PHASE 3 (STAGE 2 REPORT):

REPORT ON NUMERICAL GROUNDWATER FLOW MODELING AT THE RUM JUNGLE MINE SITE, NT

Submitted to:

Northern Territory Government
Department of Resources - Minerals and Energy

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EXECUTIVE SUMMARY

Robertson GeoConsultants Inc. (RGC) has undertaken Phase 3 groundwater studies at the Rum Jungle Mine Site in order to advance our understanding of current hydrogeologic conditions at the site and thereby assist the NT Department of Resources (DoR) in rehabilitation planning.

The current report describes the setup and calibration of a numerical groundwater flow model for the Rum Jungle Mine Site. This model enables a quantitative analysis of the groundwater system at the site by simulating monthly variations in flows and groundwater levels from August 2010 to November 2011.

The numerical groundwater flow model is based on the conceptual flow model described in RGC (2011b) and Section 4 of this report. That conceptual model contains a description of the main hydrostratigraphic units at the site and their hydraulic characteristics, a description of seasonal variations in groundwater levels and current groundwater quality conditions and a conceptual water balance.

The primary objective of Stage 2 has been to calibrate a numerical flow model (which is based on the conceptual model) using observed rainfall, pit lake levels, and groundwater level data collected by the DoR. Specific objectives of the Stage 2 numerical flow modeling have been to:

- Constrain the rate of groundwater recharge via rainfall infiltration to the mine waste units and undisturbed areas under current conditions;
- Provide a more rigorous description of the hydraulic properties of waste rock and the bedrock aquifer at the Rum Jungle Mine Site;
- Estimate current contaminant loads from the mine waste units to the groundwater system and the East Branch of the Finniss River.

To achieve these objectives a transient groundwater flow model was constructed for the Rum Jungle Mine Site using the finite-difference code MODFLOW and calibrating the model using seasonal variations in groundwater levels (August 2010 to November 2011). The calibrated flow model was partially validated using observed drawdown in the local bedrock aquifer in response to pumping of the Intermediate Pit for about 100 days in late 2008 (by HAR Resources).

Key findings of the numerical modeling work are summarized as follows:

- Groundwater flow across the site tends to follow topography; upland areas to the north and south of the central mine area are major recharge zones and the East Branch of the Finniss River is a groundwater discharge zone;
• Mine waste units represent areas of preferential recharge and hence affect local groundwater flow fields in their vicinity; groundwater levels near the Main and Dyson’s Overburden Heaps were simulated to mound due to the low permeability of bedrock beneath these heaps; no such mounding occurs near the Intermediate Overburden Heap due to the higher permeability of the underlying bedrock;

• In Dyson’s Area, shallow (highly-impacted) groundwater tends to flow south towards the upper East Branch of the Finniss River based on local topography; groundwater flowing west from Dyson’s Area is relatively unimpacted, which suggests that contaminants are not transported beyond Dyson’s Area via deep groundwater;

• The Main and Intermediate Open Pits represent net annual sources of water to the groundwater system (i.e. 4 L/s and 7 L/s, respectively); larger flows to and from the Intermediate Open Pit are related to a particularly strong hydraulic connection between this pit and the Coomalie Dolostone;

• The Browns Oxide Open Pit is a net annual sink (22 L/s) for groundwater due to active pit de-watering; the de-watered pit strong affects groundwater levels in the vicinity of the pit and near the East Branch of the Finniss River downstream of the road bridge.

Preliminary contaminant load estimates indicate that the Main and Intermediate Overburden Heaps account for about 75% of annual SO4 load to the East Branch of the Finniss River and at least 50% of metal loads to the river. Dyson’s Overburden Heap accounts for most of the remaining SO4 load. Dyson’s (backfilled) Open Pit is a major source of Cu, Mn, and Ni to the East Branch of the Finniss River due to seepages from highly-contaminated soils and heap leach material in shallow portions of the open pit.

The following work is recommended in light of numerical modeling results and the preliminary contaminant load balance:

• Update and re-calibrate the numerical flow model with groundwater and seepage flow estimates for the 2011/2012 wet season;

• Calibrate the preliminary contaminant load estimates with seepage flows and observed loads in the East Branch of the Finniss River for the 2010/2011 and 2011/2012 wet seasons;

• Evaluate and finalize the following rehabilitation options through consultation with local stakeholders;
  o Option 1. Collect & Treat
  o Option 2. High Quality Covers
  o Option 3. Relocate the Main Overburden Heap
  o Option 4. Relocate the Intermediate Overburden Heap
  o Option 5. Relocate the Intermediate Overburden Heap and mine waste units in Dyson’s Area
• Simulate the finalized rehabilitation options using the re-calibrated numerical flow model and contaminant load model to determine
  o Groundwater flow and seepage rates after rehabilitation
  o Residual contaminant loading from the different mine waste units to the East Branch of the Finnis River after rehabilitation

Completion of the recommended work will allow a comprehensive assessment of how the water quality conditions in the East Branch of the Finnis River could be improved by the alternative rehabilitation options and thereby enable the DoR to select the preferred rehabilitation option in light of stakeholder interests and priorities.
REPORT NO. 183003/2

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LIST OF ACRONYMS & ABBREVIATIONS

ARD Acid rock drainage
bgs below ground surface
DoR Department of Resources
EFDC East Finniss Diversion Channel
Head hydraulic head (or water level)
K Hydraulic conductivity
K_H Horizontal hydraulic conductivity
K_V Vertical hydraulic conductivity
RGC Robertson GeoConsultants Inc.
RJ Rum Jungle
SO_4 Sulphate
SRK SRK Consulting
S_S Specific Storage
S_Y Specific yield
TDS Total Dissolved Solids
1 INTRODUCTION

1.1 TERMS OF REFERENCE

The former Rum Jungle Mine Site is located 105 km by road south of Darwin in the headwaters of the East Branch of the Finniss River. Rum Jungle was one of Australia's first major uranium mines and produced approximately 3,500 tonnes of uranium and 20,000 tonnes of copper concentrate between 1954 and 1971 (Davy, 1975). Acid rock drainage (ARD) and heavy metal mobilization at the site have led to significant environmental impacts on local groundwater and the East Branch of the Finniss River and radioactive tailings remain in some areas (Kraatz, 2004).

In 2009, the Mining Performance Division of the Department of Resources (DoR) was tasked with developing a comprehensive rehabilitation plan for the Rum Jungle Mine Site. Scoping studies completed prior to 2009 suggested that local hydrogeology was poorly understood and that further study was needed prior to rehabilitation planning (Kraatz, 2004; Moliere et al., 2007). Robertson GeoConsultants Inc. (RGC) was therefore retained in May 2010 to assist the DoR with aspects of site rehabilitation planning that pertain to the contamination of groundwater and surface water at the Rum Jungle Mine Site by ARD and radionuclides.

In June 2010, RGC submitted an initial review of geochemical and hydrogeological data collected since the mid-1980s (RGC, 2010a). That review included an assessment of ARD sources, current groundwater and surface water quality conditions, and the identification of any data gaps that would hinder future rehabilitation planning. RGC recommended a second phase of work that would include additional drilling in areas that are under-represented in the existing bore network. This second phase of work was completed between August and December 2010 under the supervision of RGC and included drilling, installation and sampling of 27 new monitoring wells and hydraulic testing of 19 monitoring wells (see RGC, 2011a).

Phase 3 investigations were undertaken after completion of the 2010 drilling program. The first stage of Phase 3 involved the development of a conceptual flow model for the site (see RGC, 2011b) and the current report describes the results of Stage 2 numerical modeling.
1.2 PURPOSE & SCOPE

The purpose of Stage 2 numerical modeling is to develop a groundwater flow model that simulates seasonal variations in the groundwater system at the Rum Jungle Mine Site under current conditions. Specific objectives are to:

- Constrain groundwater recharge rates by rainfall infiltration to the major mine waste units;
- Provide a more rigorous description of the hydraulic properties of waste rock and the bedrock aquifer at the Rum Jungle Mine Site and the movements of groundwater across the site;
- Enable a preliminary assessment of contaminant loads from the Overburden Heaps and Dyson’s (backfilled) Open Pit to the groundwater system.

These objectives were achieved by calibrating a transient groundwater flow model to groundwater level data collected by the DoR from August 2010 to November 2011. These groundwater level data (and water quality data) are described in Section 3 of this report.

The conceptual flow model for the Rum Jungle Mine Site is described in Section 4 of this report and how this conceptual model was represented numerically is described in Section 5. Model calibration and validation and the implications of the modeling results to rehabilitation are described in Sections 6 and 7, respectively.
2 STUDY AREA DESCRIPTION

2.1 LOCATION & CLIMATE

The Rum Jungle Mine Site is located in Australia’s Northern Territory about 105 km by road south of Darwin near the township of Batchelor (Figure 2-1 and 2-2). The region is characterized by a tropical savannah-like climate and typically receives about 1500 mm of annual rainfall. 90% or more of this rainfall occurs during a distinct wet season that lasts from November to April, as no sustained rainfall occurs from May to September (see Table 2-1).

The total rainfall for the 2010/2011 wet season was very high (2,390 mm) with particularly high rainfall observed in January 2011 and February 2011. Some differences between rainfall amounts at the Rum Jungle Mine Site and Batchelor Airport were observed due to localized storm events but annual rainfall amounts are comparable. The total rainfall for the 2010/2011 water year was 2391 mm or 1.6 times higher than the long-term average (1,519 mm). Rainfall accumulation for the 2011/2012 water year (as of February 2012) is below the long-term average (see Table 2-1).

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<th>Nov</th>
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2.2 LOCAL GEOLOGY

The Rum Jungle mineral field is located in northern Australia and contains numerous polymetallic ore deposits, such as the Ranger and Woodcutters ore deposits and the ore deposits associated with the Rum Jungle Mine (i.e. the Main, Intermediate, Dyson’s, and Browns Oxide ore deposits).

The Rum Jungle Mine Site is situated in a triangular area of the Rum Jungle mineral field that is bounded by the Giant’s Reef Fault to the south and a series of east-trending ridges to the north (Figure 2-3a). This triangular area is known as The Embayment and it lies on the shallow-dipping limb of a northeast-trending, southwest plunging asymmetric syncline that has been cut by northerly-dipping faults (see Figure 2-4).
The main lithologic units in The Embayment are the Rum Jungle Complex and meta-sedimentary and subordinate meta-volcanic rocks of the Mount Partridge Group. The Rum Jungle Complex consists mainly of granites and occurs primarily along the southeastern side of the Giant’s Reef Fault, whereas the Mount Partridge Group occurs north of the fault and consists of the Crater Formation, the Geolsec Formation, the Coomalie Dolostone, and the Whites Formation (Figure 2-3b).

2.3 SITE LAYOUT

The Rum Jungle Mine Site features three waste rock piles (or ‘Overburden Heaps’), the flooded Main and Intermediate Open Pits, Dyson’s (backfilled) Open Pit (or ‘landform’) and the partially-mined Browns Oxide Open Pit (see Figure 2-5). Other notable features shown in Figure 2-5 are the East Finniss Diversion Channel (EFDC), the former Tailings Dam area along Old Tailings Creek, and the former Copper Extraction Pad between the flooded Open Pits.

An air photo of the Rum Jungle Mine Site taken prior to rehabilitation in the 1980s is shown in Figure 2-6. Some minor clean-up operations had been completed in the late 1970s but this photo essentially illustrates the major features of the site as they existed when mining operations ceased in the 1960s. An air photo of the site taken in 2010 is shown in Figure 2-7 for comparison.

The main features of the mine site are described briefly in the sub-sections below.

2.3.1 Open Pits

The Main and Intermediate Open Pits are located in the central mine reach along the pre-mining course of the East Branch of the Finniss River. These pits were mined out in the 1950s and 1960s and became flooded with contaminated groundwater and seepage when mine de-watering ceased (Davy, 1975). The Main Open Pit was mined to about 105 m below ground surface (bgs) but was partially backfilled (to 50 m or so) with tailings and other mine waste in the 1960s. The Intermediate Open Pit was mined to about 57 m bgs and has not been backfilled.

Dyson’s Open Pit was mined to a depth of about 50 m bgs in the late 1950s. Tailings from the Intermediate ore body were discharged to Dyson’s Open Pit from 1961 to 1965 and the pit was later backfilled to near ground surface with additional tailings from the Old Tailings Dam. The surface of the tailings was limed and overlaid with a single layer polypropylene geofabric and a rock blanket comprised of dolomitic material recovered from the Intermediate Overburden Heap (SRK, 2012). Leached low-grade ore and contaminated soils removed from the Copper Extraction Pad area were then placed on top of the rock blanket and the backfilled open pit was covered to reduce infiltration and prevent capillary rise of contaminants (Allen and Verhoeven, 1986). Water flowing along the rock blanket currently expresses via a toe drain near the southern edge of the landform.
The Browns Oxide Open Pit is located west of the central mine reach on private property. This pit is relatively shallow (< 30 m bgs) and is at present actively de-watered (but not mined) by HAR Resources.

2.3.2 Overburden Heaps

The Main, Intermediate, and Dyson’s Overburden Heaps contain waste rock removed from the open pits during mining operations. The Main Overburden Heap is the largest of the three heaps (30 ha) and is located near the southeastern boundary of the mine lease adjacent to Fitch Creek. The footprints of the Intermediate and Dyson’s Overburden Heaps are 8 ha and 9 ha, respectively.

Each of the Overburden Heaps was covered in the 1980s to reduce rainfall infiltration and oxygen transport into the heaps but the covers have deteriorated since that time. Only the top of Dyson’s Overburden Heap was covered in the 1980s so waste rock is exposed near the edges of the heap and the condition of the cover is considered particularly poor (Fawcett, 2007).

2.3.3 Diversion Channel

The East Branch of the Finniss River was diverted to the EFDC to allow access to the Main and Intermediate ore bodies during mining operations. The EFDC is relatively shallow and has been cut into bedrock south of the Main and Intermediate Overburden Heaps. The head of the EFDC is marked by a ‘weir structure’ near the old Sweetwater Dam and it ends at the point of outflow from the Intermediate Open Pit just upstream of the road bridge.

The EFDC currently receives wet season flows from the East Branch of the Finniss River and seepage collected from the Main and Intermediate Overburden Heaps. Seepage collected from the eastern edge of the Main Overburden Heap is delivered to the EFDC near the ‘weir structure’ and from the southwestern edge via Wandering Creek. Seepage from the Intermediate Overburden Heap enters the EFDC directly via a seepage face located about 250 m upstream of the road bridge.

2.3.4 Former Copper Extraction Pad area

In the 1960s, copper from sub-grade ore (and the oxidized capping) of the Intermediate ore body was extracted via heap leaching on a ‘non-permeable’ pad located between the Main and Intermediate Open Pits (Davy, 1975). Contamination of the local soils and local groundwater due to seepage losses was extensive. Most of the contaminated soils were ultimately removed and used to backfill Dyson’s Open Pit but residual amounts of contaminated soils and heap leach material remain. Groundwater in this area remains highly-contaminated (see RGC, 2011b).

2.3.5 Old Tailings Dam area

Slurried tailings were discharged to a relatively flat area north of the central mine reach during mining operations. Drainages from this area formed a small creek that eventually flowed to the East Branch.
of the Finniss River (Watson, 1979). As tailings piled up, perimeter walls were built towards the eastern end of the creek to form a series of small dams commonly referred to as the “Old Tailings Dam” (Davy, 1975).

Most of the tailings in this area were removed during reclamation works in the 1980s and the area was limed, re-shaped, and covered to promote the re-establishment of vegetation. Residual tailings do, however, remain throughout the area (Fawcett, 2007).

2.4 HYDROLOGY

2.4.1 Overview

The Rum Jungle Mine Site is located along the East Branch of the Finniss River about 8.5 km upstream of its confluence with the West Branch of the Finniss River (Figure 2-2).

Surface water enters the mine site from the east via the upper East Branch of the Finniss River and from the southeast via Fitch Creek. Before mining, these creeks met near the northeast corner of the Main Overburden Heap and subsequently flowed eastward via the natural river course. During mining, the river was diverted to the EFDC to allow access to the Main and Intermediate ore bodies (see ‘former river channel’ and ‘EFDC’ in Figure 2-5).

Today, flows from the upper East Branch of the Finniss River and Fitch Creek flow directly into the EFDC and the Main Open Pit near the former Acid Dam. Water then flows from the Main Open Pit to the Intermediate Open Pit via a channel that roughly follows the pre-mining river course. Outflow from the Intermediate Open Pit to the EFDC occurs near the western boundary of the mine site and combined flows from the flooded Open Pits and EFDC continues northward via the natural course of the East Branch of the Finniss River.

2.4.2 River flows

Flows in the East Branch of the Finniss River downstream of the mine site are currently monitored at gauge GS8150200 (near the road bridge) and then again 5.6 km downstream at gauge GS8150097. Gauge GS8150200 drains an area of 53 km² that includes the central mine area and Dyson’s Area but does not capture flows from Old Tailings Creek. Gauge GS8150097 captures flows from Old Tailings Creek and several other tributaries that do not drain the Rum Jungle Mine Site.

Gauge GS8150097 has long been considered the principal compliance point for surface water monitoring so flows have been monitored almost continuously since the 1960s (Davy, 1975). Gauge GS8150200 was established in 1991 and has since been used to monitor flows and water quality conditions in the East Branch of the Finniss River (see Lawton and Overall, 2002a). An additional stream flow gauge was set up in late 2010 between gauges GS8150200 and GS8150097 (see Figure 2-5) and will eventually be used as the compliance point for surface water monitoring (RGC, 2011a).
River flows vary predictably in response to intra-annual variability in rainfall and typically vary by several orders-of-magnitude over the course of a year. First flows are usually observed in early December or January in response to high-intensity rainfall events that can occur during the early wet season (Taylor et al., 2003).

Sustained flows at gauges GS8150200 and GS8150097 typically occur by mid-January and continue until the end of May with peak flows usually occurring in February or March. No appreciable flow is observed at gauges GS8150200 and GS8150097 from June to November due to minimal rainfall.

2.5 GROUNDWATER MONITORING NETWORK

The Rum Jungle Mine Site features a network of 103 historic monitoring bores and a series of new monitoring bores installed in 2010. The historic bores were installed during previous groundwater investigations or as production bores during mining operations, whereas the new bores were installed to augment the existing bore network (see RGC, 2011a). The locations of the historic and new monitoring bores are shown in Figures 2-8a and 2-8b, respectively, and details of their construction are provided in Appendix A.

Each of the bores shown in Figure 2-8 has been classified as shallow (<5 m), intermediate (5 to 15 m), or deep (>15 m) based on its installation depth. Most of the historic monitoring bores are shallow and clustered together near one of the major mine waste units or along the principal drainages of the site. Bores installed in 2010 are located mainly near the former Copper Extraction Pad area or north of the central mine area. Further details regarding bore locations and construction are provided as necessary in Section 3.
3 REVIEW OF 2010/2011 GROUNDWATER MONITORING DATA

3.1 MONITORING PROGRAMME

Groundwater levels and water quality at the Rum Jungle Mine Site have been routinely monitored by the DoR since early 2011. Groundwater levels at 130 bores are measured monthly during the dry season and bi-monthly during the wet season. DoR staff also measure pit water levels in the Main and Intermediate Open Pits during these water level surveys and compile data for the Browns Oxide Open Pit from HAR Resources.

Water samples are collected twice per year from 55 bores by the DoR’s Environmental Monitoring Unit (“EMU”). EMU collects water levels and field measurements of pH, temperature, and electrical conductivity (EC) as part of their sampling program to ensure collection of a representative sample. Samples are sent to NTEL in Darwin for analysis of major ion and dissolved metal content.

