aquifer just north of the proposed pit. The numerical groundwater flow modelling shows, the total amount of water to be re-injected over the life of the Project is estimated to be 2.27 Gl.

The highest rate of reinjection occurs in Year 3 of the Project. During this year of operation, groundwater extracted from the Pit from dewatering operations will be reinjected at the rate of approximately 1.28 Gl/a (3.5 Kl/d).

Table 9-44: Water Demand and Groundwater Abstraction

Year	Estimated water demand (Gl/a)	Predicted annual dewatering abstraction (Gl/a)	Simulated annual well abstraction (Gl/a)
1	1.04	0.85	0.66
2	1.44	1.14	0.82
3	1.44	2.23	0.82
4	3.18	2.73	2.14
5	3.18	1.26	2.93
6	3.18	0.95	3.18
7	3.18	0.79	3.21
8	3.18	0.97	3.2
9	3.18	1.41	3.2
10	3.18	0.8	3.2
11	3.18	1.33	3.21
12	3.18	0.77	3.2
13	3.18	0.66	3.2
14	3.18	0.67	3.2
15	3.18	0.59	3.21
16	3.18	0.55	3.2
17	3.18	0.52	3.2
18	3.18	0.5	3.2
19	0.42	0.04	0.44
20	0.42	0.04	0.44
21	0.42	0.05	0.44
22	0.42	0.05	0.44
Total	53.35	18.90	50.72

Note: The simulated abstraction figures include a level of conservatism of 26 % (i.e. 26 % more than is required).

Source: after Cameco (2015a)

Modelling predicts that during reinjection, the height of groundwater levels will rise by approximately 1.1 m and that this increase will be limited to an area of radius of approximately 525 m from the reinjection point or an area of approximately 86 ha. At the reinjection point natural groundwater levels are approximately 8 m below ground level and reinjection is therefore unlikely to cause groundwater levels to rise to such an extent as to cause waterlogging and impact on vegetation.

In year 4, reinjection is predicted to reduce to approximately 0.24 Gl/a and modelling predicts that the groundwater levels in the mound caused by reinjection is reduced back to normal levels by Year 5.

All of the area affected by reinjection occurs within the area where groundwater will subsequently be lowered by dewatering and groundwater abstraction and therefore does not contribute to an increased area of impact.

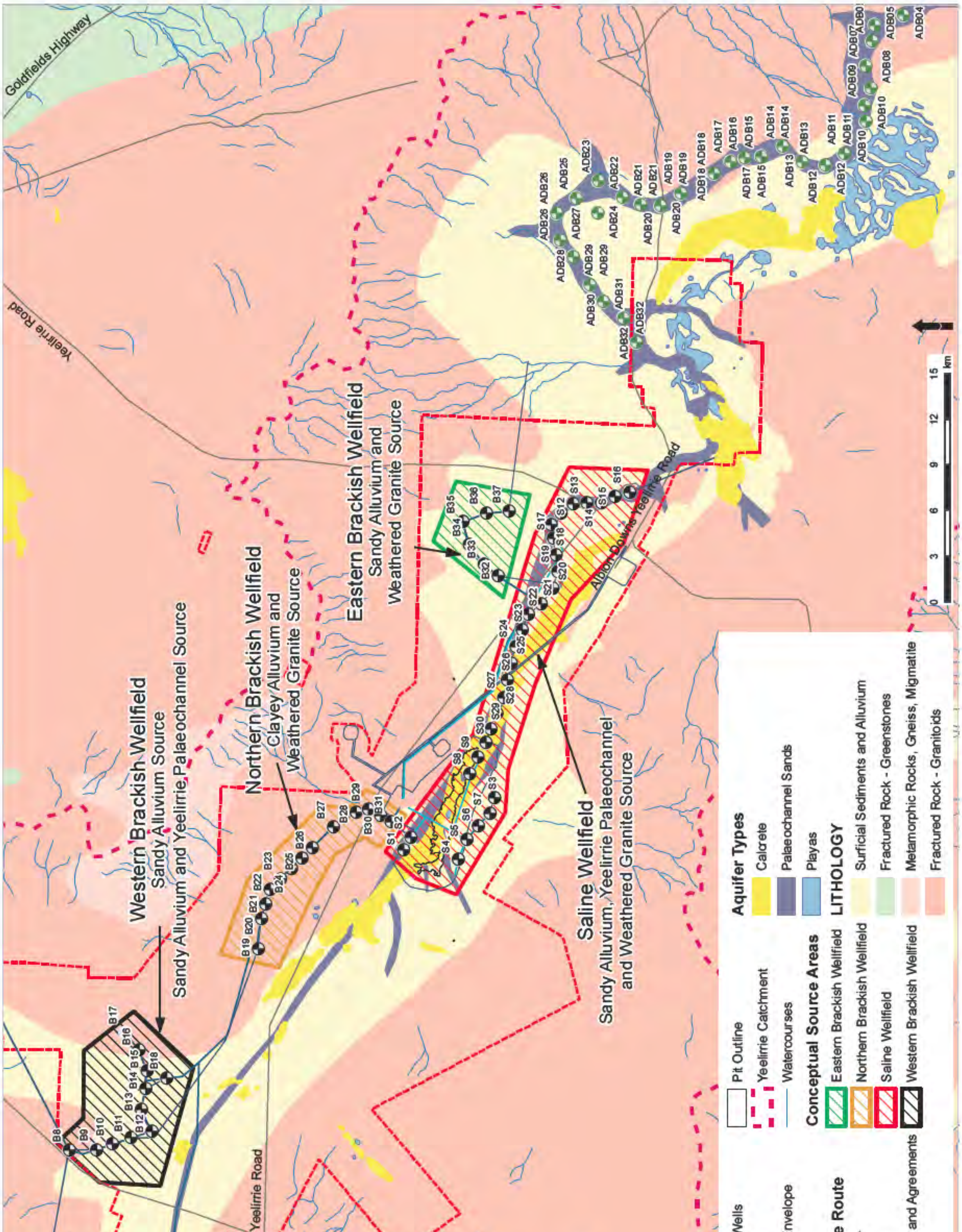

Figure 9-35: Location of proposed wellfields

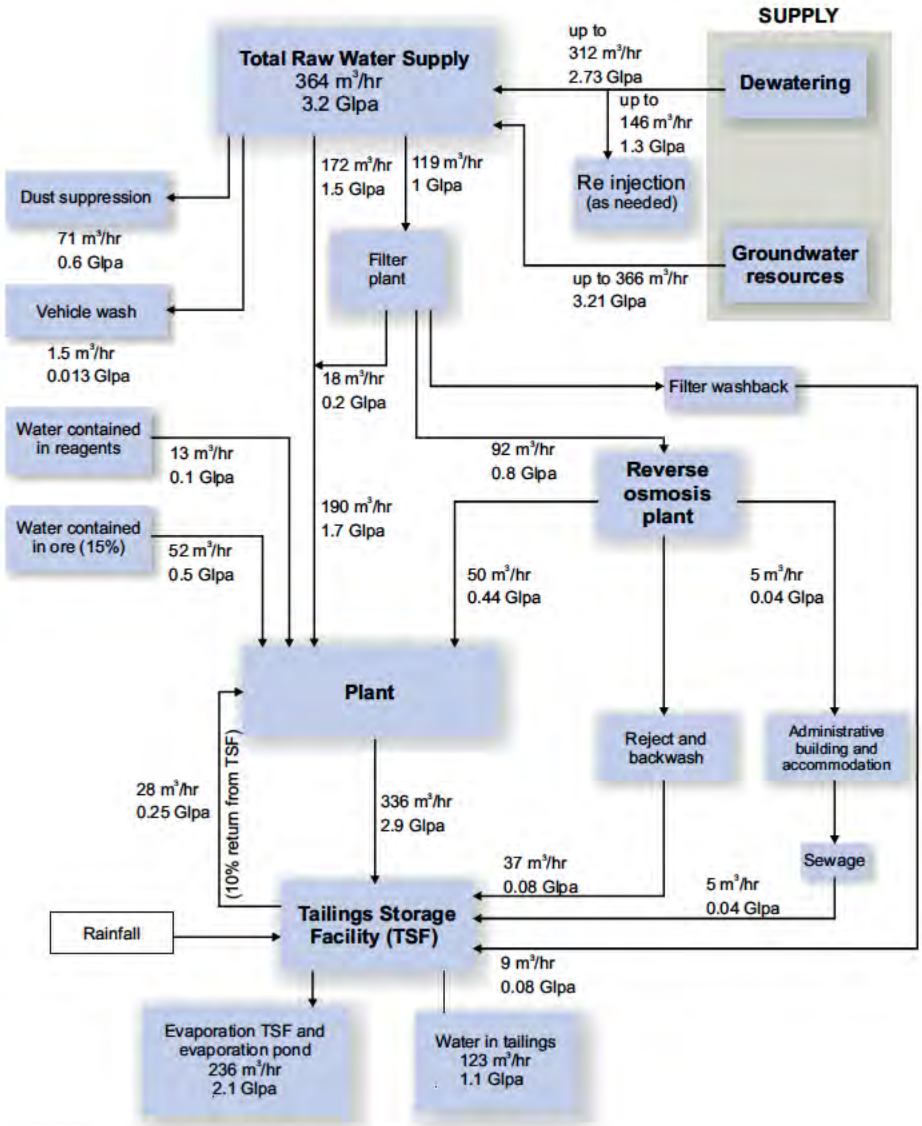

Figure 9-36: Project water balance

A detailed indicative water balance for the operational (milling phase) phase of the project is shown in Figure 9-36. A detailed water balance model was completed by URS, (2015) using the GoldSim modelling package to validate the performance of the Project water management strategy. The water balance model report is provided in Appendix H2. The assessment showed that within the assumptions adopted the proposed water management strategy is adequate in containing the mine impacted water onsite.

Groundwater abstraction throughout the project

As groundwater abstraction from the proposed wellfields is determined by the project phase and the amount of water sourced from mine pit dewatering, the volumes extracted from this source will vary with time. Modelling was undertaken to determine daily groundwater abstraction volumes thought the Project life. The results of this modelling are shown in Figure 9-37.

The modelling determined the individual volumes of groundwater abstraction from each of the four wellfields. The results of this modelling are shown in Figure 9-38.

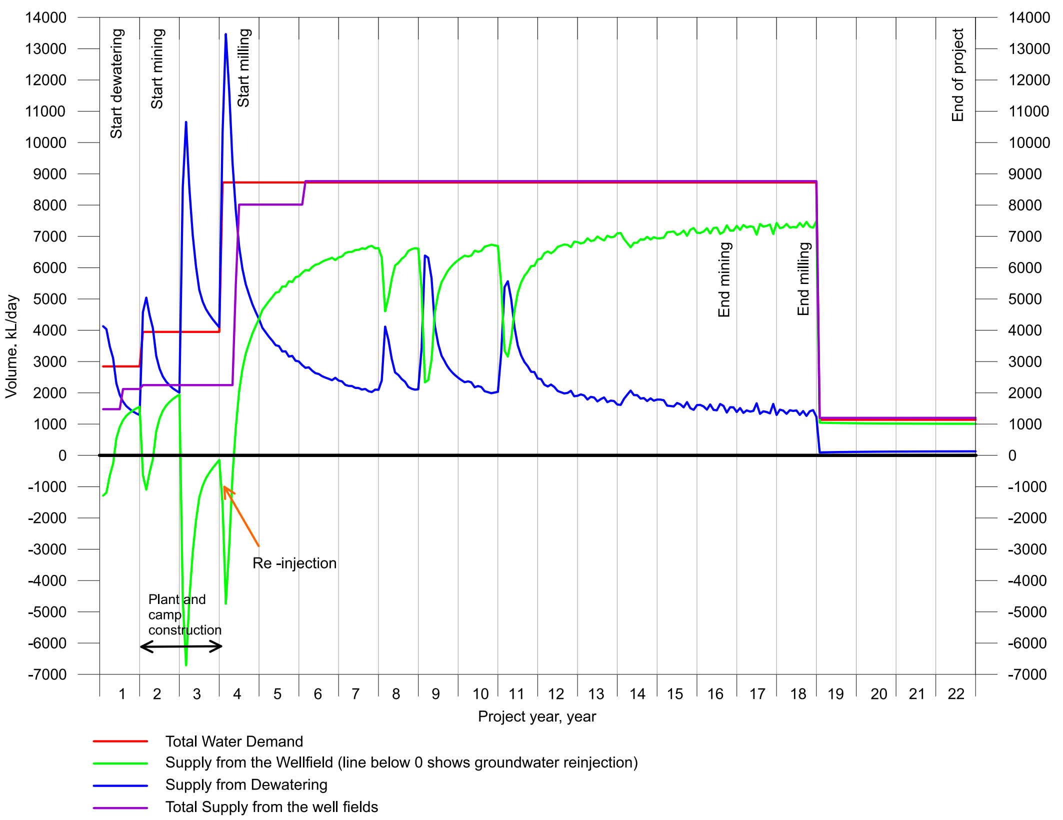

Figure 9-37: Simulated water demand and supply over time

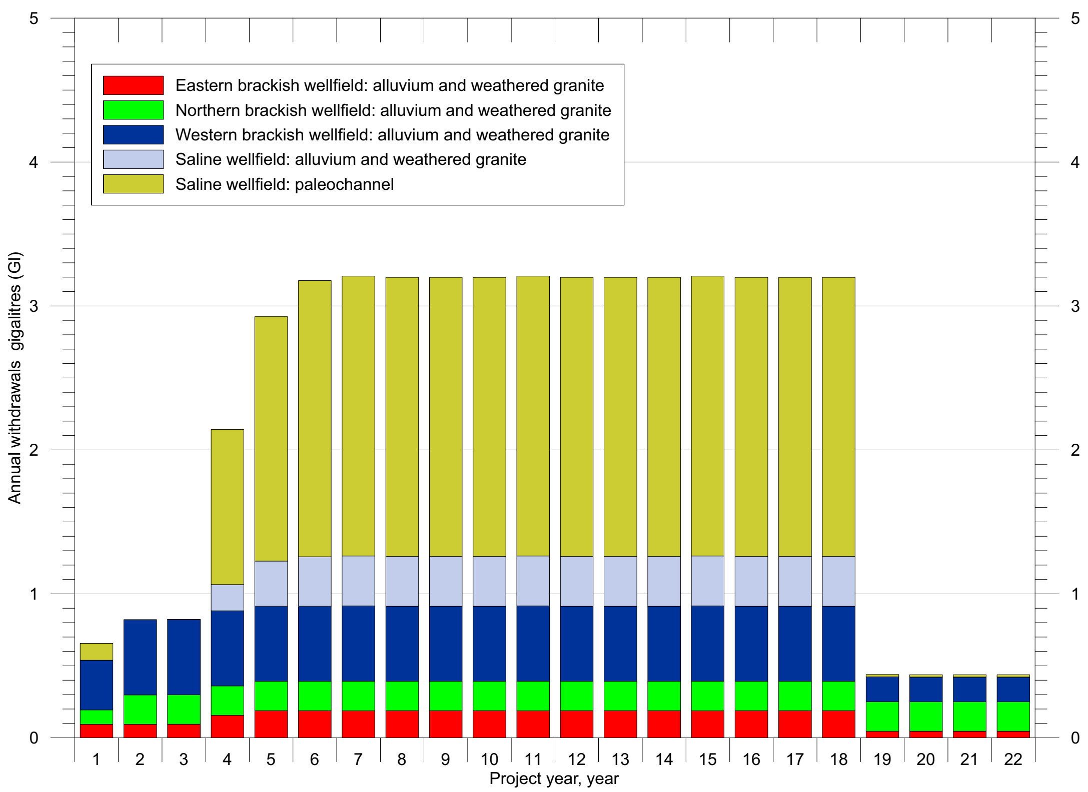

Figure 9-38: Annual abstraction of groundwater by wellfield

9.5.5.2 Groundwater drawdown

Methodology

The numerical groundwater flow and solute transport model was used to predict the extent of water table drawdown and recovery and the transport of solutes from the TSF. Computer modelling packages Groundwater Vistas (version 6.7) with MODFLOW-SURFACT Version 4 (HydroGeoLogic, Inc.) were used for groundwater flow and solute transport modelling.

The computer model required input of topographical, stratigraphic, recharge, climatic, geochemical and hydrogeological data, all of which were obtained from the previous studies as detailed in URS (2011). The model was calibrated using dewatering data from the Slot 1 trial (referred to in Section 9.5.3), catchment wide water table elevations, observed drawdown of the water table associated with the long term abstraction by the Albion Downs Wellfield and observed salinity concentrations at discharge zones.

The model was used to simulate operations, closure and long term solute transport to:

- define the pre-project groundwater regime;
- predict the drawdown caused by dewatering;
- predict the drawdown caused by groundwater abstraction;
- estimate the groundwater mounding effect caused by the aquifer recharge system;
- assess the impacts on other groundwater users such as pastoral wells and the Nickel West Mt Keith operation Albion Downs wellfield;
- predict the groundwater level recovery process after mine decommissioning; and
- conduct solute transport modelling to predict the movement of contaminants from the TSF and stockpile areas into the local groundwater system and their potential impact on environment.

In the modelling conservative approaches were adapted. For example, as noted in Section 9.5.3, the modelled supply is 26% greater than the estimated demand. Similarly, the solute transport source terms were increased by 20%.

Extent of drawdown

The results of the modelling undertaken to predict the cumulative water table drawdown from proposed pit dewatering, wellfield abstraction and aquifer recharge are shown in Figure 9-39 to Figure 9-42. The figures show drawdown contours at the end of Project year three (immediately prior to milling), year 18 (end of milling) and year 22 (end of project) respectively. Figure 9-43 shows a transverse cross section in the northwest corner of the pit and illustrates the modelled maximum drawdown across the palaeochannel.

The water table drawdown modelling shows:

- Groundwater re-injection through the aquifer recharge system causes groundwater mounding around the injection well, with a predicted maximum groundwater level increase of approximately 1 m. The injection ceases at the beginning of year four and the groundwater mound disappears by the end of that year.
- The groundwater mound from reinjection (greater than 0.1 m) does not extend past the area affected by drawdown greater than 0.5m, from the operation of the production wellfield.
- Drawdown in the vicinity of the proposed wellfields increases over time and is the greatest at the end of year 18 (end of milling). The typical drawdowns in the Western, Northern and Eastern brackish wellfields are approximately 2, 5 and 3 m, respectively. Around the mine pit the drawdown typically exceeds 7 m.