Groundwater quality data collected during the 2010/2011 wet season are plotted in Figures 3-1 to 3-4 and groundwater level time trends (as of February 2012) are plotted in Figures 3-5a to Figure 3-5g. Dry and wet season groundwater levels are plotted with inferred contours and flow directions in Figure 3-6a and 3-6b, respectively. These data are described in sub-sections below in the context of conceptualizing groundwater flow and contaminant transport at the Rum Jungle Mine Site.

3.2 DYSON’S AREA

Dyson’s Area is located east of the central mine reach adjacent to the upper East Branch of the Finniss River. The bedrock aquifer in Dyson’s Area is cross-cut by the Giant’s Reef Fault and a series of NE-trending faults. Dyson’s Open Pit was dug into pyritic black shale of the Whites Formation and waste rock from this operation was piled atop the Rum Jungle Complex south of the Giant’s Reef Fault.

3.2.1 Groundwater Levels

Groundwater in the Dyson’s Area generally flows in a southerly direction from the backfilled open pit (which is located on higher ground) towards the floodplain of the upper East Branch of the Finniss River (Figure 3-6).

The highest groundwater levels in this area were consistently observed in monitoring bore RN023792, which is located along a ridge west of the backfilled Dyson’s Open Pit. This bore is screened in tight bedrock of the Geolsec Formation and the high water level is believed to be a result of the low permeability of the local bedrock and may not be indicative of the flood level in the backfilled Dyson’s Open Pit. Hence, a mound in local groundwater levels has been inferred to follow the ridge line located immediately upgradient (north and west) of the backfilled Dyson’s Open Pit (Figure 3-6).
The seasonal response in groundwater levels during the 2010/2011 wet season in the Dyson’s Area can be grouped into three categories (Figure 3-5a):

- Groundwater levels to the north of the Dyson’s Open Pit in the more permeable Coomalie Dolostone (e.g. RN023304, RN022547) showed the highest seasonal increase (by up to 7 m) and a relatively fast recovery.
- Groundwater levels in proximity of the backfilled Dyson’s Open Pit in the Geolsec Formation (e.g. RN023790, RN023793) showed only a very modest increase in groundwater levels (about 1.0 to 1.5 m) during the wet season and a slow recovery.
- Groundwater levels in close proximity of the Upper East Finniss River channel (in weathered/fresh bedrock as well as in the alluvial sediments) remained close to or at ground surface throughout the wet season (indicating groundwater discharge to the nearby river flood plain).

### 3.2.2 Groundwater Quality

The low permeability of bedrock in the Dyson’s Area causes groundwater to flow preferentially towards the upper East Branch of the Finniss River in shallow zones of the aquifer and not beyond the Dyson’s Area in deeper zones of the aquifer (RGC, 2011b). Shallow groundwater in the vicinity of Dyson’s Overburden Heap (i.e. at bores RN023413 and RN023419) and Dyson’s (backfilled) Open Pit (at PMB1b) is therefore highly-contaminated (see Figure 3-1). SO₄ and metals concentrations are lowest in the wet season due to the dilution of shallow groundwater by flows in the nearby river channel.

High contaminant concentrations in the dry season suggest a chronic load to the East Branch of the Finniss River via shallow groundwater but total loads to the river are expected to be highest in the wet season when groundwater levels rise and seepage occurs to the south of the mine waste units. This is particularly relevant to Dyson’s (backfilled) Open Pit, as contaminants are repeatedly flushed from the landform in the wet season and report to the East Branch of the Finniss River primarily via toe seepage.

Groundwater west of Dyson’s Area towards the Main Open Pit (i.e. at bores RN023792 and RN022036) is only modestly-impacted (if impacted at all). These data suggest that most contaminant loads from the mine waste units in Dyson’s Area report primarily to the East Branch of the Finniss River via shallow groundwater discharge and that neither mine waste unit is a major source of ARD products to deep groundwater towards the central mine area.

### 3.3 Near the Overburden Heaps

The Main Overburden Heap is located to the south of the Giant’s Reef Fault and hence is underlain by the Rum Jungle Complex. Bores RN022082S and RN022082D are screened directly beneath the
Main Overburden Heap whereas numerous other bores are screened in along the perimeter of the heap (see Figure 3-2). All of these bores are screened in shallow, variably-weathered granite that lies above competent (and low-permeability) bedrock of the Rum Jungle Complex.

3.3.1 Groundwater Levels

Groundwater flow in the vicinity of the Main and Intermediate Heaps generally follows topography, i.e. groundwater moves from the higher elevations in the southern-most portion of the mine lease (near bore RN025166) towards Fitch Creek and the former floodplain of the East Branch of the Finniss River (now replaced by the central mining area; Figure 3-6).

Due to the relatively ‘tight’ bedrock underlying the Main Overburden Heap, seepage from the heap has resulted in significant mounding of the groundwater table in this area and groundwater flows radially away from the Main Overburden Heap in all directions (Figure 3-6). Consequently, seepage from the Main Overburden Heap is observed at shallow depths year-round and seepage discharges from the toe of the Main Heap throughout the wet season. Note that groundwater mounding under the Main Overburden Heap has resulted in significantly higher hydraulic gradients from this heap towards Fitch Creek and towards the EFDC than are typically observed in this part of the mine lease.

Note also that no such mounding of groundwater levels is observed near the Intermediate Overburden Heap likely due to the higher permeability of bedrock underlying this heap (i.e. the Coomalie Dolostone and Whites Formation).

The seasonal response in groundwater levels in proximity of the Main Overburden Heap during the 2010/2011 wet season can be summarized as follows (Figure 3-5b):

- Groundwater mounding under the southern portion of the Main Overburden Heap in the granitic bedrock (at bores RN022082S/D and RN022084) appears to show very limited seasonal variation suggesting relatively steady recharge (basal seepage through the footprint of the heap year-round)
- Groundwater levels in weathered granite near the Main Overburden Heap (e.g. bores RN022083, RN025165, RN025166, and RN025170) showed a rapid increase at the onset of the ‘wet’ (about 3 m in January) followed by a gradual recession after the end of the ‘wet’ (in late April)
- Groundwater levels in the deeper Coomalie Dolostone to the NW of the Main Overburden Heap showed a more modest seasonal increase (e.g. only about 1.5 m in bore RN022081) and showed a faster recession after end of heavy precipitation
- Groundwater levels in close proximity of the main drainages near the Main Overburden Heap typically showed very small seasonal variations:


0.2 to 0.5 m near the northeastern seep of Main Overburden Heap into Fitch Creek (bores RN022411 and RN029993)

About 0.9 to 1.0 m near the EFDC (at bores PMB3 and PMB4) and near the southwestern seep area of Main Overburden Heap towards Wandering Creek (bores RN030001 and RN030002)

The seasonal response in groundwater levels in proximity of the Intermediate Overburden Heap during the 2010/2011 wet season can be summarized as follows (Figure 3-5c):

- Groundwater levels in the granitic bedrock to the east of the Intermediate Overburden Heap (in bores RN025173, RN022037) showed modest seasonal mounding of about 1.5 to 1.7 m
- Groundwater levels along the western toe of the Intermediate Heap screened in weathered Whites Formation (bores RN023057, RN023060, PMB5) showed lower seasonal variations (only about 1 m) likely due the proximity to the drainage of Wandering Creek and/or the EFDC

Note that groundwater levels in the more permeable Coomalie Dolostone to the south of the Main and Intermediate Heaps (at bore RN022085) showed a distinctly greater seasonal trend with over 7 m increase until the end of February followed by a very rapid recession from April to June. This rapid response is characteristic of highly-permeable Coomalie Dolostone (see also historic production wells RN023304 and RN022547) located in the northeastern portion of the site (Figure 3-5a) and suggests preferential recharge to the local bedrock (possibly along vertical fractures) in this area.

### 3.3.2 Groundwater Quality

Key aspects of groundwater quality near the Main and Intermediate Overburden Heaps are summarized as follows:

- Groundwater beneath the heap (at bores RN022082S/D) is characterized by very high SO$_4$ and metals concentrations; groundwater quality conditions have improved somewhat since the heap was covered in the mid-1980s due to reduced infiltration and a reduction in basal seepage loads to groundwater (RGC, 2011b)
- Groundwater east of the Main Overburden Heap (at bore RN022083) is moderately-acidic (pH 6.0 to 6.5) and appears to be impacted primarily by a TDS plume; elevated SO$_4$ in this area suggest that a TDS plume extends east from the Main Overburden Heap and past bore RN022083 towards Fitch Creek but that the leading edge of a metals plume still resides closer to the heap.
- Groundwater near the southwestern toe of the Main Overburden Heap (at bores RN022084, RN022417, and RN029997) is highly-acidic (pH 3.6 to 5.2) and characterized by very high concentrations of Mg (2,000 to 2,500 mg/L), SO$_4$ (9,000 to 11,000 mg/L), and most dissolved
metals; the particularly high metals concentrations observed in bores RN022084 and RN029997 are related to their proximity to a seepage face that characterizes the southwestern batter of the Main Overburden Heap during the wet season whereas slightly lower concentrations at bore RN022417 reflects some dilution and/or metals attenuation along a flowpath that originates near the toe of the heap.

- Groundwater further from the heap (at bores RN022037 and RN025173) is characterized by elevated levels of conservatively-transported species (e.g. SO₄, Mg) but groundwater is only slightly acidic and metals concentrations are much lower than in groundwater closer to the Main Overburden Heap; these data and prevailing hydraulic gradients in this area therefore suggest a northwesterly direction of seepage flow from the Main Overburden Heap towards the eastern toe of the Intermediate Overburden Heap.

- The majority of contaminants from the Intermediate Overburden Heap appear to be delivered to the EFDC via the seepage face near bores PMB5 and PMB6 or deeper groundwater beneath the heap (such as bores PMB5 and PMB6), SO₄ and metals concentrations in groundwater upstream near the head of the EFDC are also relatively low suggesting that groundwater in the immediate vicinity of the EFDC is not modestly-impacted by ARD.

3.4 NEAR THE FORMER COPPER EXTRACTION PAD AREA & FLOODED OPEN PITS

3.4.1 Groundwater Levels

Groundwater flow fields in the central mine reach are strongly influenced by standing water levels in the flooded Open Pits. Under wet season (high flow) conditions, the Main Open Pit represents a local discharge zone for groundwater. In other words, groundwater from the higher-elevation area to the northwest (former production bores RN022548 and RN023304), the reclaimed tailings area to the north (e.g. bores PMB14 and RN22107), and potentially from the Main Overburden Heap to the south (e.g. bore RN220381) all flow towards the Main Open Pit. Similarly, the Intermediate Open Pit represents a local discharge zone for groundwater flowing into this area from the southeast.

Near the former Copper Extraction Pad, groundwater flows westward towards the Intermediate Open Pit via the fault that hosts mineralization at the site (see Figure 3-6). The groundwater flow field and available bore yields in this area suggest that this fault represents a preferential flow path for groundwater flow.

Preferential flow paths due to fracturing and/or chemical dissolution (“karst” features) also characterize groundwater flow within the Coomalie Dolostone (which is intersected by both the Main and Intermediate Open Pits). Specifically, the northern third of the Intermediate Open Pit intersects the Coomalie Dolostone whereas this unit is inferred to intersect the southern portion of the Main Open Pit.
A strong hydraulic connection between the Intermediate Open Pit and the Coomalie Dolostone was
demonstrated by a ‘large-scale’ pumping test conducted in late 2008 by HAR Resources (tenement
holders of the Browns Oxide Mine Site). During that test, the water level in the Intermediate Open Pit
was pumped down by a total of 10 m and groundwater levels in several nearby monitoring bores
deprecated as a result. Of particular interest was the decline in the groundwater level and the
deterioration of groundwater quality in bore RN22108 (now refurbished as nested bores PMB9S/D)
during the drawdown period of the test (see Figure 3-7).

The groundwater flow field suggests that most impacted groundwater from this central mining area
discharges into the flooded Intermediate Open Pit and mixes with relatively unimpacted pit water
under the high flow conditions shown in Figure 3-6. The pit water from the Intermediate Open Pit then
continues westward towards the East Branch of the Finniss River primarily via the pit overflow but
also as groundwater along the fault structure and within the more permeable Coomalie Dolostone.

Figures 3-5d and 3-5e illustrate seasonal time trends in groundwater levels and pit water levels for
the eastern and western sub-reaches near the Main Open Pit and the Intermediate Open Pit,
respectively. The key observations may be summarized as follows:

- The groundwater level in the highly-permeable Coomalie Dolostone to the north of the Main
  and Intermediate Open Pits (e.g. at RN022107, PMB12, PMB13) showed a rapid increase (of
  about 4 m) after the onset of the wet season
- Considerably lower increases in groundwater levels (about 2 m) were observed in bores
  screened in the Whites Formation (e.g. RN023054, RN022544, PMB10, PMB11)
- The seasonal change in the pit water level in the flooded Open Pits (in particular during the
  recession period after the wet season) was much less pronounced than in the Whites
  Formation, likely due to the large pit volume (high storage) and higher surface
  inflows/outflows compared to groundwater inflows/outflows
- Groundwater discharge to the flooded Open Pits likely occurs during the wet season whereas
  pit water recharges the surrounding bedrock during the dry season

It should also be pointed out that groundwater levels observed at bores PMB9S/D are usually almost
identical to the pit water level in the Intermediate Open Pit, which suggests a very good hydraulic
connection.

3.4.2 Groundwater Quality

Groundwater quality conditions near the flooded Open Pits and former Copper Extraction Pad are
summarized as follows:

- Groundwater near the former Copper Extraction Pad area (at bores PMB11, PMB23, and
  PMB24) is characterized by very high metals concentrations that are thought to be derived
from seepage (or ‘liquor’) lost during the copper extraction process; groundwater from this area likely represents the same type of water that initially filled the Main and Intermediate Open Pit when de-watering ceased in the 1950s (and which still resides at the bottoms of the pits);

- Groundwater quality at PMB9S is relatively unimpacted by ARD but samples of deeper groundwater from bore PMB9D is highly-impacted by ARD (i.e. ~3000 mg/L SO\(_4\) and elevated levels of various dissolved metals) (see Figure 3-3); these data are consistent with the water quality profile observed in the flooded Intermediate Open Pit, which is characterized by unimpacted water in the upper 30 m but impacted water at greater depths; the bedrock aquifer at bore PMB9D therefore appears to be hydraulically connected to the Intermediate Open Pit, which in turn is likely connected to the bedrock aquifer beneath the former Copper Extraction Pad area.

### 3.5 OLD TAILINGS DAM AREA

#### 3.5.1 Groundwater Levels

The groundwater flow field north of the central mine reach near the Old Tailings Dam suggests inflow of (unimpacted) groundwater from the northeastern portion of the mine lease where several historic production bores are screened in permeable Coomalie Dolostone (RN022547, RN022548 and RN023304). Groundwater flow in the Old Tailings Creek area itself is generally in a westerly direction towards the East Branch of the Finniss River.

The nested monitoring bores in close proximity of the Old Tailings Creek (PMB18 and PMB19) show an upward gradient which is consistent with groundwater discharge along this drainage line.

The seasonal response in groundwater levels in the Old Tailings Creek area during the 2010/2011 wet season can be summarized as follows (Figure 3-5f):

- Groundwater levels in the Coomalie Dolostone (e.g. PMB14, PMB17, PMB18 and PMB19) showed a rapid rise of about 4 m during the onset of the wet season and continued to fluctuate thereafter in response to precipitation; after the end of the wet season the groundwater levels showed a steady decline of about 2 to 3 m from mid-April to early July
- The two monitoring bores screened in the Geolsec Formation (PMB8S/D) showed a slightly smaller increase and a faster recession likely due to the closer proximity to the East Finniss River (shorter drainage path)

#### 3.5.2 Groundwater Quality

Groundwater entering the Old Tailings Dam area from the north (e.g. RN023140, RN023302) and the northwest (RN022547, RN022548) is unimpacted from historic mining activity (i.e. very low in EC and
SO\textsubscript{4} and non-detect metals). Note that groundwater quality in relatively deep Coomalie Dolostone (at bore PMB13) showed only minor impacts, which suggests that contamination by ARD in this area is limited to shallower zones of the bedrock aquifer (Figure 3-4).

Note that bore RN023304 (which is located near the old Borrow Pit 5 southeast of bore RN022548) shows uncharacteristically high SO\textsubscript{4} levels (i.e. 600 mg/L) which are likely indicative of a historic TDS plume pulled into this area during historic pumping of this production bore or some localized oxidation of tailings that were not removed during the rehabilitation program in the 1980s (see Fawcett, 2007).

Groundwater from bores PMB18 and PMB19 is characterized by elevated SO\textsubscript{4} concentrations that likely reflect residual impact from tailings in the Old Tailings Dam area. Groundwater north of the central mine reach (near bores PMB14 and PMB17) may also be affected by this residual plume but contaminants from the old plant area near the Main Open Pit is also plausible.

3.6 NEAR THE EAST FINNISS RIVER DOWNSTREAM OF THE MINE SITE

3.6.1 Groundwater Levels

The East Branch of the Finniss River is inferred to be a major groundwater discharge zone for this area with modestly-impacted groundwater from the east and unimpacted groundwater from the west discharging directly into the river and/or into the underlying alluvial sediments.

The groundwater levels observed at the nested monitoring bores PMB20 (screened in shallow river alluvium) and PMB21 (screened in granitic bedrock) showed similar seasonal increases in response to the wet season (about 2.5m maximum rise) (see Figure 3-5f). During the rising portion of the hydrograph a small downward gradient was observed, suggesting recharge from the alluvium into bedrock. However, by mid-February an upward gradient from the bedrock into the alluvium had developed which was sustained throughout the recessional flows into the early ‘dry’.

Note that geodetic groundwater levels in both the alluvium and underlying bedrock were consistently higher than the level of the East Branch of the Finniss River throughout the wet season at the nearby gauging station (by about 0.5 to 1.0 m), which suggests that groundwater is discharging to the river at this location.

3.6.2 Groundwater Quality

Detailed water quality surveys conducted in the mid-1990s suggest that the area immediately downstream of gauge GS8150200 is a discharge zone for groundwater (Lawton and Overall, 2002a; RGC, 2011). This scenario is consistent with comments from Davy (1975) and the local groundwater flow field shown in Figure 3-6. Specifically, modestly-impacted groundwater is thought to discharge from the bedrock aquifer to the eastern side of the East Branch of the Finniss River and unimpacted groundwater is thought to discharge to the western side (RGC, 2011b).
Groundwater quality conditions at bores PMB7 and PMB16 are representative of the type of impacted groundwater that likely discharges to the East Branch of the Finniss River within 500 m of gauge GS8150200. Specifically, groundwater in this area contains the high concentrations of SO₄ but low concentrations of metals that are indicative of a neutralized TDS plume (see Figure 3-3a-c). This plume likely originates in the former Copper Extraction Pad area near bores PMB23 and PMB24 and characterizes the bedrock aquifer at bore RN022543 (near the perimeter of the Intermediate Open Pit), bore PMB12 (northeast of bore PMB16), and bores PMB7 and PMB16 near the East Finniss River.

Further downstream, groundwater from bores PMB8D appears modestly unimpacted by ARD (Figure 3-4). Specifically, SO₄ concentrations in groundwater from deeper bedrock are slightly elevated but metals concentrations are low. The source of these elevated SO₄ concentrations is unclear at this time but they are likely related to a residual TDS plume from the former Tailings Dam area.

Near the mid-point gauge station, groundwater in bedrock beneath the East Branch of the Finniss River is unimpacted by ARD. This suggests that annual contaminant loads in the river at the mid-point gauge station represent the combined loads from surface water and groundwater (meaning no appreciable loads bypass the gauge via the sub-surface).

### 3.7 BROWNS OXIDE PIT

#### 3.7.1 Groundwater Levels

Groundwater levels near the Browns Oxide Pit are monitored by HAR Resources and selected data were made available for this review. Figure 3-5g shows the time trends of selected monitoring bores in proximity of the Browns Oxide Pit and Figure 3-6 shows the inferred groundwater flow field in this area.

The groundwater levels in the Coomalie Dolostone in immediate proximity of the Browns Oxide Pit (at TPB4 and TPB5) showed an increase of about 4 to 5 m in response to the wet season onset which is similar in magnitude to the water level increases seen in the Old Tailings Creek area (in the same formation).

The wet season resulted in flooding of the Browns Oxide Pit and HAR Resources therefore started de-watering of the flooded pit to gain access to the pit. The groundwater levels at the nearby bores screened in the Coomalie Dolostone (at TPB4 and TPB5) showed an almost identical decline to that observed in the flooded pit due to pumping (see Figure 3-5g) suggesting very good hydraulic connection. In contrast, groundwater levels in the nearby monitoring bore RN023137 (screened in the Whites Formation) showed a much more modest decrease. This much more muted response is inferred to be a result of the greater distance from the pit perimeter and the lower permeability of the local bedrock (Whites Formation). In addition, groundwater levels at RN023137 may also be
influenced by seepage from the near-by sedimentation pond which likely remained at full capacity throughout this monitoring period (Note: the water elevation in the sedimentation pond was not available at the time of report writing).

For comparison purposes, we also plotted the groundwater level time trends observed in RN022085 (which is located about 500 m to the south of the Browns Oxide Pit but is also screened in Coomalie Dolostone). The groundwater rise and subsequent recession observed in this portion of the Coomalie Dolostone was more pronounced than at the Browns Oxide Pit. This observation and its distance from the pit (separated by lower permeability bedrock of the Whites Formation) suggest that this portion of the Coomalie Dolostone (and this bore) is not directly connected to the Browns Oxide Pit.

Note also that pumping of the flooded Browns Oxide Pit created a hydraulic gradient from the Rum Jungle Mine Site towards the Browns Oxide area. For example, in early July the groundwater elevation at PMB9S/D was about 57.9 m AHD compared to about 55.2 m AHD in the Browns Oxide Pit. However, no suitable monitoring bore is available along the east side of the Browns Oxide Pit to determine whether any appreciable movement of contaminated groundwater from the Rum Jungle Mine Site (known to be present at shallow depth in the alluvium and at greater depth in the Coomalie Dolostone) is occurring onto the HAR property due to pit dewatering.

3.8 GROUNDWATER QUALITY

Groundwater quality data for bores TPB4 and TPB5 suggest that groundwater near the Browns Oxide Pit is unimpacted by ARD. Groundwater from bore TPB4, for instance, contains non-detect levels of SO₄ and background metals concentrations. Bore TPB5 is located east of the Browns Oxide Pit closer to the East Finniss River. Shallow groundwater at this location is characterized by low SO₄ and metals concentrations but EC levels are even lower than background levels for groundwater and could be indicative of surface water in this bore.

Given the absence of a deep monitoring bore near the Browns Oxide Pit we cannot determine at this time whether the TDS plume that characterizes groundwater at bore PMB9S/D (on the east side of the East Finniss River) has been pulled across the property boundary due to pit de-watering. However, groundwater modeling results from Coffey (2006) suggested that most of the groundwater drawn into the de-watered Browns Oxide Pit would be derived from the Coomalie Dolostone and that over time the water entering the pit would likely be characteristic of groundwater near bores PMB9S/D (formerly bore RN022108). Installation of an additional monitoring bore in the deep Coomalie Dolostone would be necessary to determine hydraulic connections and contaminant transport in this area (and would be advisable prior to further rehabilitation).
4 CONCEPTUAL FLOW MODEL

4.1 OVERVIEW

A conceptual flow model is a simplified representation of the essential features of a hydrogeologic system that provides the basis for numerical simulations of groundwater flow. In this section we therefore:

- Define the major hydrostratigraphic units at the Rum Jungle Mine Site and characterize their hydraulic properties based on hydraulic testing data;
- Interpret seasonal and spatial variations in groundwater levels across the site in order to determine the directions of groundwater flow;
- Characterize groundwater quality across the site in order to identify major sources of recharge to the groundwater system and infer flow directions; and
- Prepare a preliminary water balance to estimate the major inflows and outflows of water from the model domain.

Much of this section is drawn from RGC (2011b) and the reader is referred to that report for a more detailed description of drilling results and hydraulic testing data.

4.2 MODEL DOMAIN

Figure 4-1 shows the boundaries of the model domain for the Rum Jungle Mine Site. These boundaries enclose an area of about 12.9 km² or about 20% of the total catchment area of the East Branch of the Finniss River at gauge GS8150097.

The boundaries of the model domain (shown in red) were defined by local topographic highs and low-lying drainage lines (creeks) such that cross-boundary flows into the groundwater system can be assumed to be negligible. Note that the area west of the East Branch of the Finniss River towards the Browns Oxide Open Pit is included in the model domain because the development of this mine may influence the local groundwater flow and contaminant transport on the Rum Jungle mine site.

Vertically, the model domain extends from ground surface to a maximum depth of about 150 m (or about 50 m deeper than the maximum depth reached during mining). All lithological contacts and/or faults within the model domain were assumed to be vertical in orientation and extend through the entire bedrock aquifer.

4.3 AQUIFER UNITS & PROPERTIES

The aquifer system at the Rum Jungle Mine Site is thought to be comprised primarily of relatively shallow (typically < 100 m deep), unconfined bedrock aquifers. No information is currently available on the potential presence of deeper, confined aquifers of regional extent yet such aquifers (if present)
are not considered likely to influence the shallow groundwater flow that controls contaminant transport at the Rum Jungle Mine Site.

Bedrock of the Rum Jungle Complex and the Mount Partridge Group comprise the main aquifer of the mine site. Cross-sections of the mine site are shown in Figures 4-2 and 4-3 to illustrate the distribution of the main aquifer units at the mine site. Note that Figure 4-2 is oriented roughly E-W and hence shows the Main and Intermediate Open Pits in profile (red dotted lines) whereas Figure 4-3 is oriented N-S and cuts across the former Copper Extraction Pad (see Figure 2-3 for exact transect locations).

The hydraulic properties of the bedrock aquifer differ according to lithology and the degree of weathering and/or fracturing (see Figure 4-4). The degree of fracturing in the bedrock aquifer is likely depth-dependent to some extent so deeper bedrock of the Rum Jungle Complex and the Mount Partridge Group is expected to be less fractured (and hence characterized by lower secondary permeability).

4.4 GROUNDWATER FLOW REGIME

4.4.1 General

Cross-boundary flows to the model domain are considered negligible so local topographic highs (i.e. ridge lines) represent no-flow boundaries and the only source of water to the model domain is recharge by rainfall infiltration. Groundwater recharge occurs mainly during the wet season and higher elevation areas tend to be preferentially recharged due to the greater available storage above the water table. As a result, more seasonality in groundwater levels occurs in upland areas than in lowland areas (which causes horizontal hydraulic gradients in the bedrock aquifer to be higher in the wet season than in the dry season).

Unimpacted groundwater from upland areas tends to flow towards the lower elevation areas that correspond to the current course of the East Branch of the Finniss River and its pre-mining course in the central mine reach. Upward vertical gradients in these low-lying areas indicate that groundwater discharges in these areas and hence contributes to surface water flows. Groundwater flow fields within the model domain have been altered by the presence of the mine waste units. Of particular interest is the 'mounding' of groundwater levels that occurs beneath and near the Main Overburden Heap (and possibly Dyson's Overburden Heap). This water table mounding suggests that the heaps represent areas of preferential recharge.

Groundwater flow fields are also affected by the flooded Open Pits, which can act as sources or sinks for groundwater depending on the pit water level and water levels in the surrounding aquifer. These aspects of the local groundwater flow regime (and additional details on recharge and structural controls on groundwater flow) are described in more detail below.
4.4.2 Recharge

Recharge to undisturbed areas of the model domain occurs primarily during the wet season when the majority of rainfall occurs. Previous studies have estimated that only 10% of incident rainfall to natural ground surfaces in humid areas of the Northern Territory infiltrates to groundwater (as the remainder of incident rainfall is lost via evapotranspiration and surface runoff). A percentage infiltration rate of 10% seems reasonable for undisturbed areas of the Rum Jungle Mine Site but could be higher or lower depending on local lithology.

Specifically, seasonal variations in groundwater levels suggest that recharge to the Coomalie Dolostone is higher than to the other units of the Mount Partridge Group and the Rum Jungle Complex. Recharge to the Coomalie Dolostone is therefore likely higher than the generalized values for undisturbed ground (say 10 to 15% of incident rainfall) whereas annual infiltration rates for the Whites Formation and the Rum Jungle Complex are likely lower by comparison (say 5 to 10% and 2%, respectively).

Infiltration rates for the mine waste units are thought to be higher than infiltration to groundwater via natural ground surfaces. This was particularly likely when the Overburden Heaps were uncovered in the 1970s and early 1980s. Daniel et al. (1982) estimated that 50 to 60% of annual rainfall percolated through the Main Overburden Heap before rehabilitation. Cover placement as part of rehabilitation works in 1984/1985 reportedly reduced infiltration to 5 to 10% of annual rainfall by the late 1990s. However, some doubt exists regarding the reliability of the lysimeter data interpreted in historic reports (Taylor et al., 2003; Phillip and O’Kane, 2006). Based on previous investigations and preliminary contaminant load estimates from RGC (2011b), we assumed a net infiltration rate of 25% of incident rainfall for the Main and Intermediate Heaps and 50% net infiltration for the Dyson’s Overburden Heap (because it was covered to a lesser extent than the other heaps in the 1980s).

4.4.3 Groundwater-Surface Water Interaction

The Main and Intermediate Open Pits cut deeply into the bedrock aquifer in the central mining reach and therefore have a potential to interact significantly with groundwater in adjacent zones of the bedrock aquifer. During active mining (and de-watering), both pits represented major sinks for groundwater and the bedrock aquifer in the central mine reach likely featured a significant cone of depression. However, the Main and Intermediate Open Pits have been flooded now for 40 to 50 years and groundwater levels have reached post-mining steady-state conditions. Note that a cone of depression may, however, still characterize the area near the Browns Oxide Open Pit as it is actively de-watered.

A comparison of the pit water levels to groundwater levels in the surrounding aquifer suggest that the flooded Open Pits tend to receive flows of groundwater during the wet season but act primarily as
sources of water to the groundwater system during the dry season. Higher flows from the Intermediate Open Pit than the Main Open Pit are expected due its strong hydraulic connection to the Coomalie Dolostone and the partial backfilling of the Main Open Pit with low-K tailings (which has likely sealed the deeper pit walls from the surrounding bedrock aquifer).

The Browns Oxide Open Pit is the shallowest of the three open pits (< 30 m deep) but it is expected to interact significantly with the groundwater system at the Rum Jungle Mine Site because it is actively de-watered by HAR Resources. Specifically, the Browns Oxide Open Pit is expected to be a major sink for groundwater (see Coffey, 2006) and therefore likely influences the groundwater flow field west of the Intermediate Open Pit near the East Branch of the Finniss River. Note that information on the groundwater system in proximity of the Browns Oxide Open Pit is generally more limited (only a few monitoring bores are available in this area and monitoring is less frequent).

Other major discharge zones for groundwater include Fitch Creek and the upper East Branch of the Finniss River, sections of the EFDC, and the East Branch of the Finniss River downstream of the mine site. Note that no appreciable underflow is thought to occur at the downstream boundary near the mid-point gauging station because this gauge is underlain by low-permeability granite of the Rum Jungle Complex. In other words, flow in the East Finniss River at the mid-point gauging station captures most, if not all, groundwater and surface water flows from the model domain.

4.5 CONTAMINANT TRANSPORT IN GROUNDWATER

4.5.1 Background Water Quality

Unimpacted groundwater in the bedrock aquifer at the Rum Jungle Mine Site is typically neutral to slightly alkaline (pH 7 to 8) and characterized by an EC of 300 to 500 μS/cm and low concentrations of SO₄ (<5 mg/L) and dissolved metals (RGC, 2011b). Groundwater of this type occurs upgradient of the central mine area (at bore RN022085) and in upland areas northeast of the central mine reach. Unimpacted groundwater has also been identified in relatively deep Coomalie Dolostone (at bore PMB13), which suggests that contamination by ARD in this area is limited to shallower zones of the bedrock aquifer.

4.5.2 ARD Sources

Seepages from the four major mine waste units at the site currently provide the bulk of contaminant loads to receiving groundwater and the East Branch of the Finniss River. Seepages are all highly-acidic but some differences with respect to SO₄ and metal concentrations are apparent due to the nature of waste rock stored in the heaps (see Table 4-1).
Table 4-1.
Selected ARD indicator species in seepage, 2010/2011

<table>
<thead>
<tr>
<th>Waste Unit</th>
<th>Date</th>
<th>pH</th>
<th>EC</th>
<th>SO4</th>
<th>Mg</th>
<th>Al_d</th>
<th>Fe_d</th>
<th>Cu_d</th>
<th>Co_d</th>
<th>Mn_d</th>
<th>Ni_d</th>
<th>U_d</th>
<th>Zn_d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseflow (dry season)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Overburden Heap (baseflow)</td>
<td>6-Aug-10</td>
<td>3.7</td>
<td>6000</td>
<td>5190</td>
<td>1120</td>
<td>12.9</td>
<td>4.8</td>
<td>4.4</td>
<td>5.2</td>
<td>11.1</td>
<td>3.8</td>
<td>0.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Dyson's Overburden Heap (baseflow)</td>
<td>6-Aug-10</td>
<td>3.7</td>
<td>4520</td>
<td>2710</td>
<td>511</td>
<td>87.6</td>
<td>5.8</td>
<td>0.2</td>
<td>0.4</td>
<td>5.1</td>
<td>1.2</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Intermediate Overburden Heap (baseflow)</td>
<td>6-Aug-10</td>
<td>3.3</td>
<td>12600</td>
<td>13800</td>
<td>2760</td>
<td>190.0</td>
<td>349.0</td>
<td>34.9</td>
<td>74.7</td>
<td>84.3</td>
<td>64.9</td>
<td>1.8</td>
<td>156.0</td>
</tr>
<tr>
<td><strong>High flow (wet season)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyson's (backfilled) Open Pit</td>
<td>16-Mar-11</td>
<td>3.4</td>
<td>2872</td>
<td>1730</td>
<td>259</td>
<td>17.0</td>
<td>11.3</td>
<td>27.3</td>
<td>18.4</td>
<td>39.9</td>
<td>15.5</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Dyson's (backfilled) Open Pit</td>
<td>13-Apr-11</td>
<td>3.4</td>
<td>3651</td>
<td>1900</td>
<td>282</td>
<td>18.9</td>
<td>9.9</td>
<td>29.6</td>
<td>20.5</td>
<td>41.8</td>
<td>16.3</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Dyson's (backfilled) Open Pit</td>
<td>10-May-11</td>
<td>3.4</td>
<td>4041</td>
<td>2940</td>
<td>450</td>
<td>26.4</td>
<td>9.7</td>
<td>35.7</td>
<td>32.6</td>
<td>72.4</td>
<td>25.7</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Dyson's Overburden Heap</td>
<td>16-Mar-11</td>
<td>4.3</td>
<td>1106</td>
<td>579</td>
<td>81.2</td>
<td>9.0</td>
<td>2.7</td>
<td>4.6</td>
<td>3.1</td>
<td>7.4</td>
<td>2.6</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Dyson's Overburden Heap</td>
<td>13-Apr-11</td>
<td>4.2</td>
<td>1356</td>
<td>766</td>
<td>104</td>
<td>14.9</td>
<td>1.9</td>
<td>5.0</td>
<td>4.1</td>
<td>9.8</td>
<td>3.4</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Dyson's Overburden Heap</td>
<td>10-May-11</td>
<td>4.2</td>
<td>1579</td>
<td>1020</td>
<td>144</td>
<td>11.8</td>
<td>0.6</td>
<td>3.8</td>
<td>6.3</td>
<td>14.9</td>
<td>4.9</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Seepage from the Intermediate Overburden Heap is characterized by very high concentrations of SO₄ and dissolved metals. Of particular interest are the very high concentrations of dissolved Cu and Zn, which reflect the geochemistry of the Intermediate ore body. Seepage from the Main Overburden Heap tends to be less concentrated than seepage from the Intermediate Overburden Heap, possibly due to some dilution by shallow groundwater or the lower sulphide content of waste rock in the Main Overburden Heap.

SO₄ and metals concentrations in seepage from Dyson’s Overburden Heap are substantially lower than seepages from the Main and Intermediate Overburden Heaps. These lower concentrations reflect the lower sulphide content of waste rock from this heap and the mining of Dyson’s ore body exclusively for uranium (and not a suite of metals). Note that SO₄ and metals concentrations are considerably lower in the wet season due to dilution by shallow groundwater.

Seepage from the Dyson’s (backfilled) Open Pit only occurs during the wet season and is characterized by high concentrations of dissolved metals. These high metal concentrations are related to seepage from highly-contaminated soils and copper heap leach material used to backfill shallow portions of the open pit (which is transported to the toe drain via the rock blanket that overlies deeper tailings). The majority of tailings in the open pit likely remain underwater throughout the year so are not actively oxidized and therefore not a major source of contaminants.

Highly-impacted water resides beneath the former Copper Extraction Pad and represents another potential source of ARD products to receiving groundwater (see Table 4-2). Groundwater in this area has been highly-contaminated by seepage lost during heap leaching. This type of contaminated water likely filled the flooded Open Pits when de-watering ceased, which is consistent with high concentrations of SO₄ and metals in untreated water that still resides at bottom of the Main and Intermediate Open Pits (see Table 4-2 and EC profiles in Figure 4-5).
4.5.3 Contaminant Plumes

Conceptual representations of the major contaminant plumes at the Rum Jungle Mine Site are delineated in Figure 4-6. Very high concentrations of SO$_4$ and metals characterize groundwater near the major mine waste units and in the vicinity of the former Copper Extraction Pad.

Metals concentrations are particularly high near the Main Overburden Heap due to the low buffering capacity of the underlying Rum Jungle Complex. Groundwater affected by seepage from the Main Overburden Heap generally moves eastward towards Fitch Creek or westward towards the Intermediate Overburden Heap but some transport towards the EFDC and Main Open Pit also likely occurs. The extents of contaminant plumes originating from the Intermediate Overburden Heap are more difficult to ascertain but the majority of contaminants are thought to report to the EFDC via toe seepage/shallow groundwater discharge from the northern edge of the heap.

In Dyson’s Area, highly-impacted groundwater resides in the shallow bedrock aquifer near Dyson’s Overburden Heap and south of Dyson’s (backfilled) Open Pit and ultimately discharges to the upper East Branch of the Finniss River. Impacted groundwater does not appear to be transported westward beyond Dyson’s Area due to local topography and/or the low permeability of bedrock.