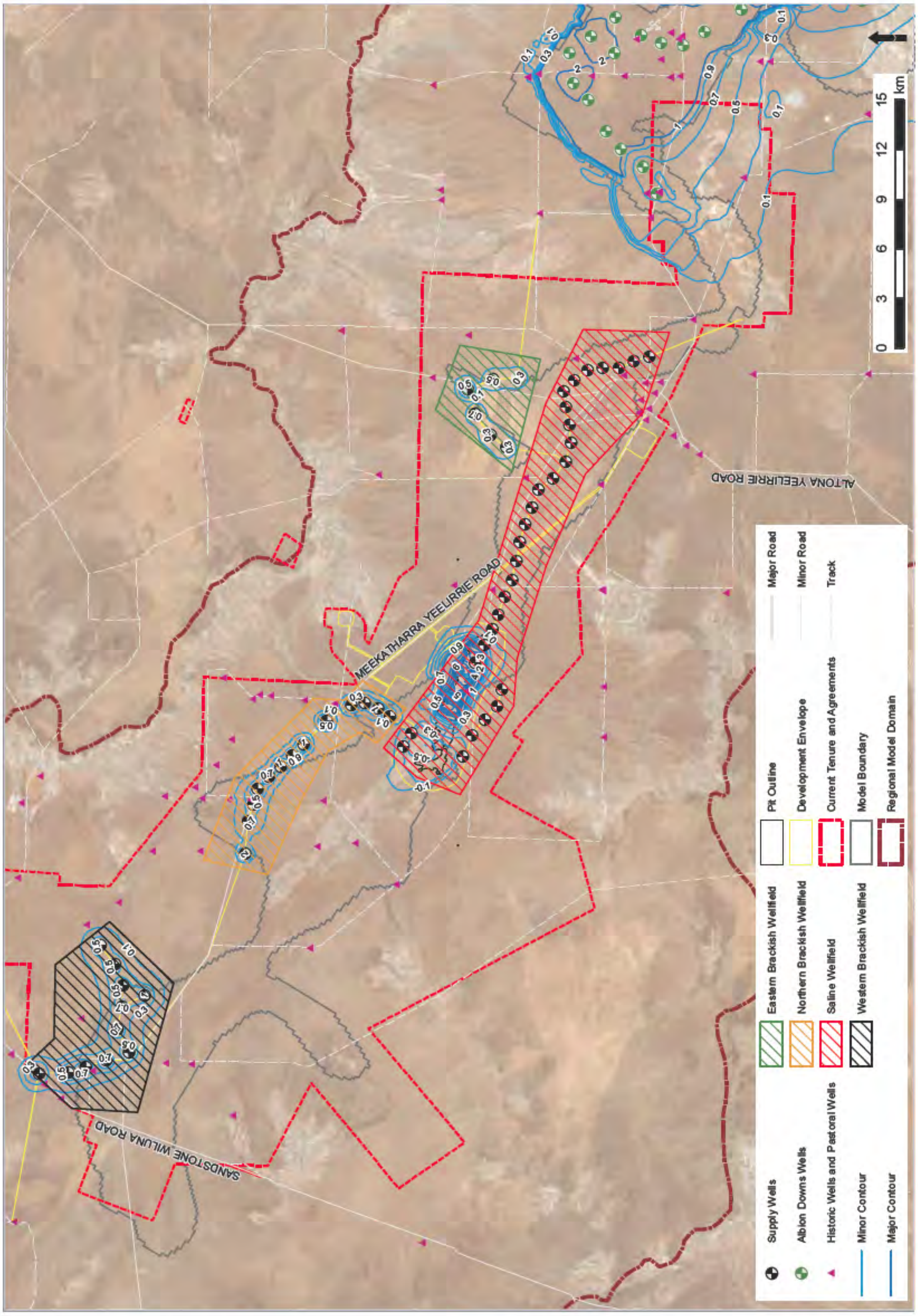

Figure 9-39: Drawdown contours at end of year 3

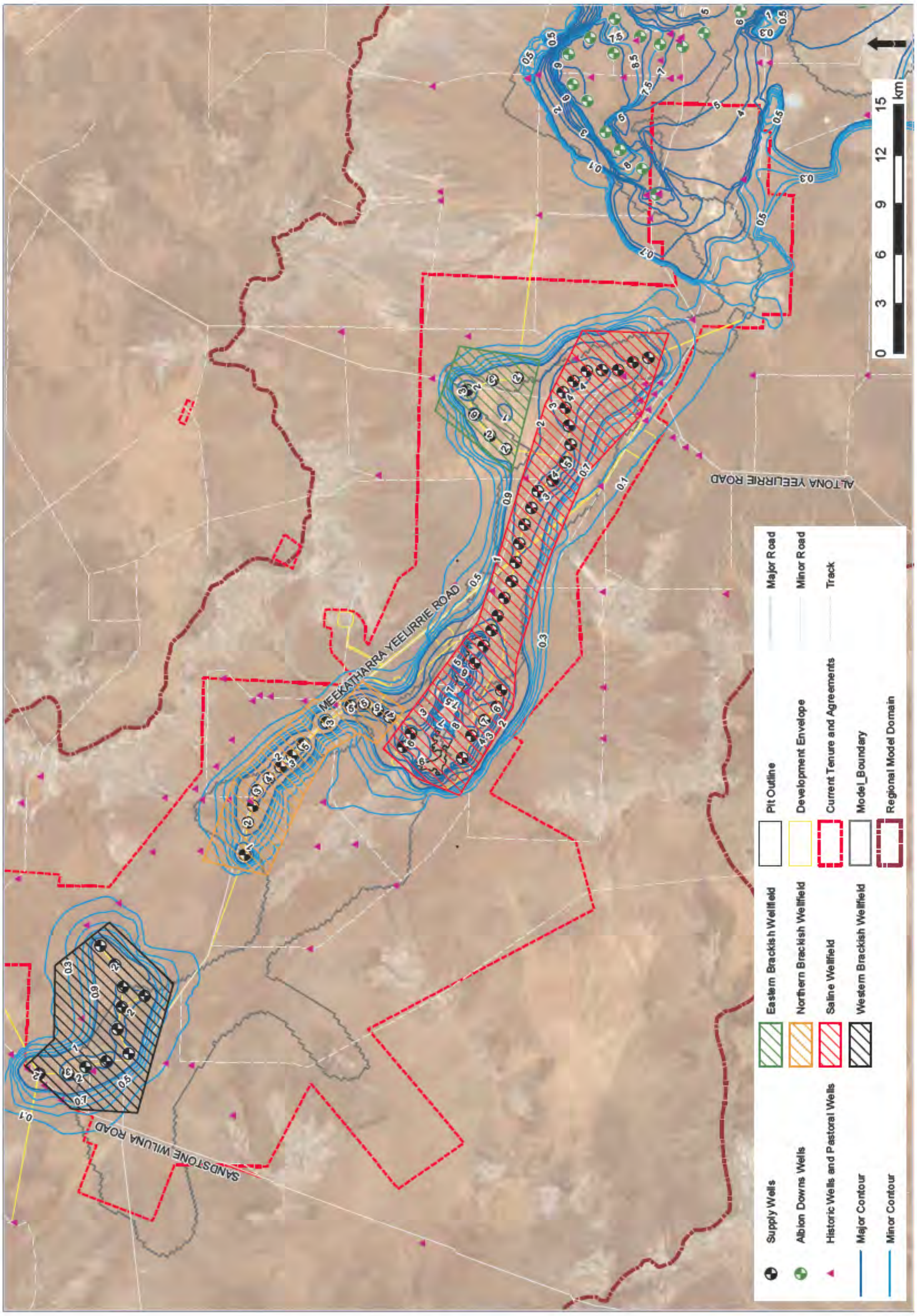

Figure 9-40: Drawdown contours at end of year 18

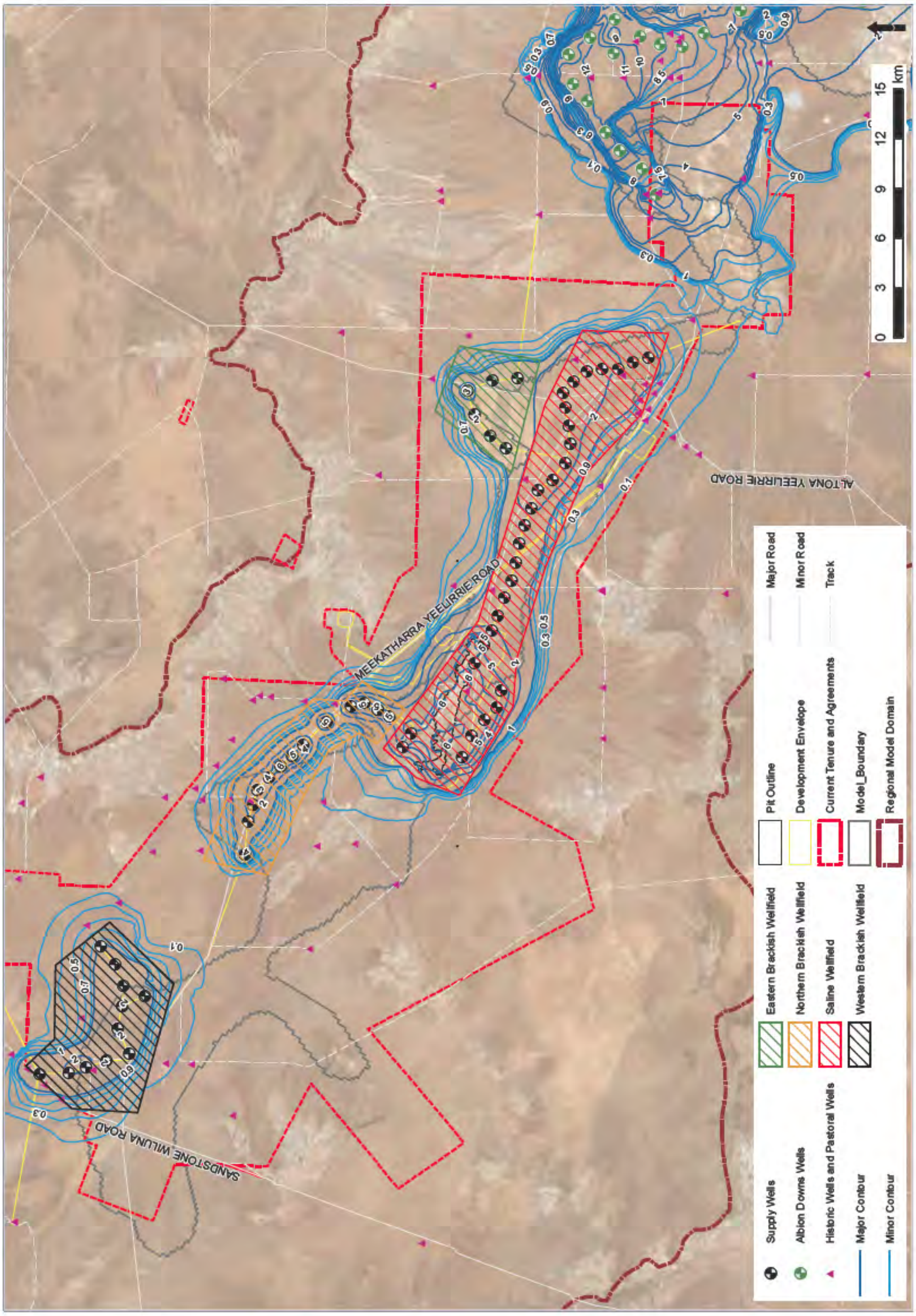