Moderately-elevated SO$_4$ concentrations characterize groundwater north of the central mine reach but metal concentrations in this area are low. This suggests that metals are naturally attenuated in groundwater due to the high buffering capacity of the Coomalie Dolostone and the low solubility of most metals under near-neutral pH conditions. Major ions, such as SO$_4$ and Mg, are unaffected by this buffering reaction (or retardation) and therefore transported conservatively in groundwater (hence the larger extents of TDS plumes compared to metal plumes).

<table>
<thead>
<tr>
<th>Date</th>
<th>pH</th>
<th>EC</th>
<th>SO$_4$</th>
<th>Mg</th>
<th>Al</th>
<th>Fe</th>
<th>Cu</th>
<th>Co</th>
<th>Mn</th>
<th>Ni</th>
<th>U</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piit Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Open</td>
<td>Aug-85</td>
<td>2.5</td>
<td>8200</td>
<td>900</td>
<td>-</td>
<td>55.0</td>
<td>-</td>
<td>230.0</td>
<td>14.0</td>
<td>-</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Pit</td>
<td>Bottom of Main Open Pit (43 m depth)</td>
<td>May-08</td>
<td>710</td>
<td>892</td>
<td>107.0</td>
<td>1160.0</td>
<td>26.0</td>
<td>220.0</td>
<td>10.4</td>
<td>-</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>Bottom of</td>
<td>Apr-98</td>
<td>4.7</td>
<td>3478</td>
<td>2410</td>
<td>322</td>
<td>0.35</td>
<td>25</td>
<td>1.1</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate Open Pit (35 m depth)</td>
<td>May-08</td>
<td>-</td>
<td>101</td>
<td>21</td>
<td>0.10</td>
<td>0.1</td>
<td>0.1</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>pH</th>
<th>EC</th>
<th>SO$_4$</th>
<th>Mg</th>
<th>Al</th>
<th>Fe</th>
<th>Cu</th>
<th>Co</th>
<th>Mn</th>
<th>Ni</th>
<th>U</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMB11</td>
<td>Dec-10</td>
<td>5.0</td>
<td>7540</td>
<td>5600</td>
<td>964</td>
<td>1.2</td>
<td>36.3</td>
<td>75.9</td>
<td>195.0</td>
<td>50.9</td>
<td>0.01</td>
<td>9.2</td>
</tr>
<tr>
<td>PMB23</td>
<td>Dec-10</td>
<td>3.5</td>
<td>6940</td>
<td>5340</td>
<td>768</td>
<td>37.7</td>
<td>13.0</td>
<td>73.7</td>
<td>143.0</td>
<td>56.4</td>
<td>0.40</td>
<td>10.5</td>
</tr>
<tr>
<td>PMB24</td>
<td>Feb-11</td>
<td>3.1</td>
<td>1367</td>
<td>600</td>
<td>81</td>
<td>17.9</td>
<td>0.8</td>
<td>28.0</td>
<td>3.1</td>
<td>11.6</td>
<td>2.9</td>
<td>0.14</td>
</tr>
</tbody>
</table>
4.6 Conceptual Groundwater Budget

Using percentage infiltration rates from Section 4.4.2 and the areas of undisturbed ground and mine waste units, annual groundwater recharge to the model domain was estimated to be 56 to 129 L/s (Table 4-3). The lower estimates reflect 2% recharge for the Rum Jungle Complex, 10% for the Coomalie Dolostone, and 25% for the mine waste units, whereas the upper bound estimates correspond to twice the recharge assumed for the lower bound.

Table 4-3: Conceptual groundwater budget for the Rum Jungle Mine Site

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow, L/s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recharge by rainfall (undisturbed areas)</td>
<td>46-93</td>
<td>Assuming 1500 mm rainfall and percentage recharge rates from Section 4.4.2</td>
</tr>
<tr>
<td>Recharge by rainfall (mine waste units)</td>
<td>6-12</td>
<td>Assuming 1500 mm rainfall and 25 to 50% recharge to mine waste units</td>
</tr>
<tr>
<td>Flows from the Main Open Pit</td>
<td>1-9</td>
<td>Assuming dry season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td>From the Intermediate Open Pit</td>
<td>2-15</td>
<td>Assuming dry season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>56-129</td>
<td></td>
</tr>
<tr>
<td><strong>Outflows (groundwater discharge)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To the Main Open Pit</td>
<td>1-9</td>
<td>Assuming wet season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td>To the Intermediate Open Pit</td>
<td>1-4</td>
<td>Assuming wet season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td>To the Browns Oxide Open Pit</td>
<td>5-25</td>
<td>Best judgement from previous model results and preliminary water level surveys</td>
</tr>
<tr>
<td>To the upper EBFR</td>
<td>6-9</td>
<td>Assuming wet season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td>To Fitch Creek</td>
<td>1-2</td>
<td>Assuming wet season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td>To the EFDC</td>
<td>2-9</td>
<td>Assuming wet season gradients, 15 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td>To the EBFR d/s of GS8150200</td>
<td>7-43</td>
<td>Assuming wet season gradients, 45 m aquifer thickness, and K values from Figure 4-4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>23-101</td>
<td></td>
</tr>
</tbody>
</table>

Note: Flows to the flooded Open Pits and tributaries of the East Branch of the Finniss River were estimated via Darcy flow calculations.

Flows to and from the flooded Open Pits and groundwater discharge to the East Branch of the Finniss River and its tributaries were estimated via Darcy flow calculations and weighted K values from Figure 4-4. Lower bound estimates in this table correspond to the lower K values provided in Figure 4-4 (and vice versa). This conceptual groundwater budget provide a reasonable set of bounds for numerical modeling and emphasizes the significance of groundwater discharge to the East Branch of the Finniss River downstream of gauge GS8150200 and to the Browns Oxide Open Pit.
5 NUMERICAL MODEL SETUP

5.1 MODELING OBJECTIVES & APPROACH

A numerical groundwater flow model was constructed to simulate variations in the groundwater system at the Rum Jungle Mine Site from August 2010 to November 2011. This numerical flow model is a mathematical representation of the conceptual model presented in Section 4 that enables a quantitative analysis of recharge and regional groundwater flows. Specific objectives of numerical modeling are to:

- Provide a more rigorous description of the hydraulic properties of the main bedrock aquifer at the Rum Jungle Mine Site and characterize the movements of groundwater across the site;
- Constrain the amounts of annual recharge to the Overburden Heaps and Dyson’s (backfilled) Open Pit under current conditions;
- Estimate monthly and net annual flows to and from the flooded Open Pits, the partially de-watered Browns Oxide Open Pit, and the East Branch of the Finniss River;
- Estimate toe seepage from the three Overburden Heaps and Dyson’s (backfilled) Open Pit.

To achieve these objectives, the conceptual model from Section 4 was represented numerically based on the following assumptions:

- The aquifer system at the Rum Jungle Mine Site can be subdivided into hydrostratigraphic units that represent either mine waste (i.e. waste rock and/or tailings) or the naturally-occurring bedrock aquifer;
- Each hydrostratigraphic unit can be represented as a single model layer with representative hydraulic properties (i.e. permeability, anisotropy, storage) and recharge can be estimated as a proportion of incident rainfall;
- Mine waste can be represented by a single model layer of variable thickness that is active only within the footprint of the Overburden Heaps or Dyson’s (backfilled) Open Pit, whereas the geological aquifer units can be represented by model layers with constant thicknesses across the model domain;
- Water movement in the hydrostratigraphic units follows Darcy’s law and hence can be modeled using the ‘equivalent porous medium’ approach, i.e. the use of effective (or ‘bulk’) hydraulic properties to approximate conditions in the aquifer;
- The flooded Open Pits can be represented by ‘specified head boundaries’ that are equivalent to observed water levels in the pit lakes during the simulation period;
- Shallow creeks and seepage areas within the model domain can be adequately represented by drain nodes that have been set below the ground surface and receive flows from the surrounding aquifer;
• Sections of the East Branch of the Finnis River downstream of gauge GS8150200 can be represented by ‘specified head boundaries’ that are nearly equivalent to observed groundwater levels in bores near the river.

These assumptions and other aspects of the numerical representation of the conceptual model are explained in more detail in the sub-sections below. Also described is our rationale for employing a finite difference model and any model parameters set prior to beginning the calibration process.

5.2 CODE SELECTION

Groundwater flow at the Rum Jungle Mine Site was simulated with a finite difference model called MODFLOW-2000 that was developed by the United States Geological Survey (Harbaugh et al., 2000). MODFLOW has been rigorously evaluated and is periodically updated since it was first published in 1984 and is widely-used by governmental and non-governmental agencies worldwide to simulate saturated flow in porous media.

For the current model, the Layer Property Flow (LPF) flow package and the Preconditioned Conjugate Gradient 2 (PCG2) solver were used to solve the flow matrix (see Hill, 1990). The LPF package involves assigning hydraulic properties to individual cells based on their location within a particular layer of the model domain. The critical assumption of this approach is that every cell within a particular section of a layer is assigned the same set of hydraulic properties and that any localized heterogeneity is subsumed into the bulk permeability of a zone. There is, however, no limit to how finely a layer can be discretized horizontally into rectangular ‘cells’ but each layer of a finite difference grid is necessarily one cell thick.

For the Rum Jungle Mine Site, MODFLOW was run transiently and hence recharge was applied on a month-by-month basis over the course of the simulation period. A transient model was used to simulate the pronounced seasonality in groundwater levels (and flows) at the site. This approach was judged to provide greater accuracy and confidence in model calibration as well as in prediction of various rehabilitation options during subsequent stages of the Phase 3 groundwater investigations.

For the current model, all drainage features (i.e. groundwater discharge to rivers, seepage faces, etc.) were modeled using the drain (DRN) package as opposed to the river (RIV) package (see Section 5.7 for additional details). Also used were the recharge (RCH), time-variant specified head (CHD), and the horizontal flow barrier (HFB) packages, which are each described in subsequent sections as necessary.

Groundwater extraction due to pumping of private production bores was assumed to be negligible at the scale of the model domain. The process of evapotranspiration was not explicitly modeled but is implicitly included in the model by the use of “net recharge”.

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5.3 MODEL BOUNDARIES & DISCRETIZATION

5.3.1 Model Domain

Boundaries of the numerical model domain are shown in Figure 5-1. Recall that the model domain was defined by topographic highs and low-lying drainage lines (creeks) such that cross-boundary flows into or out of the groundwater system could be assumed to be negligible. For this reason, net recharge by rainfall and inflows from the flooded Open Pits are the only sources of water to the groundwater system within the model domain, whereas any outflows are accounted for by groundwater discharge.

5.3.2 Spatial Discretization

The numerical model domain was spatially discretized into a 3-dimensional grid with a uniform grid spacing of 25 m (see Figure 5-2). In planar view, each cell is therefore represented by a 25 m x 25 m square, whereas the thickness of the cells depends on the number of layers used to vertically discretize the model domain.

Initially, 3-layer and 4-layer models were developed and partially-calibrated but the model domain was ultimately discretized as a 6-layer model (i.e. the finite difference grid is 6 cells thick). Layer thicknesses are summarized as follows:

- Layer 1: waste rock and/or tailings (variable thickness)
- Layer 2: 0 to 7.5 m
- Layer 3: 7.5 to 15 m
- Layer 4: 15 to 45 m
- Layer 5: 45 to 105 m
- Layer 6: 105 to 150 m

Current topography at the Rum Jungle Mine Site was used to define the top of Layer 1 and the top of Layer 2 outside of the footprints of the Overburden Heaps and Dyson’s (backfilled) Open Pit. Figure 5-3a shows a plan view of current ground elevations across most of the model domain and side views of these elevations in the central mine reach and Dyson’s Area are provided in Figures 5-3b and 5-3c, respectively.

Within the footprints of these mine waste units, the top of Layer 2 was defined by the pre-mining ground elevation in that area. This means that the thickness of Layer 1 represents the difference between current and pre-mining ground elevations (and hence is variable). The tops and bottoms of Layers 3 to 6 are offset by the thicknesses listed above and hence are fixed throughout the model domain (see e.g. Figure 5-4).
Layer 1 is only active within the footprints of the Overburden Heaps and Dyson’s (backfilled) Open Pit. Active cells for Layer 1 are shown in Figure 5-4 with vertical cross-sections for the Main Overburden Heap and Dyson’s (backfilled) Open Pit. For Dyson’s Open Pit, the portion of the backfilled pit that lies above the pre-mining ground surface was represented by cells from Layer 1 and deeper zones of the backfilled pit were represented in Layers 2, 3, and 4. This implies that a mixture of tailings, waste rock, and contaminated soils fills the volume of the pit from current ground surface to 45 m bgs within the footprint of the pit (which corresponds to the total depth reached during mining operations).

Layers 2 to 6 were active throughout the model domain except for within the boundaries of the three open pits (see Figures 5-5 to 5-8). Inactive cells in these layers represent mined out portions of the model domain that are now flooded with surface water and hence not part of the groundwater system (see Section 5.5.1 for more details).

5.3.3 Temporal Discretization

The simulation period was temporally discretized into 40 stress periods that each represent one month. The period of interest is the 16 month period from August 1, 2010 to December 1, 2011. The 24 stress periods prior to August 2010 were added solely to approach initial conditions consistent with the assumed recharge conditions. Note that the model is fully-initialized at the onset of the last 16 months.

A constant initial water level of 90 m AHD was assumed across the model domain as an initial condition. Recharge rates and other time-varying inputs (e.g. open pit water levels) for the first 24 stress periods were based on data for the 2010/2011 wet season. Recharge

The final distribution of hydrostratigraphic units used to assign recharge rates (and hydraulic properties) to the model domain is shown in Figure 5-9. Recharge rates were initially assigned solely by lithology as per our conceptual model (i.e. one recharge polygon per lithologic unit) but rates were later modified as part of the calibration process. Also modified during calibration was the number of recharge polygons per lithologic unit, which allowed higher or lower recharge rates to be applied to areas within a lithologic unit to better match observed water levels. These aspects of recharge to the model domain are considered part of the calibration process and are therefore explained in more detail in Section 6.

Groundwater recharge to the bedrock aquifer in undisturbed areas of the Rum Jungle Mine Site and the mine waste units was estimated as follows:

- Total rainfall accumulation for the 2010/2011 wet season was estimated from measurements collected from the gauge atop the Main Overburden Heap;
An amount of rain needed to ‘wet up’ the unsaturated zone during the early wet season was subtracted from the total rainfall accumulation to yield an estimate of net rainfall; and then Net rainfall was multiplied by a percentage infiltration rate to yield a “net recharge rate”.

Total rainfall to the gauge atop the Main Overburden Heap was 2,576 mm for the 16-month simulation period (Table 5-1). Net rainfall was estimated to be 2,372 mm by subtracting the average amount of rainfall that accumulates during the early wet season before an increase in the water level at bore RN022081 is observed. Water levels in this bore have been monitored continuously for 20 years or so but no data for the 2010/2011 wet season was available (and hence a long-term average of 102 mm was used). Note that this amount was also subtracted from the 110 mm of rainfall recorded at the Batchelor Airport in the early 2011/2012 wet season.

### Table 5-1.

<table>
<thead>
<tr>
<th>Wet season</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total rainfall</td>
<td>0</td>
<td>36</td>
<td>138</td>
<td>84</td>
<td>322</td>
<td>578</td>
<td>697</td>
<td>382</td>
<td>96</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>110</td>
<td>133</td>
</tr>
<tr>
<td>Net rainfall</td>
<td>0</td>
<td>0</td>
<td>72</td>
<td>84</td>
<td>322</td>
<td>578</td>
<td>697</td>
<td>382</td>
<td>96</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

Recharge rates for the Overburden Heaps and the naturally-occurring aquifer in undisturbed areas of the model domain are shown in Figure 5-10. Time steps for recharge to the Overburden Heap and the Coomalie Dolostone are also illustrated Figures 5-11. Note that each ‘step’ shown in this figure represents a single stress period (i.e. one of the 16 months under consideration) and that the pattern of recharge is identical for all of the lithologic units.

### 5.4 SOURCES & SINKS

#### 5.4.1 Flooded Open Pits

Heads in cells from Layers 2, 3, and 4 that are intersected by the perimeters of the Main and Intermediate Open Pits were specified using a transient head boundary. These cells represent the bedrock aquifer that is in contact with standing water within the pits and were assigned a head that is equal to the geodetic elevation of the water level in the pit lakes (see Figure Table 5-2 and Figure 5-12). Note that flows within the flooded Open Pits themselves are not simulated by the model so cells within the transient head boundary were set to be inactive.
Table 5-2.

Specified heads for the flooded Open Pits and the East Branch of the Finniss River

<table>
<thead>
<tr>
<th>Date</th>
<th>Flooded Open Pits, in m AHD</th>
<th>East Branch of Finniss River, in m AHD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Main</td>
<td>Intermediate</td>
</tr>
<tr>
<td>August-10</td>
<td>59.5</td>
<td>57.3</td>
</tr>
<tr>
<td>September-10</td>
<td>59.4</td>
<td>57.2</td>
</tr>
<tr>
<td>October-10</td>
<td>59.3</td>
<td>56.9</td>
</tr>
<tr>
<td>November-10</td>
<td>59.8</td>
<td>57.4</td>
</tr>
<tr>
<td>December-10</td>
<td>60.2</td>
<td>57.9</td>
</tr>
<tr>
<td>January-11</td>
<td>60.5</td>
<td>58.5</td>
</tr>
<tr>
<td>February-11</td>
<td>60.8</td>
<td>58.7</td>
</tr>
<tr>
<td>March-11</td>
<td>61.1</td>
<td>58.9</td>
</tr>
<tr>
<td>April-11</td>
<td>60.4</td>
<td>58.4</td>
</tr>
<tr>
<td>May-11</td>
<td>60.1</td>
<td>58.0</td>
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<tr>
<td>June-11</td>
<td>59.9</td>
<td>57.7</td>
</tr>
<tr>
<td>July-11</td>
<td>59.6</td>
<td>57.5</td>
</tr>
<tr>
<td>August-11</td>
<td>59.5</td>
<td>57.3</td>
</tr>
<tr>
<td>September-11</td>
<td>59.4</td>
<td>57.2</td>
</tr>
<tr>
<td>October-11</td>
<td>59.3</td>
<td>57.1</td>
</tr>
<tr>
<td>November-11</td>
<td>59.3</td>
<td>57.1</td>
</tr>
</tbody>
</table>

Heads in cells along the edge of the Browns Oxide Open Pit were assigned based on water level data collected by HAR Resources (J. Hill, personal communication). Specifically, pit water levels and groundwater levels at bore TPB5 were used to represent the open pit via a transient head boundary (see Figure 5-12b). Note that the water level in the Browns Oxide pit varies primarily as a result of de-watering (as opposed to seasonal variations in rainfall and river flow) and hence the pattern in water levels differs from that of the Main and Intermediate Open Pits.

The Browns Oxide Open Pit is not completely flooded so heads were only specified for cells in Layers 3 and 4. Specifically, a ring of transient head cells was placed in Layer 3 (see Figure 5-6) and heads across the entire footprint of the pit were assigned to cells in Layer 4 (see Figure 5-7). Note that heads were not specified for cells at the bottom of the Main Open Pit (in Layer 5) because the portion of the pit that lies in Layer 5 (from 45 to 105 m bgs) was assumed to be backfilled with low-K tailings.