Figure 9-41: Drawdown contours at end of year 22

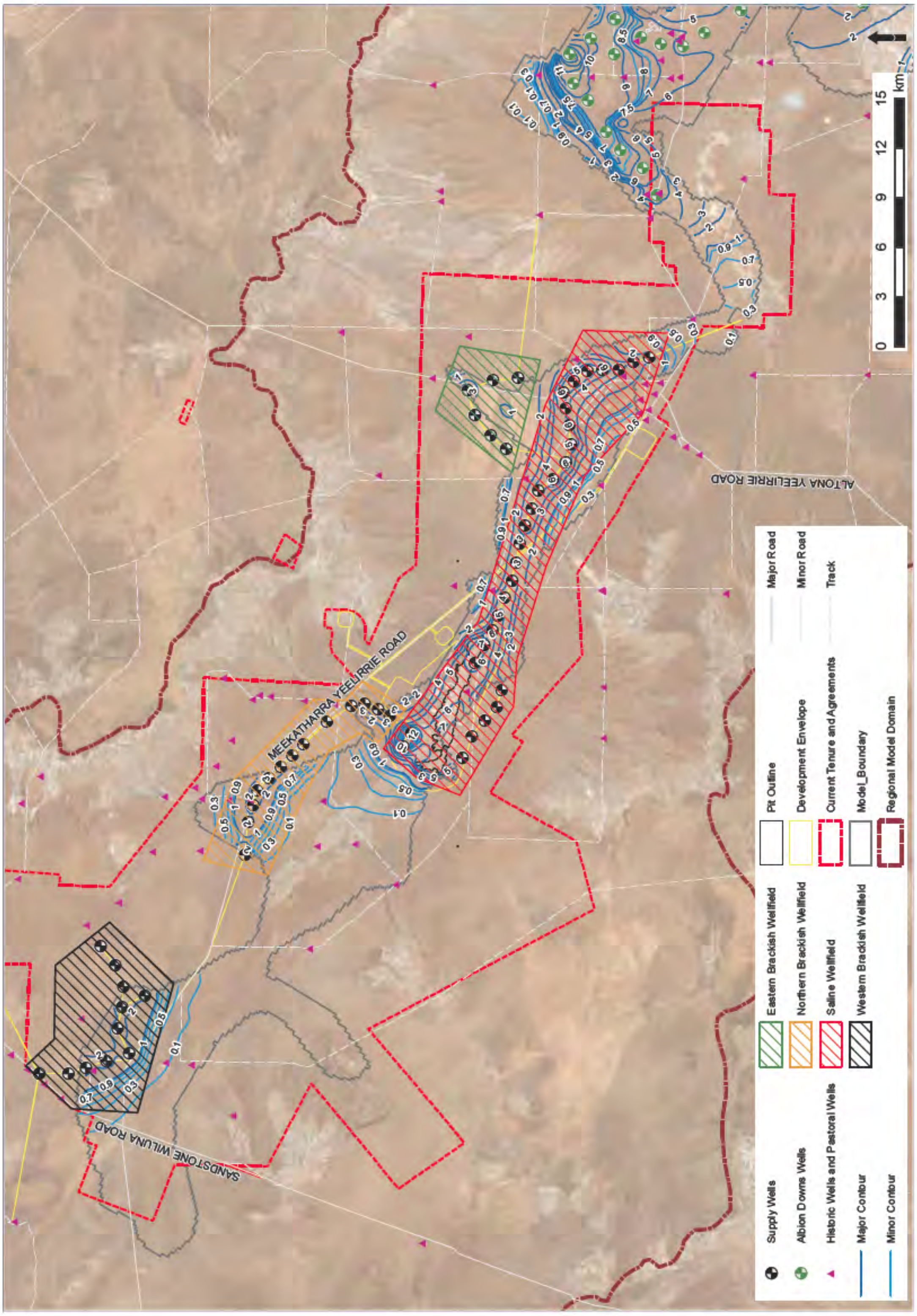

Figure 9-42: Predicted water level drawdown in palaeochannel aquifer after end of milling (Year 18)

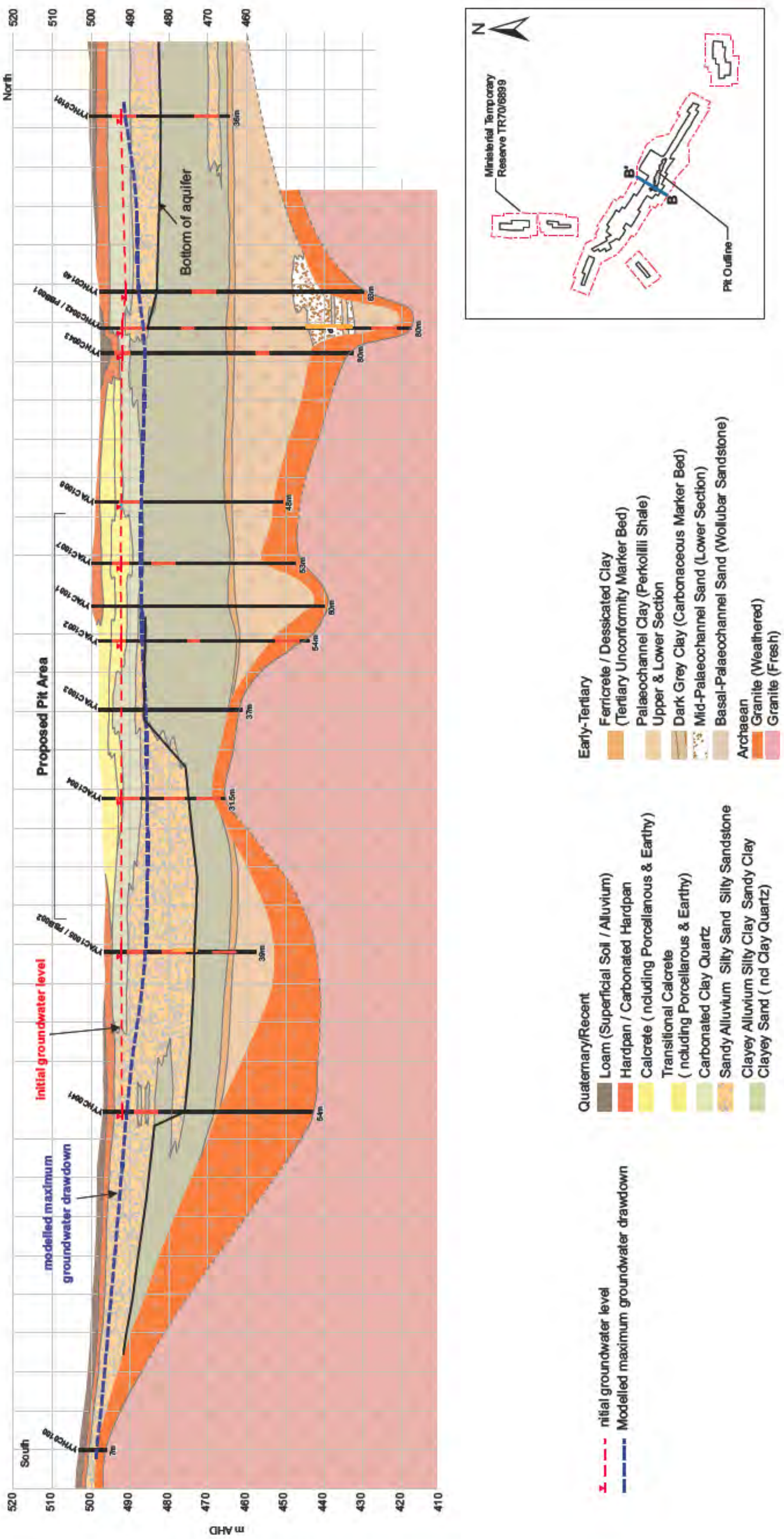

Figure 9-43: Transverse cross section

- Slow expansion of the drawdown cone indicates that the groundwater sources in the proposed wellfields are relatively abundant compared to the extraction rate suggesting a sustainable yield.
- The drawdown from pit dewatering, the Saline, Eastern and Northern wellfields overlap, which broadens the overall drawdown footprint and increases the magnitude of the associated drawdown.
- The model-predicted water table drawdown cone caused by the proposed saline wellfield has a limited overlap with the water table drawdown cone caused by the Albion Downs wellfield. This slight hydraulic interference starts to occur from year 12. It is noted that, depending on future production from the Albion Downs wellfield, this interference may not happen.

Water table recovery

The results of the modelling undertaken to predict the recovery of the water table following the end of the proposed project are shown in Figures 9-44 to 9-46. The figures show regional drawdown contours after 50, 100 and 200 years of recovery (i.e. after the close of the proposed project). The results predict the following:

- Groundwater levels recover significantly within 50 years following cessation of the Project.
- The water table at the pit/TSF location recovers to baseline levels within 100 years, but small residual drawdowns of 0.3 to 0.5 m below the baseline elevations would persist in the area of the nearby eastern and northern wellfield for more than 200 years.
- Within the TSF area, the water table eventually recovers to levels about 0.5 m below the baseline elevations. This suggests a new steady state would occur locally due to the different geological properties of the TSF.
- There would be some change in the down-valley groundwater flow path at the local scale in the vicinity of the pit; however, no discernable change in groundwater flow is expected at the catchment scale.

Impacts to existing users

Big Well bore (Yeelirrie Homestead)

The modelling shows a slight drawdown (0.3 m) of the water table at the Yeelirrie Homestead at year 18 after the end of milling. A residual drawdown (0.1 m) remains for approximately 150 years after the end of the Project.

Existing wellfields and pastoral wells

After year 12 there is a slight interference between the water table drawdown due to the proposed development and the water table drawdown caused by the operation of the Albion Downs Wellfield. This assumes that the Albion Downs Wellfield would continue to be operated indefinitely at historical pumping rates. If abstraction rates are reduced in the future, the proposed project is unlikely to cause interference between the wellfields.

As shown in Figure 9-37, there would be no notable interference between the proposed withdrawals from the palaeochannel and the drawdown in the palaeochannel due to pumping from the Albion Downs Wellfield.

The modelling shows there would not be an impact of the proposed development on existing pastoral wells.

Groundwater dependent ecosystems

The impact of the proposed project on groundwater dependent ecosystems is described in Sections 9-1 and 9-3.