5.4.2 Groundwater discharge to creeks, seepage areas, and the EBFR

Relatively shallow creeks, engineered drainage features, and areas where seepage is known to express itself at ground surface are represented by drain nodes in Layers 1 and 2 of the model (see Figures 5-4 and 5-5). Drain nodes can only receive groundwater discharge from the simulated groundwater system and are characterized by a geodetic elevation and a conductance that represents the ease with which water can flow to the drain node from the surrounding aquifer.
Drain conductances across the model domain were typically set to one or two orders of magnitude higher than K values for the surrounding aquifer (values not provided). In other words, groundwater discharge was assumed to be solely controlled by the permeability of the surrounding aquifer material. Drain elevations across the model domain were set to 1 m below ground surface based on the DTM provided by DoR. Drains in Layer 2 were intended to represent groundwater discharge to the East Branch of the Finniss River in Dyson’s Area, Fitch Creek, the EFDC, Wandering Creek, and Old Tailings Creek amongst numerous other shallow drainage features within the model domain. Drains in Layer 1, on the other hand, were placed along the edges of the Overburden Heaps and Dyson’s (backfilled) Open Pit to allow discharge of shallow seepage along the side slopes of the mine waste units.

The East Branch of the Finniss River downstream of gauge GS8150200 is a major discharge zone for groundwater and was represented by a combination of drains and cells with transient heads assigned to them based on groundwater levels observed in nearby bores (see Figure 5-5).

Groundwater levels at bores PMB8D, RN023302, and PMB21 were used to estimate the water level in the East Branch of the Finniss River along various sections of the river (see Table 5-2). Note that the value of the specified head is less than the observed groundwater level due to some assumed head loss in the aquifer between the bore and the river.

5.5 CONVERGENCE CRITERIA

Using matrix solution techniques, MODFLOW simultaneously calculates the solution of large sets of algebraic equations and then iterates accordingly until the model converges on a 'good' solution. For the current model, the head change criterion used for the iterative solution technique was set to 1 cm but the model did not converge to a single solution. However, a detailed inspection of the transient flow solution indicated that non-convergence was caused by minor wetting-drying issues for cells in Layers 2 and 3. Furthermore, the simulated hydraulic head solution was plausible and the water balance was acceptable (less than 0.5% error). It was therefore concluded that the transient flow solutions are acceptable.
6 MODEL CALIBRATION & VALIDATION

The numerical flow model for the Rum Jungle Mine Site was calibrated to monthly groundwater level data for a selection of bores monitored since December 2010. Bore locations are shown in Figure 6-1 and geodetic water levels for these bores are provided in Appendix C.

6.1 CALIBRATION METHODS

During model calibration the principle of parsimony was followed, i.e. an attempt was made to keep the model complexity to a minimum. Initially, the model domain was therefore discretized solely on the basis of lithology and estimates of recharge, horizontal and vertical hydraulic conductivity (K_h and K_v, respectively), specific storage (S_s), and specific yield (S_y) from our conceptual model were assigned. The model was then calibrated by manually adjusting recharge and the aquifer properties within an acceptable range in order to fit simulated water levels to observed water levels.

The quality of the fit between simulated and observed water levels was visually evaluated based on the geodetic elevation of the simulated water level and the early wet season response of the simulated water level to recharge (and not by means of a statistical analysis). This approach enabled deeper bores or bores in high-priority areas (i.e. near the Overburden Heaps and north of the flooded Open Pits) to be given more weight than very shallow bores or bores located upgradient of the central mine reach at the discretion of the modeler.

During the calibration process, the large zones (polygons) used initially to represent entire lithologic units were further subdivided to represent local differences in hydraulic properties within the unit. This process was crucial to model calibration because the bedrock aquifer at the Rum Jungle Mine Site is characterized by substantial heterogeneity due to weathering and/or fractures. We did, however, elect to delineate polygons based primarily on local topography or known fault zones rather than arbitrarily assigning polygons to individual bores. In some areas, this decision led to some sacrifices in terms of the quality of fit but this approach was judged to be more consistent with our current level of confidence in our conceptual model and the availability of water level data (for only a single wet season).

6.2 CALIBRATED RECHARGES & HYDRAULIC PROPERTIES

Calibrated hydraulic properties and net recharge values for the mine waste units and the bedrock aquifer are provided in Appendix C.

6.2.1 Mine waste

The key aspects of the calibrated recharge rates and hydraulic properties for the Overburden Heaps and Dyson's (backfilled) Open Pit are summarized as follows:
The Overburden Heaps represent preferential recharge areas so rainfall infiltration was assumed to be higher than in undisturbed areas; specifically, 25% of net rainfall (593 mm) was simulated to infiltrate into waste rock in the Main and Intermediate Overburden Heaps and 50% (1186 mm) infiltrated into waste rock in Dyson’s Overburden Heap because it was only partially covered during rehabilitation;

Waste rock in the Overburden Heaps is inferred to be relatively permeable \( (K_H = \sim 5 \times 10^{-5} \text{ m/s}) \) and characterized by higher specific yields than bedrock aquifer units \( (i.e. S_Y = 15 \text{ to } 25\%) \); the mixture of waste rock, tailings, and contaminated soils used to backfill Dyson’s (backfilled) Open Pit is inferred to be much less permeable by comparison \( (i.e. K_H = 2 \times 10^{-7} \text{ m/s}) \) due to the presence of fine tailings in the mixture;

Waste rock and tailings backfill are characterized by higher vertical anisotropy than the bedrock aquifer \( (i.e. K_H > K_V) \), which implies that the movement of water downward through mine waste is more restricted than movement in the horizontal direction; the relative magnitudes of \( K_H \) and \( K_V \) are not well-known however and anisotropy ratios are not very well constrained in the current model.

It should be noted that the lack of flow data (in particular seepage flows from overburden heaps) for model calibration introduces some uncertainty. Without such calibration targets, the model calibration is non-unique, i.e. alternative combinations of recharge and hydraulic properties may explain the observed groundwater levels equally well.

This aspect of model calibration and its implications for seepage loads are discussed in more detail in Section 6.6 as part of the sensitivity analysis.

### 6.2.2 Bedrock aquifer

Calibrated K values for layers 2 and 3 are shown in Figure 6-2. The key aspects of the calibrated recharge rates and hydraulic properties for the bedrock aquifer units are summarized as follows:

- The Coomalie Dolostone is the most permeable aquifer unit; K values are estimated to reach \( 1.5 \times 10^{-4} \text{ m/s} \) in permeable zones north of the central mine reach (near bores RN022107 and PMB14) and recharge was typically 20% of net rainfall;
- The Whites Formation is inferred to be an order-of-magnitude or more less permeable than the Coomalie Dolostone \( (i.e. K_H = 10^{-5} \text{ m/s}) \); this unit is typically more permeable in the central mine reach than in the area west of the Main Open Pit and in Dyson’s Area;
- The Geolsec Formation is estimated to be the least permeable of the bedrock aquifer units \( (i.e. K_H < 1 \times 10^{-6} \text{ m/s}) \); of particular interest are the low K values in shallow zones of the aquifer in Dyson’s Area and near the Main Open Pit, which tend to increase water levels and isolate the Main Open Pit from the Coomalie Dolostone;
• The Rum Jungle Complex is typically characterized by relatively low K values, in particular at
greater depth (where secondary permeability is inferred to be very low) and near the
northeast corner of the Main Overburden Heap (at bores RN022037, RN025172, and
RN025173); shallow zones of the bedrock aquifer east of the Main Overburden Heap
towards Fitch Creek (at bore RN022083) are relatively permeable due to weathering.

6.3 SIMULATED GROUNDWATER LEVELS

6.3.1 Overview

Simulated groundwater levels and calibration targets are illustrated in Figures 6-3 to 6-8 and
simulated groundwater flow fields for April 2011 (wet season) and September 2011 (dry season) are
shown in Figures 6-9 and 6-10, respectively.

Groundwater generally flows from topographic highs towards the central mine reach and the East
Branch of the Finniss River. In many lowland areas, the groundwater table is predicted to reach the
ground surface during the wet season which is represented as “flooded cells” in the MODFLOW
simulation. Flooding in these areas is reasonable as they often correspond to floodplains and
swampy areas near the East Branch of the Finniss River.

Some flooding also occurs in upland areas at the height of the wet season in March and April. This
temporal flooding may be indicative of a relatively poor match between local recharge rates and local
K values during the peak of the wet season. However, a further adjustment of the seasonal
distribution of the recharge rates and/or an introduction of a shallow soil/bedrock layer with higher K
was beyond the scope of this study and not considered essential to meet the overall objectives of this
study.

Simulated groundwater levels in upland areas, near the major mine waste units, and downgradient of
the central mine reach are discussed in the sub-sections below.

6.3.2 Upland Areas

The major flows of unimpacted groundwater towards the central mine reach originate in the higher-
elevation areas near the northeast and southwest boundaries of the model domain. The bedrock
aquifer in these areas is comprised of the Coomalie Dolostone and large seasonal variations in
groundwater levels are observed (i.e. 7 to 8 m difference between dry and wet season water levels).

Bores RN022547, RN022548, and RN023304 were installed as production bores during mining
operations and bore RN022085 is a monitoring bore installed in the 1980s. Groundwater levels for
each of these bores was well-simulated by the model (see Figure 6-3). Note that the excellent fit
between observed and simulated water levels in upland areas required the use of a low specific yield
(Sy) which increases the response of the simulated groundwater system to recharge and enables the
recession of groundwater levels in the early dry season to be accurately simulated. Higher $S_y$ values used in Coffey (2006) to simulate groundwater flows to the Browns Oxide Open Pit yielded unsatisfactory results so the relatively low storage values obtained in our calibration are considered more representative of local conditions.

### 6.3.3 Dyson’s Area

The highest ground elevations within the model domain occur east of the Main Open Pit towards Dyson’s Area. Groundwater levels in this area are highest near the top of the hill above Dyson’s Area and groundwater tends to flow westward towards the Main Open Pit or south towards the East Branch of the Finniss River (see Figures 6-9 and 6-10).

Dyson’s Open Pit was dug into the southern slope of this hill between the top of the hill and the upper East Branch of the Finniss River. Groundwater flowing westward is only modestly impacted by ARD, as contaminants from Dyson’s (backfilled) Open Pit are delivered primarily to the East Branch of the Finniss River via shallow groundwater flows or surface seepage near the southern batter of Dyson’s (backfilled) Open Pit.

Flows of shallow, highly-impacted groundwater from Dyson’s (backfilled) Open Pit towards the upper East Branch of the Finniss River in Dyson’s Area are illustrated via a flowpath analysis in Figure 6-10a. Groundwater quality data are consistent with the results of the flowpath analysis, as shallow groundwater south of Dyson’s (backfilled) Open Pit is highly-impacted but groundwater further west contains only modest levels of contaminants. This pattern of contaminant transport is explained mainly by local topography but also the low permeability of the deeper bedrock aquifer in Dyson’s Area (which limits the rate of contaminant transport via deeper groundwater).

Groundwater levels near Dyson’s Overburden Heap were simulated to mound up during the wet season due to high recharge to the heap and the presence of relatively impermeable granite beneath the heap. Groundwater levels in the river channel near Dyson’s Overburden Heap are generally close to ground surface and do not vary considerably over the course of the wet season. This lack of seasonality was well-simulated in the model as drain nodes that represent the upper East Branch of the Finniss River tend to dictate groundwater levels in the vicinity of the heap.

In summary, groundwater south of Dyson’s (backfilled) Open Pit and near Dyson’s Overburden Heap is typically highly-impacted by flows from those heaps but contaminants do not appear to be transported beyond Dyson’s Area in deeper zones of the bedrock aquifer. Hence the majority of contaminant loads from this area are delivered to the upper East Branch of the Finniss River via shallow groundwater discharge and ultimately represented in surface water loads downstream at gauge GS8150200 (see Section 7 for additional discussion).
6.3.4 Near the Main & Intermediate Overburden Heaps

Groundwater flow fields south of the EFDC are strongly influenced by the presence of the Main and Intermediate Overburden Heaps. Of particular interest is the ‘mounding’ of groundwater levels that occurs near the Main Overburden Heap and the radial flow of groundwater away from the heap towards Fitch Creek, Wandering Creek, and the EFDC. This ‘mounding’ is particularly apparent during the wet season (see Figure 6-9) and from the flowpath analysis shown in Figure 6-11b.

The 'mounding' of groundwater levels near the Main Overburden Heap is caused by the low permeability of the Rum Jungle Complex directly beneath the heap and the consequent lack of downward flow into the deeper portions of the bedrock aquifer. In contrast, very little mounding occurs near the Intermediate Overburden Heap because it is underlain by more permeable bedrock of the Coomalie Dolostone and the Whites Formation.

Other key aspects of simulated groundwater flows in this area are summarized as follows:

- Unimpacted groundwater tends to flow northeast from the area near bores RN025165 and RN025167 towards Fitch Creek and bore RN022083; groundwater level variations at bore RN022083 are strongly influenced by flows from the Main Overburden Heap, which is consistent with the highly-impacted condition of groundwater from this bore;
- Groundwater levels near the perimeter of the Main Overburden Heap (at bores RN022084, RN022411, RN029993 and bores PMB3/4) tend to be relatively consistent year-round, as levels in the wet season are often only 1 m or so higher in the wet season than the dry; water levels in these bores were well-simulated by the model due to their proximity to drains (i.e. Wandering Creek, the EFDC, or the seepage area northeast of the Main Overburden Heap);
- Observed groundwater levels for bore RN022082D (beneath the Main Overburden Heap) are consistently around 71 m AHD and no seasonal variation is evident; because recharge to the heap was assumed to be highly-seasonal, this pattern could not be simulated by the model without compromising the fit between observed and simulated water levels at RN022083 and further upgradient near bore RN025167;
- Groundwater levels between the Main and Intermediate Overburden Heaps (at bores RN025172, RN025173, and RN022037) showed a similar degree of seasonality as those located near the southern and eastern edges of the Main Overburden Heap; local hydraulic gradients suggest that groundwater flows towards the Intermediate Overburden Heap and that the Main Overburden Heap is the major source of flows/contaminant loads (which is consistent with our conceptual model of contaminant transport);
- Groundwater levels in the Coomalie Dolostone near the EFDC (at bores RN022039, RN022081, and RN023056) showed less seasonal variation than other bores screened in this unit of the bedrock aquifer; this dampening of seasonal variations suggests a hydraulic
connection between the Coomalie Dolostone in this area and the Main Open Pit, which is consistent with historic reports of highly-contaminated water from the Main Open Pit discharging to the EFDC via the Coomalie Dolostone;

- West of the Intermediate Overburden Heap, groundwater tends to flow from the south towards the Browns Oxide Open Pit and a cone of depression develops around this pit in the wet season (due to de-watering).

6.3.5 Near the former Copper Extraction Pad & flooded Open Pits

The Main and Intermediate Open Pits cut deeply into the bedrock aquifer in the central mining reach and hence groundwater levels in this area are strongly influenced by standing water levels in the pits. Note that water levels in the Main and Intermediate Open Pits co-vary due to surface flows between the two pits. The geodetic elevation of the water level in the Main Open Pit is usually about 2 m higher than the geodetic water level in the Intermediate Open Pit (see Figure 5-12a).

Groundwater levels in the former Copper Extraction Pad area are affected by water levels in both Open Pits and hence tend to vary seasonally between the low and high water levels in the pit lakes (i.e. 56 to 60 m AHD). Most of the bores in this area are screened in the Whites Formation close to the Intermediate Open Pit but a highly-permeable fault zone is assumed to connect the Open Pits and this fault tends to connect the entire area hydraulically.

The influence of the Intermediate Open Pit on groundwater levels in the Coomalie Dolostone is particularly apparent for bores RN022543, PMB7, and PMB16. Simulated groundwater levels for these bores mimic the water level in the Intermediate Open Pit because each is located close to the pit and is screened in the same highly-permeable Coomalie Dolostone that is intersected by the pit. The bedrock aquifer in this area is therefore simulated to be closely-connected to the Intermediate Open Pit. Bore PMB9D is also screened in this permeable zone of the bedrock aquifer but groundwater levels for this bore are also affected by water levels in the Browns Oxide Open Pit to the east (Figure 6-6).

The Coomalie Dolostone north of the former Copper Extraction Pad area is not well-connected to the Main Open Pit and hence simulated groundwater levels at bores PMB14 and RN022107 do not respond to changes in the water level in this pit. The lack of hydraulic connection is due to the Main Open Pit not intersecting the Coomalie Dolostone and the presence of low-K Geolsec Formation near the northern perimeter (which tends to shield the Coomalie Dolostone from the influence of the pit water levels).

Simulated groundwater levels at bores PMB14 and RN022107 are higher than water level in the Main Open Pit in the wet season but drop below the pit water level in the dry season. This implies a reversal in the horizontal hydraulic gradient in this area and indicates that the Main Open Pit receives
groundwater from the surrounding aquifer in the wet season but is a source of water to the aquifer in the dry season. This is consistent with our conceptual model and an important aspect of the water balance described in Section 6.4.

The flowpath analysis shown in Figure 6-12 provides some perspective on contaminant transport across the former Copper Extraction Pad area towards the East Branch of the Finniss River. This analysis involved the release of particles near the Main Open Pit and former Copper Extraction Pad under current conditions. Figure 6-11a shows that groundwater flows across the area between the flooded Open Pits and ultimately to the Intermediate Open Pit or passed the pit and towards the East Branch of the Finniss River. Groundwater flow in this area is influenced by a high-permeability fault zone that runs between the Main and Intermediate Open Pits. Specifically, groundwater near the former Copper Extraction Pad flows along the fault and ultimately discharges to the Intermediate Open Pit (which could explain poor water quality conditions at the bottom of the pit).

The current groundwater flow field is strongly-influenced by the de-watered Browns Oxide Open Pit and does not explain well the current distribution of contaminants near the Intermediate Open Pit (or further downgradient near PMB8D). Figure 6-12b shows the simulated flow field for the site prior to development of the Browns Oxide Open Pit. This historic flow field better explains the presence of impacted groundwater in the bedrock aquifer north of the Intermediate Open Pit (at bores PMB7 and PMB16) and implies that higher flows/loads could have reported to the East Branch of the Finniss River prior to development of the Browns Oxide Open Pit.

6.3.6 Old Tailings Dam area

Groundwater levels in the Coomalie Dolostone further west of bores PMB13 and PMB17 and towards the Old Tailings Dam area are not affected by water levels in the flooded Open Pits and hence vary solely as a result of seasonal recharge. These bores are screened in the same highly-permeable Coomalie Dolostone that is closely-connected to the Intermediate Open Pit so the lack of hydraulic connection is merely due to the distance that separates them from the pit. In general, this area is characterized by very weak horizontal hydraulic gradients that facilitate the westward flow of groundwater from the high-elevation area to the east towards the East Branch of the Finniss River.

Groundwater in the vicinity of bore PMB13 and PMB17 is characterized by modestly-elevated levels of SO$_4$ and low concentrations of dissolved metals that typify a TDS plume. This TDS plume could have originated in the Old Tailings Dam or near the old plant site near the Main Open Pit. The current groundwater flow field suggests contaminants from the old plant site is more likely and that a tailings-derived TDS plume is likely restricted to the area near Old Tailings Creek and bores PMB18 and PMB19.
6.3.7 **East Branch of the Finniss River near Old Tailings Creek**

The East Branch of the Finniss River downstream of gauge GS8150200 is a major discharge zone for groundwater so groundwater levels near the river channel are lower than in the bedrock aquifer upgradient.