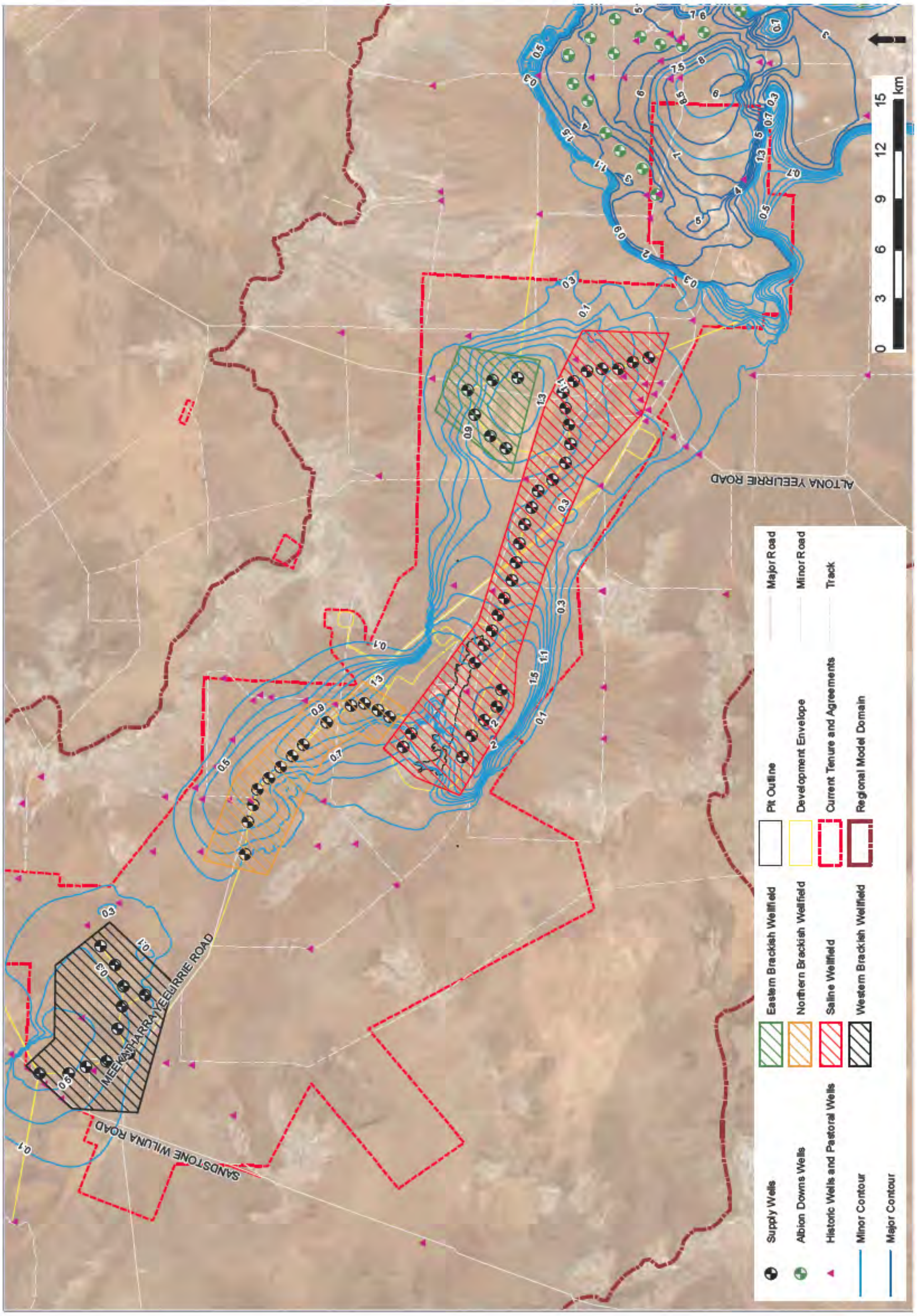

Figure 9-44: Predicted water table drawdown after 50 years of recovery

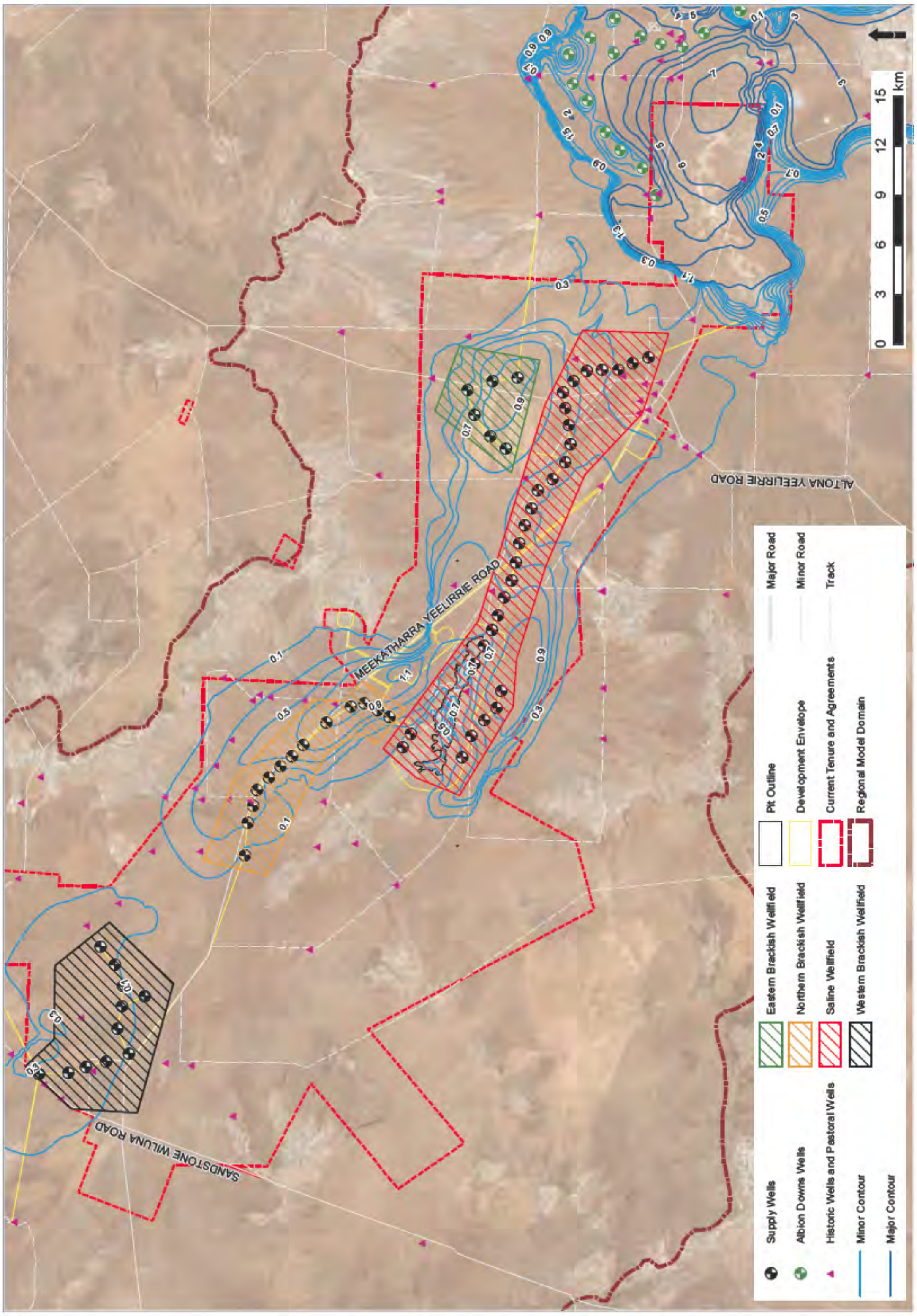

Figure 9-45: Predicted water table drawdown after 100 years of recovery

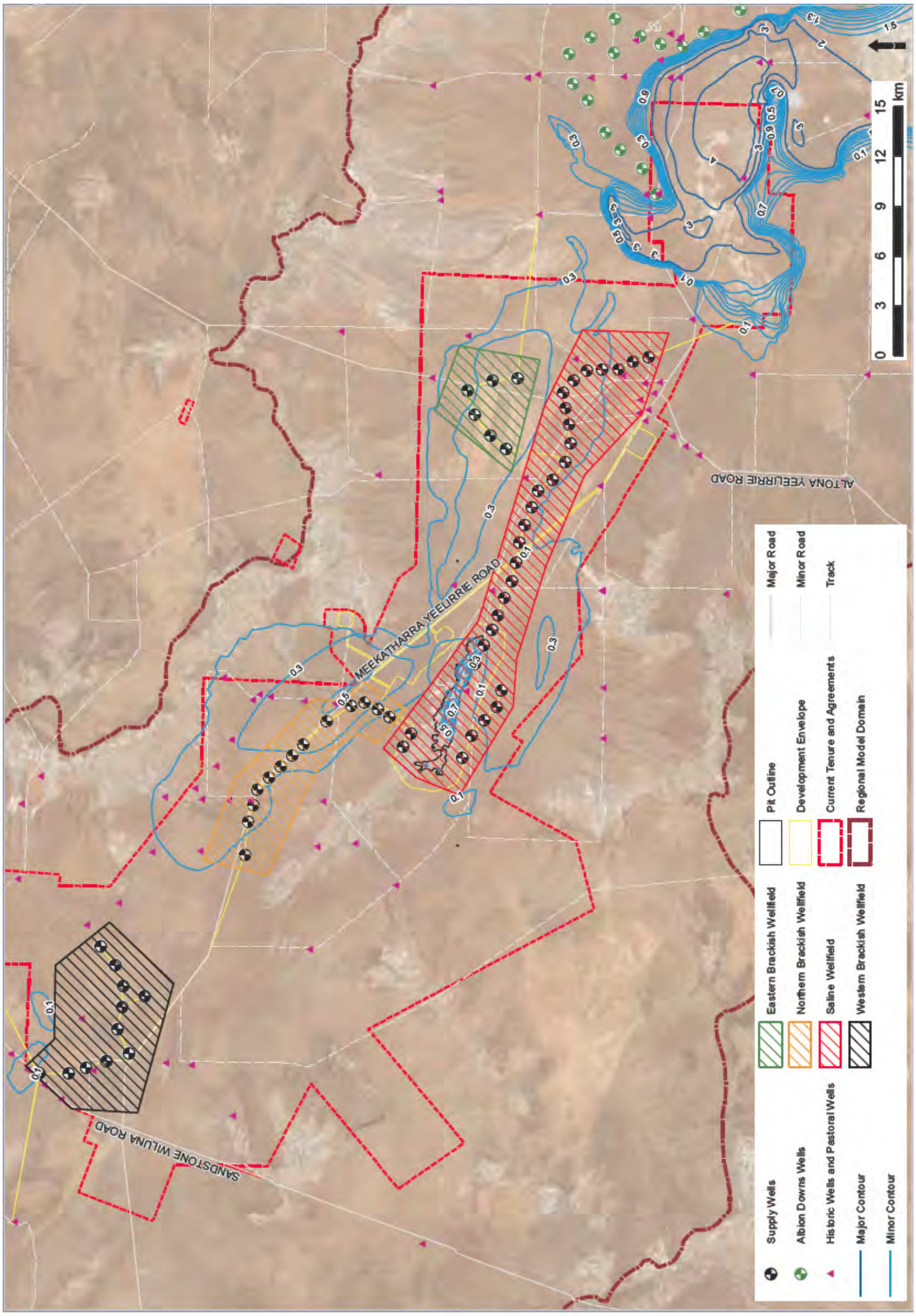

Figure 9-46: Predicted water table drawdown after 200 years of recovery

Contingency Water Supply

At this stage of the Project, Cameco has not investigated a contingency water source for a number of reasons.

Firstly, the extraction intensity of water proposed to be supplied from Yeelirrie Borefield is relatively low at approximately 0.80 GL/km. The proposed extraction intensity is less than 30% of other similar paleochannel aquifers in the region that have significant operational history (i.e. the Albion Downs Borefield at 2.92 GL/km and the Leinster Process Borefield at 2.72 GL/km).

Based on the high level of definition achieved in the water studies completed to date and the relatively low extraction intensity proposed for the Yeelirrie Borefield, Cameco considers a supply shortfall unlikely.

Secondly, following presentations to the DoW, they advised that the hydrogeological studies more than satisfy the requirements for Operational Policy 5.12 – Hydrogeological reporting associated with a groundwater well licence (DoW, 2009) at a H3 Level of Assessment. The DoW also advised that the hydrogeological studies provide sufficient rigour and accuracy to enable an adequate assessment of impacts on the environment, other users and the aquifer system. After receiving this feedback from the DoW Cameco was further satisfied that the DoW had no concern with the proposed extraction intensity from the perspective of a potential supply shortfall and Cameco did not consider that a contingency plan was necessary at this stage of the Project.

Furthermore, the Yeelirrie Agreement Act provides a contingency regime (both prior and subsequent to the granting of water licences) for water supply. This contingency regime provides rights of land access and State involvement in contingency investigations, as well as the granting of water licences in respect of water supplies. This contingency regime therefore removes potential risks regarding access to alternative water sources that would otherwise be suitable for the project. Therefore, Cameco is of the view that it was not necessary to include a separate contingency plan within the PER.

As previously discussed in Section 9.2, prior to the commencement of the Project, Cameco will undertake a definitive feasibility study. During the study and in consultation with the State, Cameco will consider potential contingency water supplies as required.

9.5.5.3 Groundwater quality

Methodology

Tailings and mine waste source terms

Solute transport modelling predicts the movement of contaminants from the TSF and stockpile materials into the local groundwater system, tailings and mine waste source terms (i.e. the concentrations of contaminants likely to be released in solute from the mine waste and tailings). A summary of the work undertaken to determine the source terms are described below.

Tailings

This involved conducting geochemical analysis of ore and field simulated mine waste and tailings, to determine contaminants of concern and their ability to be released in solute. Aged tailings tests in conjunction with thermodynamic geochemical speciation modelling were used to develop the source terms that would describe conditions in the TSF in the long term.

Solute transport model

The potential for solute release from tailings in the short and long term was evaluated primarily based on aging tests on fresh tailings slurries from various categories of ore material. In addition, the chemical composition of potential stockpile material was evaluated by performing leach tests (deionized water and 'barren liquor' solution) on selected samples in order to determine the solute loadings that could result from these materials.

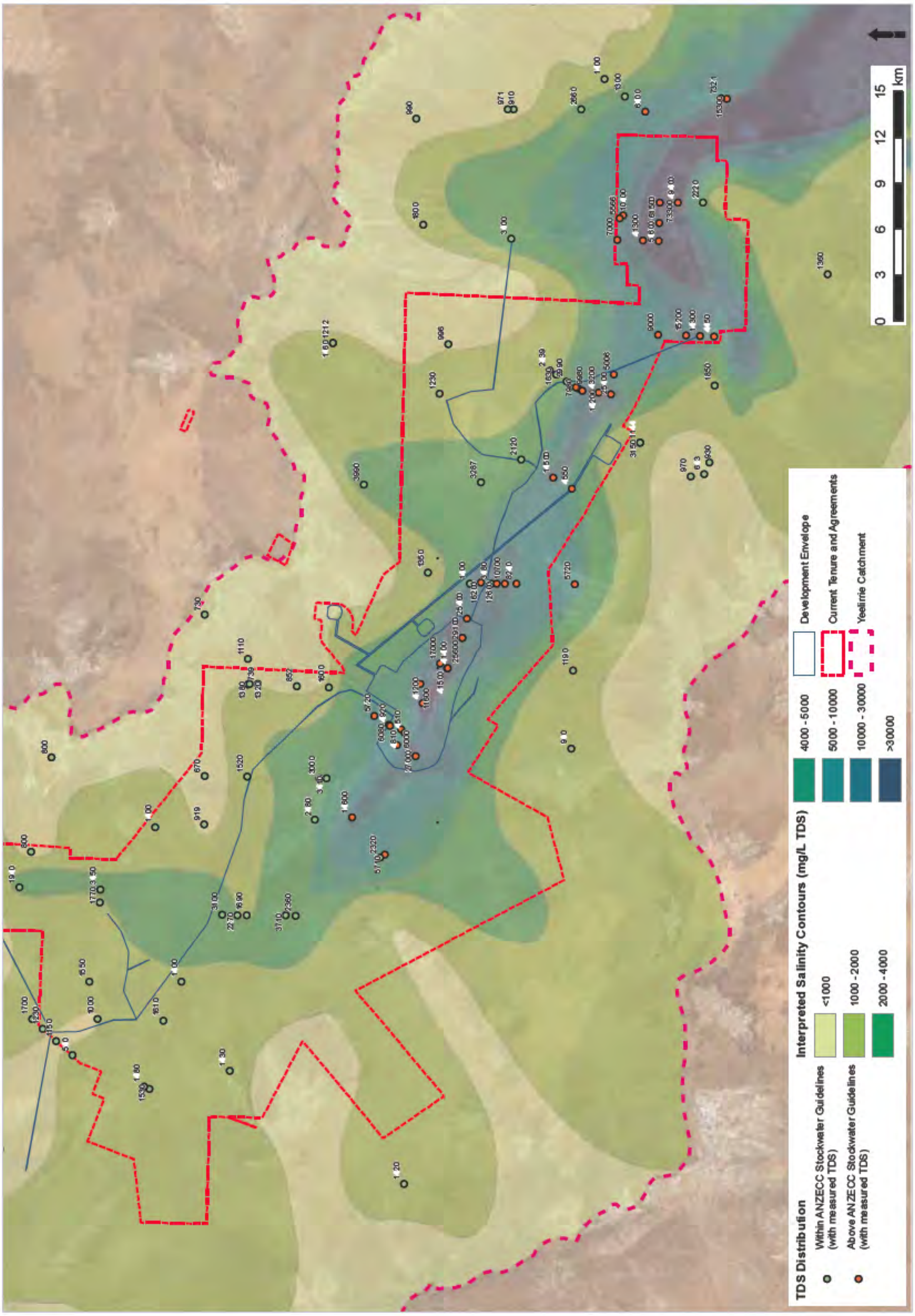

Figure 9-47: Distribution of total dissolved solids (TDS) at the water table

The thermodynamic data used were those contained in the thermo.dat database for Geochemist's Workbench with modifications. The database was updated with data from the Harwell/Nirex Thermodynamic Database for Chemical Equilibrium Studies (HATCHES), version 20 released in July 2013 as well as recent publications that improve thermodynamic data for relevant species. The HATCHES database is based on the database provided with the US Geological Survey computer program PHREEQC and is used, in conjunction with chemical and geochemical computer programs, to simulate a wide variety of reactions in aqueous environments. The database is currently maintained by the company AMEC (HATCHES, 2013) for the Radioactive Waste Management Directorate of the Nuclear Decommissioning Authority (Cameco, 2015b).

The aged tailings tests in conjunction with thermodynamic geochemical speciation modelling were used to develop conservative source terms that would describe conditions in the TSF in the long term. Sorption controls were not considered in the development of tailings source terms as a further conservative measure despite the presence of significant ferruginous soils available as a sorbent for tailings contaminants of concern.

The source terms data was used in the long term solute transport modelling to determine the extent of movement of the contaminants of concern 15,000 years after the closure of the project. The long term solute transport modelling is described in Appendix I1.

Figure 9-47 shows the majority of the groundwater from the wellfields will be low quality water (high salinity) from the palaeochannel aquifer.

Contaminants of concern

Based on the geochemical analyses undertaken, chloride, uranium, vanadium, arsenic, and molybdenum were selected for solute transport modelling. These contaminants of concern (CoCs) were chosen as they are expected to be the least retarded in the Yeelirrie environment because they exist as negatively charged species (arsenic and molybdenum), and uranium and vanadium because they are of particular concern because of the geochemistry of the carnotite deposit. Chloride was included because it is a non-retarding conservative tracer.

Contaminant transport

Mass transport involves the following processes:

- advection;
- hydrodynamic dispersion (including mechanical dispersion and diffusion); and
- chemical, nuclear and biological processes.

The results of the modelling of the transport of chloride and uranium are shown in Figures 9-48 to 9-51. The results are presented pictorially as increases (on a logarithmic scale) in concentrations of COCs above the baseline (pre-development condition) after Project closure.

Chloride

- Along the valley, the predicted plume is expected to travel up to 50 km eastward. Concentration increases above pre-development conditions within the plume are typically < 10 mg/L. Elevated concentrations (>10 mg/L above pre-development conditions) occur only in a limited number of locations. Given that high concentrations of chloride occur naturally in the Yeelirrie Catchment, predicted increases in chloride concentrations beyond approximately 1,000 m east of the TSF are considered negligible.
- Chloride could migrate up to 600 m northward from the TSF due to local northward groundwater flows north of the TSF cells and transverse dispersion. Southward migration is limited.
- In the vertical direction, the downward transport of chloride is limited to diffusion in the presence of an upward hydraulic up-gradient. Therefore, the downward transport is limited, but could reach the weathered granite.