Groundwater flow fields north of the central mine reach suggest westward flow across the model domain (parallel to Former Copper Creek) and not northward from the central mine reach. These flow fields and groundwater quality conditions in the bedrock aquifer suggest that most of the groundwater that discharges to the East Branch of the Finniss River is likely unimpacted by ARD. Some modestly-impacted groundwater may discharge to the East Branch of the Finniss River immediately downstream of the road bridge (west of bore PMB16) but it is unlikely that the river course west of bore PMB8D receives a considerable load of contaminated groundwater. This may not have been the case prior to development of the Browns Oxide Open Pit due to differences in the groundwater field at that time.

6.4 **Simulated Water Balance**

Simulated annual inflows and outflows to the model domain are summarized in Table 6-2 and monthly inflows and outflows to the three open pits and the East Branch of the Finniss River are shown in Figure 6-13.

Positive numbers denote an inflow to the groundwater system, such as recharge or flows from one of the open pits. Negative numbers represent an outflow from the groundwater system (i.e. groundwater discharge). Net fluxes in Table 6-2c are the difference between annual inflows and outflows for a particular component of the water balance and indicate whether that component is a net source or sink with respect to groundwater.

Total annual inflow to the groundwater system from the beginning of August 2010 to the end of July 2011 was \(4.9 \times 10^8\) L (or 156 L/s). No change in storage was assumed to occur over the course of year so roughly the same amount of water flows from the groundwater system. Total inflow to the numerical model domain was about 2.8 times higher than the lower bound estimate from our conceptual groundwater budget and 1.5 times higher than the upper bound estimate (see Table 4-2). These higher inflows were due to the higher recharges needed to calibrate the model in areas comprised of the Coomalie Dolostone and the Rum Jungle Complex near the Main Overburden Heap.
Table 6-2a.

Inflows to the simulated groundwater system

<table>
<thead>
<tr>
<th></th>
<th>L/s</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge to undisturbed areas</td>
<td>120</td>
<td>77%</td>
</tr>
<tr>
<td>Recharge to mine waste units</td>
<td>13</td>
<td>8%</td>
</tr>
<tr>
<td>Inflows from the Intermediate Open Pit</td>
<td>11</td>
<td>7%</td>
</tr>
<tr>
<td>Inflows from the Main Open Pit</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>Inflows from the Browns Oxide Open Pit</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Inflows from the East Branch of the Finniss River</td>
<td>6</td>
<td>4%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>156</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 6-2b.

Outflows from the simulated groundwater system

<table>
<thead>
<tr>
<th></th>
<th>L/s</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge to creeks &amp; tributaries</td>
<td>-73</td>
<td>47%</td>
</tr>
<tr>
<td>Discharge to the East Branch of the Finniss River</td>
<td>-44</td>
<td>28%</td>
</tr>
<tr>
<td>Discharge to the Browns Oxide Open Pit</td>
<td>-23</td>
<td>15%</td>
</tr>
<tr>
<td>Flows captured by drains near the mine waste units</td>
<td>-12</td>
<td>8%</td>
</tr>
<tr>
<td>Discharge to the Intermediate Open Pit</td>
<td>-4</td>
<td>3%</td>
</tr>
<tr>
<td>Discharge to the Main Open Pit</td>
<td>-1</td>
<td>1%</td>
</tr>
<tr>
<td>OUT</td>
<td>-157</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 6-2c.

Net flows to and from the groundwater system

<table>
<thead>
<tr>
<th></th>
<th>L/s</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Open Pit</td>
<td>4</td>
<td>n/a</td>
</tr>
<tr>
<td>Intermediate Open Pit</td>
<td>7</td>
<td>n/a</td>
</tr>
<tr>
<td>Browns Oxide Open Pit</td>
<td>-22</td>
<td>n/a</td>
</tr>
<tr>
<td>East Branch of the Finniss River</td>
<td>-38</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Key aspects of the water balance are summarized as follows:

- The Main and Intermediate Open Pits are net annual sources of water to the groundwater system; specifically, net annual flows to groundwater from the Main and Intermediate Open Pits are 4 L/s and 7 L/s, respectively; higher flows from the Intermediate Open Pit are related to its strong hydraulic connection to highly-permeable zones of the Coomalie Dolostone and less seasonality in flows compared to the Main Open Pit (which is a source of water to the
bedrock aquifer in the dry season but receives a net inflow of groundwater in the wet season);

- The Browns Oxide Open Pit receives a net annual inflow of 22 L/s and hence is a major discharge zone for groundwater due to active de-watering; note from Figure 6-12 that groundwater discharge to the pit is highest in the wet season when groundwater levels in the vicinity of the pit rise (and more pumping is needed);

- Annual groundwater discharge to the East Branch of the Finniss River downstream of gauge GS8150200 was simulated to be 44 L/s; minor flows from the river to the groundwater occur during the wet season but fluxes are small by comparison to groundwater discharge and likely an artifact of small inconsistencies between local topography and assumed drain elevations along the river reaches;

- Groundwater discharge to the various creeks and tributaries of the East Branch of the Finniss River represents 73 L/s; most of this flow is attributed to Fitch Creek, the upper East Branch of the Finniss River in Dyson’s Area and Old Tailings Creek but Wandering Creek and the EFDC are also significant discharge zones for groundwater;

- Shallow drains near the major mine waste units capture 12 L/s of toe seepage and shallow groundwater; flows from the Main Overburden Heap and Dyson’s Overburden Heap account for half of this annualized flow (4 L/s and 2 L/s, respectively); flows from the Intermediate Overburden Heap and Dyson’s (backfilled) Open Pit both represent less than 1 L/s.

### 6.5 Model Validation – Pit De-Watering Trial

In late 2008, HAR Resources conducted a large-scale de-watering trial that involved drawing down the water level in the Intermediate Open Pit and monitoring groundwater levels at bores RN022107, RN022108, and RN022081. The response of the groundwater system to de-watering the pit was simulated to validate the current numerical model.

Aspects of the pit de-watering trial that are pertinent to model validation are summarized as follows:

- The water level in the Intermediate Open Pit was pumped down to 46 m AHD (or ~10 to 12 m below its typical level) over a 3.5-month period from August 29 to December 18, 2008;

- Groundwater levels at bore RN022108 were drawn down in tandem with the water level in the Intermediate Open Pit, which suggests a direct hydraulic connection between the pit and the Coomalie Dolostone at this location; note that bore RN022108 was a 55-m deep open-hole bore in 2008 but has since been retrofitted with a pair of nested bores (i.e. bores PMB9S and PMB9D);

- Electrical conductivity (EC) values for groundwater collected from bore RN022108 during the pumping test increased from ~400 uS/cm at the start of the test to 2,600 uS/cm when pumping ceased in December 2008; groundwater pumped near the end of the test is
consistent with samples collected from bore PMB9D, which suggests contaminated groundwater in the deep bedrock aquifer between this bore and the Intermediate Open Pit; samples from PMB9S are representative of the shallower groundwater collected during the early stages of the pumping test;

- Groundwater levels at bore RN022107 were drawn down by 0.7 m during the de-watering trial; this bore is screened in a zone of the Coomalie Dolostone that is only weakly-connected to the Intermediate Open Pit;
- Groundwater levels at bore RN022081 (located to the south of the Intermediate Open Pit) were only slightly affected by drawing down the water level in the Intermediate Open Pit (i.e. a 0.3 m drawdown over the course of the de-watering trial); this small drawdown is indicative of a relatively weak hydraulic connection between the Intermediate Open Pit and the finger of the Coomalie Dolostone screened by this bore.

Simulated groundwater flow fields for the 4 months of the pumping test are shown in Figure 6-14. Time trends of simulated and observed groundwater levels for bores monitored during the test are shown in Figures 6-15 and 6-16.

A cone of depression clearly develops around the Intermediate Open Pit during the de-watering trial. This cone of depression radiates outward from the pit and affects groundwater levels in the Coomalie Dolostone and Whites Formation near the pit but not groundwater levels in the Rum Jungle Complex.

Simulated groundwater levels at bore PMB9D were ultimately drawn down by a total of 5.2 m over the course of the pumping test (or slightly less than the 6.4 m observed in 2008) (see Figure 6-15). This suggests that the strong hydraulic connection that is known to exist between the Intermediate Open Pit and the Coomalie Dolostone is well-simulated by the model. The model also simulates the modest drawdown of groundwater levels at bore RN022107, which screens a zone of the Coomalie Dolostone that is only weakly-connected to the flooded Open Pits.

At bore RN022081, the total simulated drawdown over the course of the pumping trial was 1.5 m or about 1 m more than observed (Figure 6-16). The modest drawdown of groundwater levels at bore RN022081 suggests that the bedrock aquifer in this area is more strongly connected to the Main Open Pit than the Intermediate Open Pit. This is well-supported by historic water level data from bores RN022081 (which show that groundwater levels for this bore mimic water levels in the pit) and consistent with historic accounts of highly-contaminated water from the Main Open Pit discharging to the EFDC via the Coomalie Dolostone in the 1970s (see Davy, 1975).

In order to match the very limited drawdown observed in bore RN022081 a low-permeability fault zone had to be introduced along the contact between the Coomalie Dolostone and Whites Formation. This low-permeability fault zone was simulated in MODFLOW using a horizontal flow barrier (HFB). Overall, subjecting the groundwater system to the additional stress of pit de-watering has clearly
established that the major hydraulic connections between the Coomalie Dolostone and the flooded Open Pits are well-represented in the numerical flow model. Moreover, the validation process suggests that the current calibration is a reasonable approximation of current flow conditions at the Rum Jungle Mine Site and can be used to predict the response of the groundwater system for rehabilitation planning.

6.6 Sensitivity Analysis

A limited sensitivity analysis was completed to highlight the uncertainty associated with the current model calibration. Of particular interest are the sensitivities of toe seepage and groundwater discharge rates to calibrated recharge and hydraulic properties of the hydrostratigraphic units. To evaluate these sensitivities, the seven scenarios outlined in Table 6-3 were modeled. Simulated flow fields and water levels for the sensitivity analyses are provided in Appendix D and implications are discussed below.

<table>
<thead>
<tr>
<th>Run</th>
<th>Adjusted Model Parameters</th>
<th>Hydraulic Conductivity</th>
<th>Specific Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Calibrated model (see Appendix D)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toe seepage from the Main and Intermediate Overburden Heaps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Recharge to heaps divided by two</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Recharge for heaps divided by two</td>
<td>K values divided by two</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Recharge to heaps increased twofold</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Recharge to heaps increased twofold</td>
<td>K values increased twofold</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater discharge to the EBFR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Recharge to Coomalie D. divided by two</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Recharge to Coomalie D. divided by two</td>
<td>K values for Coomalie D. divided by two</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>-</td>
<td>S_y for Coomalie D. increased to 5% (from 2%)</td>
</tr>
</tbody>
</table>

Because groundwater flows radially outward from the Main Overburden Heap, flows to drains near this heap are comprised almost exclusively of toe seepage from the heap. For this reason, higher recharge leads to a near proportional increase in flows from the heap (and vice versa) (see Figure 6-17). Groundwater levels near the Main Overburden Heap, on the other hand, are relatively insensitive to assigned recharge as the configuration of drains near the heaps tends to capture additional flows (and thereby limit changes to groundwater levels).

Unlike the Main Overburden Heap, groundwater levels near the Intermediate Heap do not mound and hence flows to nearby drains consist mainly of groundwater from the upgradient bedrock aquifer. This explains why flows to drains near the Intermediate Heap are comparable to flows from the Main Overburden Heap and the sensitivity of flows from the Intermediate Overburden Heap to the
permeability of the bedrock aquifer upgradient. Other key results of the sensitivity analysis are summarized as follows:

- The observed degree of seasonality in water levels within the bedrock aquifer (e.g. at bore RN022083) cannot be simulated by assuming 10% recharge to the heaps and seepage flows for this low recharge/low K scenario seem implausibly low based on preliminary seepage flow measurements;
- Lowering K values for waste rock and the bedrock aquifer near the heaps caused considerable flooding near the heaps and lower toe seepage than the base calibration;
- High recharge to the Main and Intermediate Overburden Heaps enhanced the degree of seasonality in groundwater levels near the heaps and increased mounding near the Main Overburden Heap; seepage flows from the Main Overburden Heap increased twofold relative to the base calibration when recharge was increased to 50%, as the majority of the additional recharge to this heap is captured by drain flows; groundwater levels could be well-simulated if K values were increased to compensate for higher recharge and simulated toe seepage was reasonable (hence sensitivity run 4 represents a plausible scenario and cannot be discounted without additional field measurements of toe seepage from the heaps).

Simulated groundwater levels for Sensitivity Runs 5, 6, and 7 are shown with the base case calibration in Figure 6-18. In upland areas, reducing recharge to the Coomalie Dolostone for Sensitivity Run 5 caused simulated groundwater levels to decrease by 2 to 3 m and a smaller increase in groundwater levels during the wet season (see Figure 6-18a).

Decreasing K values to compensate for reduced recharge led to higher simulated water levels than the base case and a reasonable degree of seasonality in upland areas. Groundwater levels for sensitivity run 6 did not increase as quickly at the onset of the wet season and the recession of groundwater levels at the end of the wet season was not particularly well simulated. Simulated groundwater levels for this run were therefore considered a poorer fit to observed water levels and the higher recharges and corresponding K values for the base case calibration were preferred.

In the lowlands closer to the central mine area, differences between the simulated water levels for the sensitivity runs and the base case calibration were smaller in magnitude (see Figure 6-18b). This suggests less sensitivity to recharge and K values closer to the central mine reach due to the influence of the flooded Open Pits on groundwater levels in their vicinity. This lack of sensitivity and the reasonable degree of seasonality simulated by sensitivity runs 5 and 6 suggest that there are other plausible combinations of recharge and K values that could adequately simulate observed groundwater levels for the 2010/2011 wet season.

Of particular interest are results from sensitivity run 5, as groundwater discharge to the East Branch of the Finniss River for this run is 50% lower than the discharge for the base case calibration. These
flows are largely unimpacted and therefore have limited significance to rehabilitation planning. Moreover, they could only be refined by calibrating the numerical flow model to results from a large-scale pumping test or to surface water flows in the East Branch of the Finniss River downstream of gauge GS8150200.

6.7 MODEL LIMITATIONS

The groundwater system at the Rum Jungle Mine Site exhibits a high degree of seasonality and is affected by numerous geologic and anthropogenic features. As for any model, the complexity of these features had to be reduced in our conceptual model that preserves the key features but is simple enough to allow representation by a numerical model of groundwater flow.

Simplifying assumptions related to our conceptual flow model include using a fixed proportion of net monthly rainfall as a proxy for groundwater recharge, the discretization of the model domain into only six hydrostratigraphic layers, and the use of an equivalent porous medium approach for groundwater flow in the fractured bedrock aquifer. The use of these assumptions is not considered problematic at regional scales but may limit our ability to predict groundwater flow locally near the Overburden Heaps and Dyson’s (backfilled) Open Pit.

Re-calibration of the groundwater flow model with additional groundwater level data and seepage flow estimates would reduce the uncertainty that is currently related to recharge rates to the mine waste units and simulated toe seepage. Groundwater level and seepage flow data for the 2011/2012 wet season (which is so far quite dry) is be particularly useful in this regard, as the final calibration would include two very different wet seasons.
7  IMPLICATIONS FOR REHABILITATION

7.1  CONTAMINANT LOADS

Contaminant loads generated by the mine waste units report to the East Branch of the Finniss River via toe seepage or via groundwater that discharges to the river from the shallow bedrock aquifer. Toe seepage typically occurs in the following areas:

- Along the eastern and southwestern edges of the Main Overburden Heap
- At the northern edge of the Intermediate Overburden Heap (next to the EFDC)
- Near the southern toe of Dyson's Overburden Heap
- Near the toe drain along the southern edge of Dyson's (backfilled) Open Pit

Simulated toe seepage from the numerical model and seepage water quality data from Table 4-1 were used to estimate annual contaminant loads in toe seepage from the Main Overburden Heap, Dyson’s Overburden Heap, and Dyson’s (backfilled) Open Pit (see Table 7-1).

<table>
<thead>
<tr>
<th>Mine Waste Unit</th>
<th>Flow, ML</th>
<th>SO4</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>Ni</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Overburden Heap</td>
<td>200</td>
<td>1144</td>
<td>0.7</td>
<td>2.2</td>
<td>1.3</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Intermediate Overburden Heap</td>
<td>23</td>
<td>593</td>
<td>1.1</td>
<td>2.7</td>
<td>5.0</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Dyson's Overburden Heap</td>
<td>64</td>
<td>385</td>
<td>0.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.2</td>
<td>7.4</td>
</tr>
<tr>
<td>Dyson's (backfilled) Open Pit</td>
<td>24</td>
<td>152</td>
<td>1.8</td>
<td>3.2</td>
<td>0.1</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Total:</td>
<td>311</td>
<td>2275</td>
<td>3.6</td>
<td>9.1</td>
<td>6.5</td>
<td>4.2</td>
<td>10.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mine Waste Unit</th>
<th>Flow, ML</th>
<th>SO4</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>Ni</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Overburden Heap</td>
<td>200</td>
<td>50%</td>
<td>18%</td>
<td>25%</td>
<td>21%</td>
<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td>Intermediate Overburden Heap</td>
<td>23</td>
<td>26%</td>
<td>31%</td>
<td>30%</td>
<td>78%</td>
<td>49%</td>
<td>9%</td>
</tr>
<tr>
<td>Dyson's Overburden Heap</td>
<td>64</td>
<td>17%</td>
<td>1%</td>
<td>11%</td>
<td>0%</td>
<td>4%</td>
<td>73%</td>
</tr>
<tr>
<td>Dyson's (backfilled) Open Pit</td>
<td>24</td>
<td>7%</td>
<td>50%</td>
<td>35%</td>
<td>1%</td>
<td>29%</td>
<td>2%</td>
</tr>
<tr>
<td>Total:</td>
<td>311</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Contaminant loads in shallow groundwater were estimated from annualized groundwater flows and representative groundwater quality data. Flows of shallow groundwater represent the proportion of annual recharge to the mine waste units that is not expressed as toe seepage but ultimately reaches...
the East Branch of the Finniss River over multi-year time-scales. Near the Intermediate Overburden Heap, shallow groundwater and toe seepage could not be differentiated with the numerical flow model so half of the annual recharge to this heap was assumed to be toe seepage and the other half was assumed to be shallow groundwater.

Groundwater quality data for bore RN022082D was used to estimate contaminant loads in shallow groundwater near the Main Overburden Heap. Contaminant concentrations at bores RN023413 and PMB1b were used to estimate loads in shallow groundwater near Dyson’s Overburden Heap and Dyson’s (backfilled) Open Pit, respectively.

Contaminant concentrations in toe seepage from the Main Overburden Heap and mine waste units in Dyson’s Area are often lower than concentrations in groundwater. These lower concentrations imply that toe seepage collected at surface is not necessarily representative of total seepage from the mine waste unit (either due to dilution along shallow flowpaths or heterogeneity in leachate chemistry from mine waste). Moreover, high concentrations of metals in receiving groundwater near the Main Overburden Heap and in Dyson’s Area are indicative of the low buffering capacity of the Rum Jungle Complex.

Due to the higher buffering capacity of the Coomalie Dolostone and Whites Formation, metal concentrations in shallow groundwater near the Intermediate Overburden Heap are thought to be lower than observed in toe seepage. However, no groundwater quality data that is considered representative of buffered groundwater near the Intermediate Overburden Heap is available. SO₄ concentrations in seepage were therefore assumed to be representative of shallow groundwater and metal concentrations in seepage from the heap were reduced by half to approximate buffered groundwater near or beneath the heap.

Key aspects of the preliminary load estimates are summarized as follows:

- The Main Overburden Heap accounts for 50% of the estimated annual SO₄ load to the East Branch of the Finniss River and is estimated to be a major source of metals (i.e. 15 to 30%); these high loads are related to relatively high contaminant concentrations and large flows from the heap due to its large footprint area;
- The Intermediate Overburden Heap accounts for an estimated 25% of the annual SO₄ load to the East Branch of the Finniss River and is estimated to be a significant source of metals (~30% of Cu and Mn, 50% of Ni, and nearly 80% of Zn); high SO₄ and metal loads from the Intermediate Overburden Heap are consistent with the high sulphide content of waste rock in this heap (see SRK, 2012);
- Dyson’s Overburden Heap accounts for an estimated 15 to 20% of the annual SO₄ load from the mine waste units and close to 75% of the annual Fe load; this heap is estimated to be a
relatively minor source of other metals due in part to the nature of waste rock from Dyson's Open Pit (which was mined solely for U and not a suite of metals);

- Dyson's (backfilled) Open Pit is estimated to be a minor source of SO$_4$ but a major source of Cu, Mn, and Ni; these high loads are related to seepage from the mixture of highly-contaminated soils and heap leach material used to backfill the shallow portions of the open pit.

Annual contaminant loads from the mine waste units (this report) and average loads in the East Branch of the Finniss River for the mid-1990s are provided in Table 7-2.

### Table 7-2.

**Historic contaminant loads in the East Branch of the Finniss River and total loads from the major mine waste units (this report)**

<table>
<thead>
<tr>
<th>Source or Gauge</th>
<th>Flow, GL</th>
<th>SO$_4$</th>
<th>Cu Diss.</th>
<th>Cu Total</th>
<th>Mn Diss.</th>
<th>Mn Total</th>
<th>Zn Diss.</th>
<th>Zn Total</th>
<th>Ni Diss.</th>
<th>Ni Total</th>
<th>Fe Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooded Open Pits (net)</td>
<td>0.3</td>
<td>520</td>
<td>2.4</td>
<td>2.8</td>
<td>9.9</td>
<td>10.1</td>
<td>0.5</td>
<td>0.3</td>
<td>3.2</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td>GS8150200</td>
<td>34</td>
<td>3672</td>
<td>5.3</td>
<td>14.3</td>
<td>24.3</td>
<td>26.8</td>
<td>7.8</td>
<td>9.5</td>
<td>5.3</td>
<td>5.9</td>
<td>0.4</td>
</tr>
<tr>
<td>GS8150097</td>
<td>40</td>
<td>3864</td>
<td>5.2</td>
<td>12.4</td>
<td>23.0</td>
<td>25.3</td>
<td>6.4</td>
<td>7.7</td>
<td>4.8</td>
<td>5.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Mine Waste Units:</td>
<td>0.4</td>
<td>2275</td>
<td>3.6</td>
<td>9.1</td>
<td>6.5</td>
<td>4.2</td>
<td>10.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Net contaminant loads from the flooded Open Pits and loads at gauges GS8150200 and GS8150097 are from RGC (2011a)

Table 7-2 shows contaminant loads for the East Branch of the Finniss River estimated from total and dissolved metal concentrations. Total loads represent the dissolved load plus any particulate or suspended matter contained in the water samples prior to acidification. Total and dissolved loads of Mn, Ni, and Zn are comparable in magnitude but total Cu loads in the river are substantially higher than the dissolved Cu loads. This is likely due to particulate Cu being washed into the river from the heaps and/or additional dissolved loads of this metal (and SO$_4$) from the former Copper Extraction Pad area.

Estimated SO$_4$ and metal loads from the mine waste units are generally lower than average dissolved loads in the river. The discrepancies are likely related to a combination of the following factors:

- Additional loads from the flooded Open Pits (not included in the mine waste unit estimate);
- Additional loads from diffuse groundwater discharge or the discharge of more highly-impacted groundwater from the former Copper Extraction Pad area to the East Branch of the Finniss River;
- Uncertainty regarding the representativeness of historical loading estimates (from the mid-1990s) for current conditions in the East Branch of the Finniss River.
Each of these factors and the discrepancy between total and dissolved contaminants loads will be discussed in more detail in the Stage 3 report in which loads for the 2010/2011 wet season are presented and evaluated.

7.2 CONSIDERATIONS FOR REHABILITATION PLANNING

The fundamental objective of further rehabilitation at the Rum Jungle Mine Site is to minimize the impact of ARD on the water quality of the East Branch of the Finniss River by reducing loads from the mine waste units. Key issues to be considered for selection of a preferred rehabilitation strategy are as follows:

- The Main Overburden Heap has a footprint area of 30 ha and contains 70% (4 Mm$^3$) of the total waste rock stored in overburden heaps at the site; this heap accounts for about 50% of the annual SO$_4$ load to the East Branch of the Finniss River and 20 to 30% of annual metal loads; this heap is also underlain by bedrock with a low buffering capacity so metals do not attenuate naturally in groundwater near this heap;

- The Intermediate Overburden Heap occupies a relatively small footprint (8 ha) and contains 0.64 Mm$^3$ of waste rock (or about 10% of total waste rock in the heaps); this heap accounts for about 25% of the total SO$_4$ load from the mine waste units and is a significant source of Cu, Mn, Ni, and Zn to the East Branch of the Finniss River; groundwater near this heap is likely buffered to some extent by local bedrock but groundwater quality conditions around the heap are not particularly well-constrained;

- Dyson’s Overburden Heap occupies a footprint area of 9 ha and contains 20% of total waste rock in the heaps (1.15 Mm$^3$); this heap is a major source of SO$_4$ to the upper East Branch of the Finniss River but metal loads are relatively small; this heap is overlying low permeable granite with limited buffering capacity so groundwater in the vicinity of the heap is highly-impacted by ARD;

- Dyson’s (backfilled) Open Pit is the smallest of the mine waste units (5 ha) and contains about 0.9 Mm$^3$ of tailings and 0.3 Mm$^3$ of contaminated soils and copper heap leach material; this mine waste unit is a small source of SO$_4$ to the East Branch of the Finniss River but a major source of Cu, Mn, and Ni due to the oxidization of former heap leach material and contaminated soils used to backfill the upper portions of the pit; the majority of tailings in deeper portions of the open pit likely remain submerged underwater throughout the year and are therefore not a major source of contaminants;

- The Main Open Pit has been partially backfilled with 0.8 Mm$^3$ of tailings but still has a remaining storage capacity of 2.3 Mm$^3$ (or about two-thirds of its original volume); pit water quality is generally good due to wet season inflows from the upper East Branch of the Finniss
River but some highly-contaminated water remains at the bottom of the pit; this pit appears to have poor hydraulic connection to the local bedrock aquifer(s);
- The Intermediate Open Pit has not been backfilled and has a capacity of 1.1 Mm$^3$; this pit has a strong hydraulic connection to the local bedrock aquifer(s) and contains some highly-contaminated water at depth (possibly due to contaminant loads from the Copper Extraction Pad area).

Relocating residual tailings and contaminated soils near the Old Tailings Dam is not considered a priority as diffuse contaminant loads to groundwater in this area are relatively minor. Remediation of highly-contaminated groundwater beneath the former Copper Extraction Pad is also considered a lower priority, since metal loading from this area to the East Branch of the Finniss River appears to be limited (due to small hydraulic gradients, high buffering capacity of the surrounding bedrock aquifer and location upgradient of the Intermediate Open Pit).

### 7.3 Rehabilitation Options

The broad rehabilitation options that are available include collection and treatment of seepage, recovering the mine waste units, and relocation of waste rock into the open pits (below the water table) to limit further oxidation. Based on our current understanding of the contaminant loading from the various mine waste units and the hydrogeological conditions at the site (see Section 7.2), five rehabilitation options have been conceptualized for purposes of discussion (see Table 7-3).

The options outlined in Table 7-3 represent alternative approaches to reducing the contaminant loads from the mine waste units to the East Branch of the Finniss River. It is recognized, however, that other factors such as cost, radiological hazards, long-term physical stability, and/or aesthetics will influence the selection of a preferred rehabilitation option. Furthermore, the preferred rehabilitation option will have to be consistent with expectations regarding future land use and will therefore require substantial input from local stakeholders.

More details on the five rehabilitation options are provided in the following sub-sections. Details provided do not represent a comprehensive consideration of every aspect of rehabilitation and should only be considered conceptual at this point. We recommend that rehabilitation options be finalized in consultation with DoR and other stakeholders prior to further evaluation (using the numerical flow model and geochemical loading model) and selection of a preferred option. Simulation of these scenarios will allow an assessment of the change in the groundwater flow field at the site and resulting decreases in contaminant loads to the East Branch of the Finniss River relative to current conditions.
Table 7-3.
Summary of Conceptual Rehabilitation Options

<table>
<thead>
<tr>
<th>#</th>
<th>Strategy</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Current conditions</td>
<td>Covers installed in the 1980s have deteriorated; seepage loads to surface water and groundwater are substantial and have impacted water quality in the East Branch of the Finniss River.</td>
<td>Ongoing contamination of surface water and receiving groundwater is expected (for reference only)</td>
</tr>
<tr>
<td>1</td>
<td>Collect &amp; Treat</td>
<td>Collect and treat seepage and shallow groundwater where feasible and cost-effective, including near the Main Overburden Heap and near both waste units in Dyson’s Area, and re-cover the Intermediate Overburden Heap.</td>
<td>Water treatment plant operated in perpetuity; sludge to be stored in new sludge disposal facility</td>
</tr>
<tr>
<td>2</td>
<td>High Quality Covers</td>
<td>Re-cover all of the mine waste units with high-quality, store-and-release covers to reduce infiltration, as per Fawcett (2007)</td>
<td>Rainfall infiltration feasibly reduced to about 1% and oxygen levels in the heaps could be reduced; no movement of waste units</td>
</tr>
<tr>
<td>3</td>
<td>Relocate the Main Overburden Heap</td>
<td>Place waste rock from the Main Overburden Heap underwater in the main and Intermediate open pits (~60%); relocate remaining 40% of waste to Intermediate Overburden Heap and re-cover this heap (and both mine waste units in Dyson’s Area)</td>
<td>No further oxidation of waste rock placed in flooded pits; liming of waste rock and/or pit water during and/or after waste backfill required</td>
</tr>
<tr>
<td>4</td>
<td>Relocate the Intermediate Overburden Heap</td>
<td>Place waste rock from the Intermediate Overburden Heap underwater in the Main Pit; re-cover the Main Overburden Heap and both mine waste units in Dyson’s Area</td>
<td>No further oxidation of waste rock from the Intermediate Heap; liming of waste rock and/or pit water during and/or after waste backfill required</td>
</tr>
<tr>
<td>5</td>
<td>Relocate the Intermediate Overburden Heap and waste units in Dyson’s Area</td>
<td>Submerge waste rock from the Intermediate Heap and heap leach material/contaminated from Dyson’s (backfilled) Open Pit in the Main Open Pit; relocate waste rock from Dyson’s Heap to Dyson’s pit; re-cover Dyson’s (backfilled) Pit and Main Overburden Heap</td>
<td>Substantial earthmoving costs to relocate material from Dyson’s Area; liming of waste rock and/or pit water during and/or after waste backfill required</td>
</tr>
</tbody>
</table>

7.3.1 Collect & Treat

The ‘collect & treat’ option involves establishing a seepage interception system (SIS) to capture toe seepage and shallow groundwater from the mine waste units wherever cost-effective and logistically...
feasible. Treated effluent could then be discharged to the East Branch of the Finniss River. This option therefore includes construction of a water treatment plant that would operate in perpetuity and a sludge disposal facility at the Rum Jungle Mine Site.

Constructing the SIS could entail augmenting the existing drainage systems near the Main Overburden Heap and in Dyson’s Area to prevent loads from reaching the upper East Branch of the Finniss River and Fitch Creek. Seepage from the Intermediate Overburden Heap could feasibly be collected from the EFDC if wet season flows from Fitch Creek and the upper East Branch of the Finniss River were diverted entirely to the Main Open Pit. This would imply that the river follows its pre-mining course after rehabilitation and that the EFDC would become part of the SIS.

The main advantages of this strategy are to ensure that known contaminant loads to the East Branch of the Finniss River are significantly reduced but a major drawback is operation of a water treatment plant in perpetuity and no real improvement in site aesthetics.

7.3.2 High-Quality Covers

This option would likely entail the installation of high-quality, store-and-release covers on each of the mine waste units as per Fawcett (2007). Improved covers could feasibly reduce infiltration to 1% of incident rainfall and also reduce oxygen transport in the heaps to limit further oxidation of waste rock. Additional study of expected cover performance under conditions at the Rum Jungle Mine Site or close consideration of analogous sites (e.g. at the nearby Woodcutters mine site) is advisable before implementing relocation of this rehabilitation option.

7.3.3 Relocate the Main Overburden Heap

This option involves placing most of the waste rock from the Main Overburden Heap underwater in the Main and Intermediate Open Pits and then re-covering the remaining waste rock. Assuming a 5 m water column above the top of the backfill, about 60% of the waste rock from the Main Overburden Heap could be placed underwater in the open pits. The remaining waste rock could then be covered alone or together with waste rock from the Intermediate Overburden Heap to reduce the total overall footprint.

To limit the impact on pit water quality, waste rock would be limed as it is placed in the open pits and some consideration could be given to construction of a temporary water treatment plant (to ensure that pit water quality is suitable for discharge). After the open pits have been backfilled, water from the East Branch of the Finniss River would flow through the pits as it does today and hence periodically flushes any residual contaminants from the flooded pits.
7.3.4 Relocate the Intermediate Overburden Heap

This option involves placing all of the waste rock from the Intermediate Overburden Heap underwater in the Main Open Pit and re-covering the Main Overburden Heap and both mine waste units in Dyson’s Area. Liming of pit water during and/or after backfilling and water treatment will likely be required to limit short-term impacts on the East Branch of the Finniss River.

7.3.5 Relocate the Intermediate Overburden Heap and waste units in Dyson’s Area

This option involves re-covering the Main Overburden Heap and placing waste rock from the Intermediate Overburden Heap and contaminated soils and copper heap leach material from shallow portions of Dyson’s (backfilled) Open Pit underwater in the Main Open Pit.

Waste rock from Dyson’s Overburden Heap (which is relatively low in sulphide content) could then be relocated on top of the partially backfilled Dyson’s Open Pit. After complete backfilling, Dyson’s open pit could be covered with a high-quality cover. Note that the large volume of waste rock in Dyson’s Overburden Heap would necessitate building a much larger landform in Dyson’s Area (in terms of height) but the overall footprint would be reduced.
8 CONCLUSIONS & RECOMMENDATIONS

8.1 CONCLUSIONS

8.1.1 Numerical flow modeling

A transient groundwater flow model was developed to simulate the groundwater system at the Rum Jungle Mine Site under current conditions. The numerical model was calibrated using detailed time trends of groundwater levels collected by DoR staff during the period August 2010 to November 2011.

Key findings of the numerical modeling work are summarized as follows:

- The Overburden Heaps and Dyson’s (backfilled) Open Pit represent areas of preferential recharge and hence affect local groundwater flow fields in their vicinity; groundwater levels near the Main and Dyson’s Overburden Heaps were simulated to mound due to the presence of low-K granite of the Rum Jungle Complex beneath them; no such mounding occurs beneath the Intermediate Overburden Heap due to higher permeability of the underlying bedrock;

- The Coomalie Dolostone is generally the most permeable unit of the local bedrock aquifer and receives the highest amount of recharge by rainfall infiltration; the Whites Formation is typically an order-of-magnitude less permeable than the Coomalie Dolostone but is still more permeable than the Rum Jungle Complex and the Geolsec Formation (which are the least permeable aquifer units);

- In Dyson’s Area, shallow (highly-impacted) groundwater tends to flow south towards the upper East Branch of the Finniss River based on local topography; groundwater flowing west from Dyson’s Area is relatively unimpacted, which suggests that contaminants are not transported beyond Dyson’s Area via deep groundwater;

- The reach of the East Branch of the Finniss River between the bridge crossing (gauge GS8150200) and the Old Tailings Creek represents a major groundwater discharge zone; most of the groundwater is likely unimpacted by ARD but some impacted groundwater may reach the river near the road bridge (west of bore PMB16);

- The Main and Intermediate Open Pits represent net sources of water to the groundwater system (i.e. 4 L/s and 7 L/s, respectively); the Browns Oxide Open Pits represents a net sink for groundwater (22 L/s) due to active de-watering; the de-watering of the Browns Oxide Open Pit has caused the development of a cone of depression that tends to pull shallow, relatively unimpacted groundwater from the area near the Intermediate Open Pit towards the de-watered Browns Oxide open pit.
8.1.2  Contaminant loads to the East Branch of the Finniss River

Key findings related to contaminant loads from the mine waste units are summarized as follows:

- The Main Overburden Heap accounts for 50% of the annual SO$_4^-$ load to the East Branch of the Finniss River and is a major source of metals (i.e. 15 to 30%);
- The Intermediate Overburden Heap accounts for about 25% of the annual SO$_4^-$ load to the East Branch of the Finniss River and is a significant source of metals (~30% of Cu and Mn, 50% of Ni, and nearly 80% of Zn);
- Dyson’s Overburden Heap accounts for 15 to 20% of the annual SO$_4^-$ load from the mine waste units and close to 75% of the annual Fe load; this heap is a relatively minor source of Cu, Ni, Mn, and Zn (i.e. ~10% or less of the total loads);
- Dyson’s (backfilled) Open Pit is a major source of Cu, Mn, and Ni to the East Branch of the Finniss River due to seepages from highly-contaminated soils and heap leach material in shallow portions of the open pit.

The majority of contaminant loads in the river are explained by seepage from the four major mine waste units. Preliminary contaminant loads provided in this report are, however, un-calibrated and will be refined during Stage 3 of this project (i.e. when seepage monitoring data for the 2011/2012 wet season is available).

8.2  RECOMMENDATIONS

In light of results from Stage 2 numerical modeling, the following work is recommended:

- Update and re-calibrate the numerical flow model with groundwater and pit water level data for the 2011/2012 wet season;
- Update and re-calibrate the numerical flow model with seepage flow measurements collected by the DoR during the 2011/2012 wet season;
- Refine the preliminary contaminant load estimates with additional seepage flow data and observed loads in the East Branch of the Finniss River for the 2010/2011 and 2011/2012 wet seasons;
- Evaluate and finalize the following rehabilitation options through consultation with local stakeholders:
  - Option 1. Collect & Treat
  - Option 2. High Quality Covers
  - Option 3. Relocate the Main Overburden Heap
  - Option 4. Relocate the Intermediate Overburden Heap
  - Option 5. Relocate the Intermediate Overburden Heap and mine waste units in Dyson’s Area
• Simulate the finalized rehabilitation options using the re-calibrated numerical flow model and contaminant load model to determine:
  o Groundwater flow and seepage rates after rehabilitation
  o Residual contaminant loading from the different mine waste units to the East Branch of the Finniss River after rehabilitation

Completion of the recommended work will allow a comprehensive assessment of how the water quality conditions in the East Branch of the Finniss River could be improved by the alternative rehabilitation options and thereby enable the DoR to select the preferred rehabilitation option in light of stakeholder interests and priorities.
9  CLOSURE

Robertson GeoConsultants Inc. is pleased to submit this report entitled Phase 3 (Stage 2 Report): Report on Numerical Flow Modeling at the Rum Jungle Mine Site.

This report was prepared by Robertson GeoConsultants Inc. for the use of the NT Department of Resources and prior consent by the Department is required before the contents of this report are considered by any third party.