Figure 9-48: Simulated chloride transport plume in model layer 1 at year 15,000

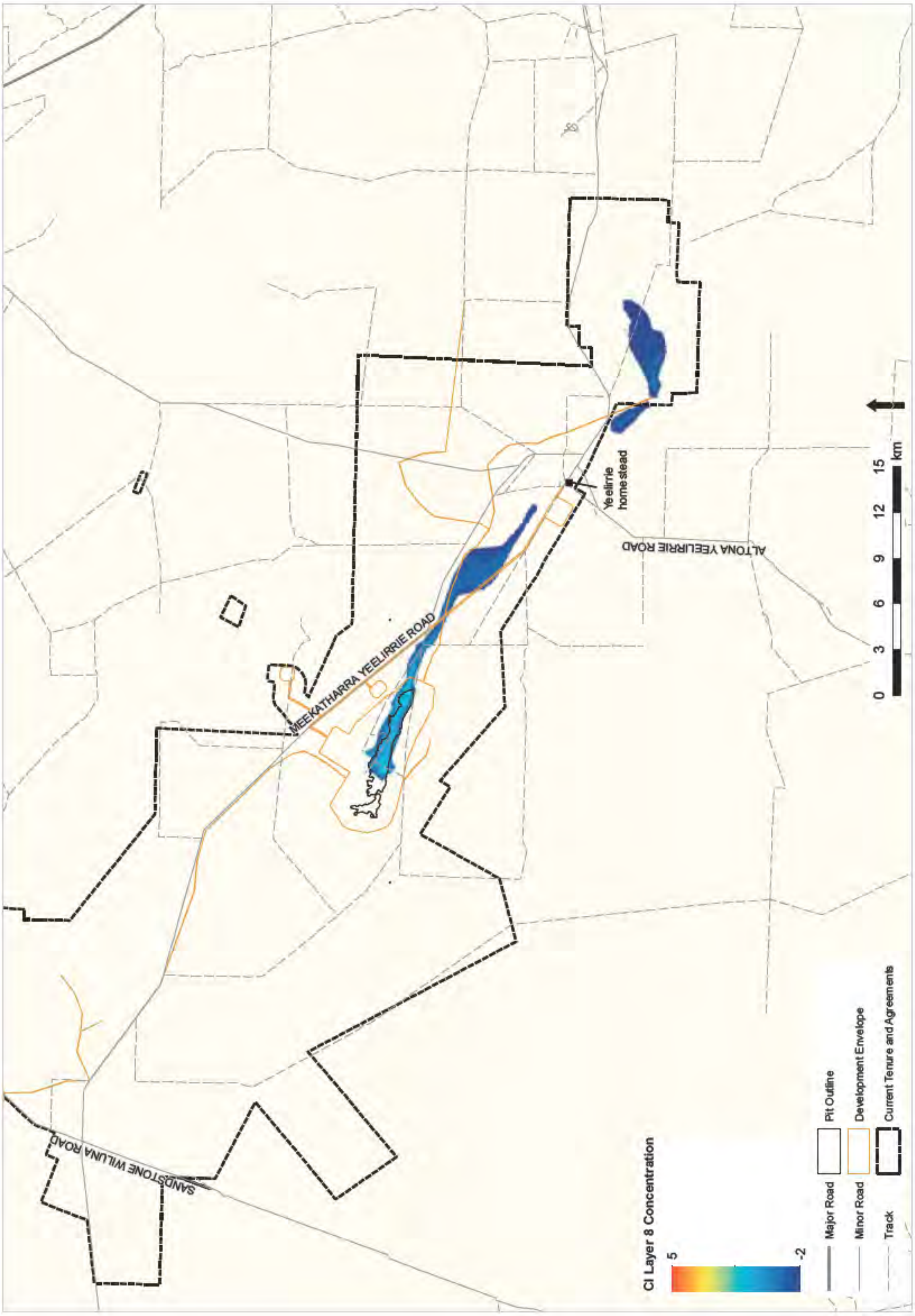

Figure 9-49: Simulated Chloride transport plume in model layer 8 at year 15,000

Figure 9-50: Simulated uranium transport plume in model layer 1 at year 15,000

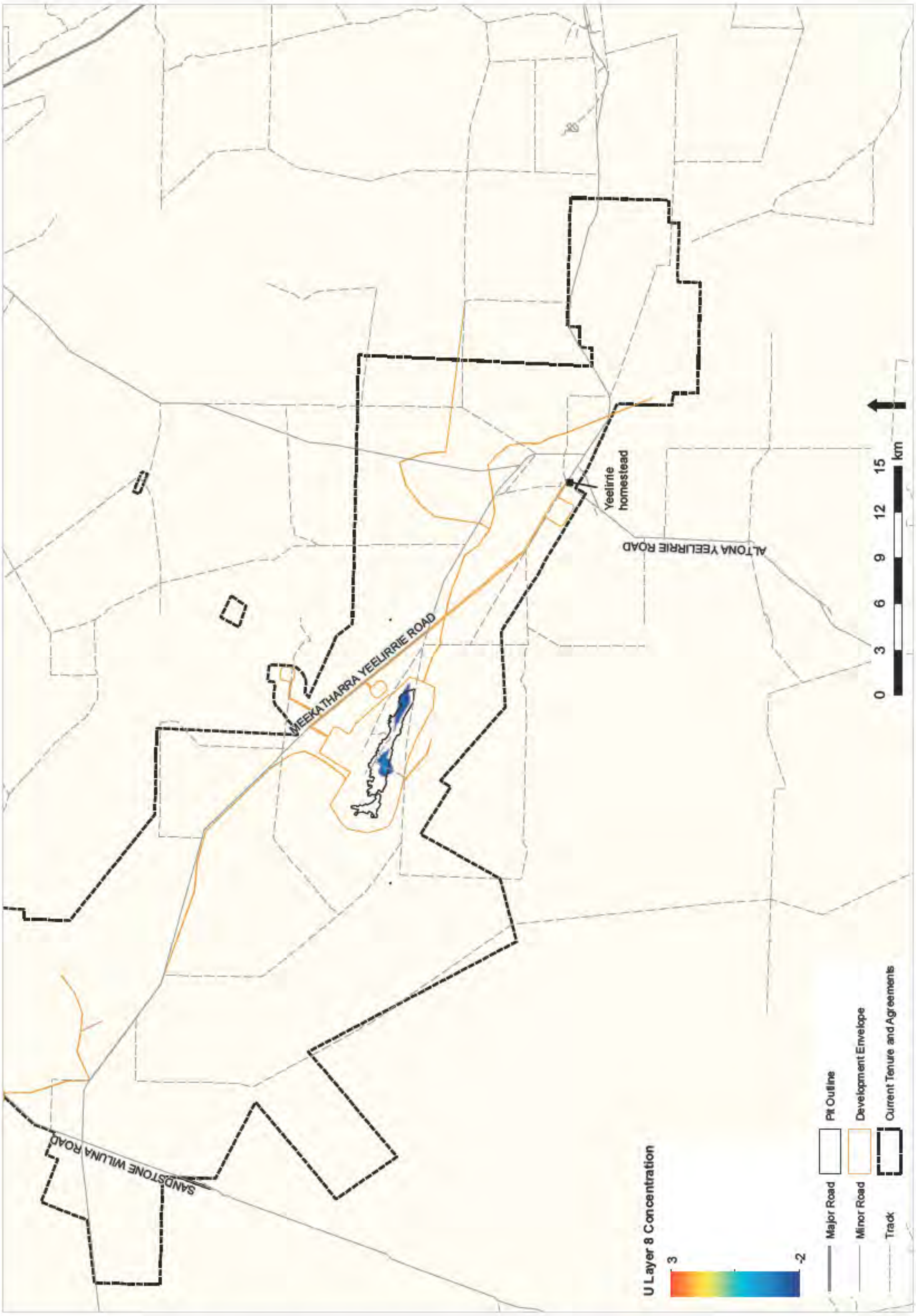

Figure 9-51: Simulated uranium transport plume in model layer 8 at year 15,000

Uranium

- In the east-west direction, the likely resultant uranium plume front (threshold of 0.2 mg/L) is predicted to remain within the mine-waste backfill (i.e. stay within the mine pit).
- In the north-south direction, the plume front (0.2 mg/L) could travel northward in the calcrete by as much as approximately 500 m.
- In the vertical direction, the predicted uranium plume could reach the weathered granite.

Vanadium

- In the east-west direction, the likely resultant vanadium plume front (0.01 mg/L) is predicted to remain within the mine-waste backfill (i.e. stay within the mine pit).
- In the north-south direction, the plume front (0.01 mg/L) could travel northward approximately 600 m, and southward approximately 200 m.
- In the vertical direction, the plume front could reach the weathered granite in a limited area.

Arsenic

- In the east-west direction, the likely resultant arsenic plume front (0.01 mg/L) is predicted to remain within the mine-waste backfill (i.e. stay within the mine pit).
- In the north-south direction, the plume front (0.01 mg/L) could travel northward in the calcrete by approximately 600 m.
- In the vertical direction, the plume front could reach the sand/clay lower paleo-channel formation and the weathered granite in a limited area.

Molybdenum

- In the east-west direction, the likely resultant molybdenum plume front (0.01 mg/L) is predicted to remain within the mine-waste backfill (i.e. stay within the mine pit).
- In the north-south direction, the plume front (0.01 mg/L) could travel northward in the calcrete by approximately 500 m.
- In the vertical direction, the plume front could reach the sand/clay lower paleo-channel formation and the weathered granite in a limited area.

Sensitivity analysis

The sensitivity analyses undertaken indicate that COC transport is more sensitive to the diffusion coefficient (Kd), infiltration through tailings and backfill cover, and the extinction depth, rather than the source concentration in the respective simulated range of these parameters.

This, along with the uncertainty in characterising Kd, infiltration through tailings cover, extinction depth and source concentration, has been taken into account in considering the transport simulation results presented in this report. High site-specific Kd values are supported by field evidence, gamma radiation surveys obtained after the removal of stockpiled materials during rehabilitation activities in 2004 at the Yeelirrie site showed very low readings after removal of the stockpile indicating a very limited release during the stockpiles lifetime (20 to 30 years) (Cameco, 2015a).

9.5.5.4 Summary of Management Measures

In summary, based on the detailed groundwater investigation and modelling of the Yeelirrie aquifers since 1978, Cameco has a high level of confidence that the required water demand can be met without any unacceptable environmental impact. Cameco will prepare and submit a detailed Groundwater Operating Strategy including a Groundwater Management Plan as part of the application of a 5C groundwater licence.

Design - Avoid

Cameco has designed the Project to enable in-pit storage of tailings, thereby avoiding additional groundwater impacts from an above-ground facility.

The in-pit TSF will incorporate an under-drainage system to capture and return any seepage to the metallurgical plant.

General - Avoid and Minimise

- Groundwater abstraction rates will be maintained at the minimum required for safe operation and for Project water supply.
- Groundwater abstraction rates and groundwater levels will be monitored to confirm predicted drawdown levels.
- Cameco will continue baseline monitoring of groundwater wells to increase levels of confidence around the response of groundwater to rainfall events.
- Continue baseline monitoring of groundwater wells to increase levels of confidence around the response of groundwater to rainfall events.

9.5.6 Commitments

Cameco will prepare and implement a detailed Groundwater Operating Strategy including a Groundwater Management Plan.

9.5.7 Outcomes

Taking into account the Project design and proposed management measures to be implemented, Cameco believes the Proposal will meet the EPA's objectives with regards to Hydrological Processes and Inland Water Quality (Groundwater).