We trust that the information provided in this report meets your requirements at this time. Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned.

Respectfully Submitted,

ROBERTSON GEOCONSULTANTS INC.

Dr. Paul Ferguson  
Senior Geochemist

Dr. Christoph Wels, M.Sc., P.Geo.  
Principal & Senior Hydrogeologist
10 REFERENCES


Coffey Geosciences Pty Ltd. (2006), Browns Oxide Project - Groundwater Modeling, Batchelor, NT.


Local Geology
Rum Jungle Mine Site
Rum Jungle Mine Site

SCALE

LEGEND
- Geikie Formation
- Wilber Formation
- Coomalie Dolomite
- Crater Formation
- Rum Jungle Complex
- Quartz Vein
- Fault

PROJECTION: MGA
ZONE: 52
DATUM: GDA 1994
UNITS: Meters

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

FIGURE: 2-3a


Robertson GeoConsultants Inc.
Figure 2-3b. Stratigraphic sequence and lithologies at the Rum Jungle mine site (adapted from Coffey, 2005)

<table>
<thead>
<tr>
<th>Graphic</th>
<th>Lithology</th>
<th>Formation</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hematitic quartzite breccia</td>
<td>Geolsec Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calcareous and carbonaceous pyritic pelites, marl, amphibolite dykes, and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>quartzite</td>
<td>Whites Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stromatolitic dolostone and magnesite, minor interbeds of metapelite and</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>para amphibolite</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brecciated zones are associated with faulting</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vuggy recrystallized zones (from metamorphosis) occur throughout the rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>and karstic zones are present near the surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arkosic arenite, quartz arenite, and conglomerate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crater Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Granitoid</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Granitoid</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rum Jungle Complex</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2-4. Idealized cross section of the Rum Jungle mine site (from Coffey Geosciences Pty. Ltd., 2005).
Air Photo of Rum Jungle Mine Site Prior to Rehabilitation (early 1980s)
NT, Australia

SCALE

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

FIGURE: 2-6
Monitoring Bores Installed in 2010
Rum Jungle Mine Site
Rum Jungle Mine Site

SCALE

MONITORING BORES INSTALLED IN 2010
Rum Jungle Site

LEGEND
- Groundwater bore (Depth <5m)
- Groundwater bore (Depth from 5 to 15m)
- Groundwater bore (Depth >15m)
- Groundwater bore (Unclassified)
- Not in Use

PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

FIGURE: 2-8b

0 250 500 750 1,000 m
Groundwater Quality Data

Dyson’s Area (2010/2011)  
Rum Jungle Mine Site

SCALE

FIGURE: 3-1a

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

Dateline: 07/06/2011 DRAWN BY: OM FILE: RumJungle_WQ_Dyson_1_2011.mxd

Geologic Formation
White Formation
Cosmella Dolomite
Crater Formation
Rum Jungle Complex
Quartz Vein
Fault

LEGEND

Groundwater Bore (Depth +5m)
Groundwater Bore (Depth from 5 to 15m)
Groundwater Bore (Depth >15m)
Groundwater Bore (Unclassified)
Not in Use

pH - pH units
EC - µS/cm
SO₄ - mg/L
Mg - mg/L

Groundwater Bore (Well) (Dry)

RN012376
pH (6.88) (5.88)
EC (7118) (1228)
SO₄ (423) (447)
Mg (247) (152)

RN012373
pH (7.0) (7.03)
EC (1209) (609)
SO₄ (268) (271)
Mg (50.3) (172)

RN012372
pH (5.14) (3.51)
EC (782) (4066)
SO₄ (355) (2720)
Mg (58.1) (442)

PMB1b
pH (6.84) (6.84)
EC (2192) (2350)
SO₄ (934) (1120)
Mg (120) (133)

RN012371
pH (5.05) (-)
EC (799) (-)
SO₄ (-) (-)
Mg (-) (-)

PMB1a
pH (5.14) (3.51)
EC (782) (4066)
SO₄ (355) (2720)
Mg (58.1) (442)

PMB2
pH (6.84) (6.84)
EC (2192) (2350)
SO₄ (934) (1120)
Mg (120) (133)

PMB1a
pH (6.84) (6.84)
EC (2192) (2350)
SO₄ (934) (1120)
Mg (120) (133)

RN012375
pH (6.63) (6.60)
EC (453) (415.6)
SO₄ (1.1) (3.4)
Mg (14.1) (40.1)

RN012384
pH (7.28) (-)
EC (-) (-)
SO₄ (-) (-)
Mg (-) (-)

RN012381
pH (7.0) (7.03)
EC (1209) (609)
SO₄ (268) (271)
Mg (50.3) (172)

RN012382
pH (6.88) (5.88)
EC (7118) (1228)
SO₄ (423) (447)
Mg (247) (152)

RN012383
pH (6.63) (6.60)
EC (453) (415.6)
SO₄ (1.1) (3.4)
Mg (14.1) (40.1)

RN012384
pH (7.28) (-)
EC (-) (-)
SO₄ (-) (-)
Mg (-) (-)

Groundwater Bore (Depth +5m)
Groundwater Bore (Depth from 5 to 15m)
Groundwater Bore (Depth >15m)
Groundwater Bore (Unclassified)
Not in Use

pH - pH units
EC - µS/cm
SO₄ - mg/L
Mg - mg/L

Coomalie Dolomite
Geolsec Formation
Crater Formation
Rum Jungle Complex
Quartz Vein
Fault

FIGURE: 3-1a

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

Dateline: 07/06/2011 DRAWN BY: OM FILE: RumJungle_WQ_Dyson_1_2011.mxd
Groundwater Quality Data Near Overburden Heaps (2010/2011)
Rum Jungle Mine Site

SCALE

0 50 100 150 200 m

LEGEND

Coomalie Dolomite
Geolsec Formation
Crater Formation
Whites Formation
Quartz Vein
Fault

Groundwater Bore (Depth <5m)
Groundwater Bore (Depth from 5 to 15m)
Groundwater Bore (Depth >15m)
Groundwater Bore (Unclassified)
Not in Use

PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

FIGURE: 3-2a
Groundwater Quality Data
Near flooded Open Cuts (2010/2011)
Rum Jungle Mine Site

**Groundwater Bore**
Depth <5m

- pH: pH units
- EC: µS/cm
- SO4: mg/L
- Mg: mg/L

**Legend**
- Geologic Formation
- Groundwater Bore (Depth <5m)
- Groundwater Bore (Depth from 5 to 15m)
- Groundwater Bore (Depth >15m)
- Groundwater Bore (Unclassified)
- Not in Use
- Fault
- Rum Jungle Complex
- Quartz Vein

**REPORT: RGC 183003**
**LOCATION: Rum Jungle Mine Site, NT, Australia**

**FIGURE: 3-3a**

**SCALE**

**PROJECT: Flow Modelling & Contaminant Load Balance**

**CLIENT: Department of Resources NT Government**

**DATE: 07/02/2011 DRAWN BY: OM FILE: RumJungle_WQ_OpenCut_1_2011.mxd**
Groundwater Quality Data
Near flooded Open Cuts (2010/2011)
Rum Jungle Mine Site

Legend:
- Geologic Formation
- White formation
- Coomalie Dolomite
- Crater Formation
- Quartz Vein
- Fault
- Groundwater Bore (Wet)
- Groundwater Bore (Dry)
- Groundwater Bore (Depth <5m)
- Groundwater Bore (Depth from 5 to 15m)
- Groundwater Bore (Depth >15m)
- Groundwater Bore (Unclassified)
- Not in Use

Cu - µg/L
Co - µg/L
Ni - µg/L
Zn - µg/L

SCALE

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia
Groundwater Quality Data
Old Tailings Dam area (2010/2011)
Rum Jungle Mine Site

**SCALE**

**LEGEND**
- Geological Formation
- Whites Formation
- Geologicsec Formation
- Crater Formation
- Whites Formation
- Rum Jungle Complex
- Quartz Vein
- Fault

**GROUNDWATER QUALITY DATA**

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</table>

**PARAMETERS**
- pH: pH units
- EC: µS/cm
- SO4: mg/L
- Mg: mg/L

**LOCATION:** Rum Jungle Mine Site, NT, Australia

**FIGURE:** 3-4a
Groundwater Quality Data
Old Tailings Dam area (2010/2011)
Rum Jungle Mine Site

SCALE

LEGEND
Geolsec Formation
Whites Formation
Coomalie Dolomite
Crater Formation
Groundwater Bore (Depth <5m)
Groundwater Bore (Depth 5 to 10m)
Groundwater Bore (Depth >15m)
Groundwater Bore (Unclassified)
Fault
Not in Use

GROUNDWATER BORE
Al - µg/L (Wet) (Dry)
Fe - µg/L
Mn - µg/L
U - µg/L

PMB18
Al (10.3) (27) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (1110)
U (0.31) (0.5) (0.7)

PMB19
Al (7) (15) (11)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB17
Al (7) (11) (11)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB16
Al (11) (23) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB15
Al (15) (26) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB14
Al (35) (114) (114)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB13
Al (15) (26) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB12
Al (22) (38) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB11
Al (11) (23) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB10
Al (27) (20) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB9
Al (11) (23) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB8D
Al (22) (38) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB8S
Al (10) (26) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB7
Al (10) (26) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB6
Al (11) (23) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

PMB5
Al (11) (23) (20)
Fe (200) (200) (200)
Mn (2.3) (9) (784)
U (0.31) (0.5) (0.7)

Groundwater Bore (Wet) (Dry)
Groundwater Bore (Unclassified)
Not in Use

Groundwater Quality Data
Old Tailings Dam area (2010/2011)
Rum Jungle Mine Site
SCALE

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

FIGURE: 3-4b
<table>
<thead>
<tr>
<th>Location</th>
<th>Cu (µg/L)</th>
<th>Co (µg/L)</th>
<th>Ni (µg/L)</th>
<th>Zn (µg/L)</th>
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<td>(304) (1110)</td>
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<td>(0.3) (0.6)</td>
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<td>(1) (4)</td>
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<tr>
<td>RN023304</td>
<td>(0.9) (0.2)</td>
<td>(0.1) (0.1)</td>
<td>(0.1) (0.5)</td>
<td>(2) (14)</td>
</tr>
</tbody>
</table>

**Groundwater Quality Data**

Old Tailings Dam area (2010/2011)

Rum Jungle Mine Site

SCALE

---

**Legend**

- Green: Geologic Formation
- Blue: Groundwater Bore (Depth <5m)
- Pink: Groundwater Bore (Depth from 5 to 15m)
- Red: Groundwater Bore (Depth >15m)
- Yellow: Groundwater Bore (Unclassified)
- Orange: Groundwater Bore (Not in Use)
- Black: Not in Use

**Location:** Rum Jungle Mine Site, NT, Australia

**Report:** RGC 183003

**Client:** Department of Resources NT Government

**Project:** Flow Modelling & Contaminant Load Balance

**Date:** 01/20/2011

**SCALE:**

**Zone:** 52

**Datum:** GDA 1994

**Units:** Meters

---

**Groundwater Bore (Depth <5m)**

- PMB2084
- PMB2085
- PMB2086
- PMB2087
- PMB2088

**Groundwater Bore (Depth from 5 to 15m)**

- PMB2089

**Groundwater Bore (Depth >15m)**

- PMB2090

**Groundwater Bore (Unclassified)**

- PMB2091

**Not in Use**

- PMB2092

---

**Projections**

- MGA

---

**Zone:** 52

**Datum:** GDA 1994

**Units:** Meters

---

**Location:** Rum Jungle Mine Site, NT, Australia

**Report:** RGC 183003

---

**Figure:** 3-4c

---

**Date:** 01/20/2011

**Drawing by:** Robertson GeoConsultants Inc.
Figure 3-5a. Groundwater level time trends for bores in Dyson's Area
Figure 3-5b. Groundwater level time trends for bores near the Main Overburden Heap
Figure 3-5c. Groundwater level time trends for bores near the Intermediate Overburden Heap
Figure 3-5d. Groundwater level time trends for bores near the Main Open Pit.
Figure 3-5e. Groundwater level time trends near the Intermediate Open Pit
Figure 3-5f. Groundwater level time trends for bores near the Old Tailings Dam.
Figure 3-5g. Groundwater level time trends near the Browns Oxide Open Pit
Figure 3-7. Groundwater Response to Dewatering of Intermediate Open Cut (November 2008)
Model Domain
Rum Jungle Mine Site
NT, Australia

LEGEND
Copper Extraction Pad (Relocated)
Historical Mining Footprint
Borrow Pit
Brown's Oxide Open Pit
Sweet Water Dam
Acid Water Dam
Main Overburden Heap
Dyson's Open Pit
Dyson's Overburden Heap
Intermediate Open Pit
Intermediate Overburden Heap
Old Tailing Dams (Relocated)
Former River Channel

SCALE
PROJECTION: MGA
ZONE: 52
DATUM: GDA 1994
UNITS: Meters

FIGURE: 4-1

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

DATE: 07/19/11 DRAWN BY: OM FILE: RumJungle_Model_BND_2011.mxd
Cross Section of Hydrostratigraphic Units (East to West)
Rum Jungle Mine Site

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance
REPORT: RGC 183003
LOCATION: Rum Jungle Mine Site, NT, Australia

FIGURE: 4-2

Projection: MGA
Zone: 52
Datum: GDA 1994
Units: Meters
Date: 15/05/11
Drawn by: OM
File: RumJungle_xSec_trans.mxd

Materials:
- Laterite
- Weathered residual black shale
- Goofen Formation
- Coomalie Bauxite
- Alluvium
- Cobar Formation
- Wuilda Formation
- Rum Jungle Formation
Figure 4-4. Conceptual hydrostratigraphic model for the model domain
Figure 4-5. EC Profiles for the Main and Intermediate Open Pits.
200 cells x 25 m = 5,000 m in x and y directions (grid is 6 cells thick in z direction)

Figure 5-2. Grid setup and spacing
Figure 5-3a. Ground surface elevations across most of the model domain (used to define the top of Layer 1 within the footprints of the mine waste units and the top of Layer 2 elsewhere in the model domain).
Figure 5-3b. Ground surface elevations near the central mine reach (used to define the top of Layer 1 within the footprints of the mine waste units and the top of layer 2 elsewhere in the model domain).
Figure 5-3c. Ground surface elevations in Dyson’s Area
(used to define the top of Layer 1 within the footprints of the mine waste units and the top of layer 2 elsewhere in the model domain).
Figure 5-4. Finite difference grid (with boundary conditions) for Layer 1 and cross-sections for the Main Overburden Heap and Dyson’s (backfilled) Open Pit.
Figure 5-5. Finite difference grid (with boundary conditions) for Layer 2 and vertical cross-section through the entire model domain.
Figure 5-6. Finite difference grid (with boundary conditions) for Layer 3
Figure 5-7. Finite difference grid (with boundary conditions) for Layer 4
Figure 5-8. Finite difference grid (with boundary conditions) for Layers 5 & 6
Figure 5-9. Hydrostratigraphic units with the polygons used to assign hydraulic properties to the finite difference grid.
Figure 5-10. Recharge rates to the hydrostratigraphic units in Layers 1 & 2.
Figure 5-11. Observed rainfall and model inputs for recharge to the Overburden Heaps and selected lithologic units (see also Table 5-1).
Figure 5-12. Observed pit water levels for the Main, Intermediate, and Browns Oxide Open Pits and corresponding model inputs.
Figure 6-2. Calibrated hydraulic conductivities for Layer 2 and 3 (see also Appendix C).
Figure 6-3. Simulated groundwater levels for bores screened in the Coomalie Dolostone northeast of the central mine reach and bore RN022085.
Figure 6-4. Simulated groundwater levels for bores in Dyson’s Area or east of the Main Open Pit.
Figure 6-5. Simulated groundwater levels for bores screened in the Rum Jungle Complex near the Main Overburden Heap.
Figure 6-6. Pit water levels and simulated groundwater levels for bores screened in the Coomalie Dolostone and Whites Formation near the flooded Open Pits and former Copper Extraction Pad.
Figure 6-7. Simulated groundwater levels for bores screened in the Coomalie Dolostone north of the Main Open Pit.
Figure 6-8. Simulated groundwater levels for bores near the East Branch of the Finniss River and Old Tailings Creek.
Figure 6-11a. Flowpath analysis for Dyson’s Overburden Heap and backfilled Open Pit.
Figure 6-1b. Flowpath analysis near the mine waste units and the flooded Open Pits.
Figure 6-12. Flowpath analysis near the flooded Open Pits. Note that the Browns Oxide Open Pit was removed for the simulation shown in (b) but is shown here for clarity.
Figure 6-13. Monthly inflows and outflow for the Open Pits and the East Branch of the Finniss River downstream of gauge GS8150200.
Figure 6-14. Simulated groundwater flow fields during the pit de-watering trial conducted in 2008. Note the development of a cone of depression around the Intermediate Open Pit and the locations of bores monitored during the trial.
Figure 6-15. Simulated and observed drawdowns at bores RN022107 and RN022108 during the pit de-watering trial used for model validation.
Figure 6-16. Simulated and observed drawdowns at bore RN022081 during the pit de-watering trial used for model verification.
Figure 6-17. Simulated toe seepage the Main and Intermediate Overburden Heaps for Sensitivity Runs 1 to 4.
Figure 6-18. Simulated groundwater levels for the base calibration and Sensitivity Runs 5, 6, and 7.
Appendix A

Construction details for monitoring bores
Table A-1a. Summary of historic monitoring bores near the Main and Intermediate Overburden Heaps

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<tr>
<th>Bore ID</th>
<th>Installation Date</th>
<th>Location/description</th>
<th>Easting (MGA94 Zone 56)</th>
<th>Northing</th>
<th>Total depth</th>
<th>Screened Interval</th>
<th>Stickup</th>
<th>TOC</th>
<th>Screened lithology</th>
<th>Yield</th>
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<td>RN022037</td>
<td>May-83</td>
<td>SE of the Intermediate Overburden Heap</td>
<td>717564</td>
<td>8562777</td>
<td>22.8</td>
<td>16 to 22</td>
<td>0.51</td>
<td>67.18</td>
<td>Rum Jungle Complex</td>
<td>0.1</td>
</tr>
<tr>
<td>RN022039</td>
<td>May-83</td>
<td>Between White's and Intermediate Overburden Heaps (near EFDC)</td>
<td>717650</td>
<td>8562960</td>
<td>18.0</td>
<td>12 to 18</td>
<td>0.32</td>
<td>67.73</td>
<td>Quartz gravels</td>
<td>5</td>
</tr>
<tr>
<td>RN022081</td>
<td>May-83</td>
<td>Between White's and Intermediate Overburden Heaps (near EFDC)</td>
<td>717669</td>
<td>8562959</td>
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<td>40.7 to 43.9</td>
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<td>68.75</td>
<td>Coomalie Dolostone</td>
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<td>June-83</td>
<td>On top of White's Overburden Heap</td>
<td>718038</td>
<td>8562447</td>
<td>17.0</td>
<td>11 to 17</td>
<td>0.49</td>
<td>94.24</td>
<td>Rum Jungle Complex</td>
<td>0.1</td>
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<td>On top of White's Overburden Heap</td>
<td>718068</td>
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<td>52.0</td>
<td>37 to 52</td>
<td>0.33</td>
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<td>June-83</td>
<td>East of White's Overburden Heap near Fitch Creek</td>
<td>718282</td>
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<td>17.9</td>
<td>10 to 16</td>
<td>0.35</td>
<td>68.59</td>
<td>Rum Jungle Complex</td>
<td>0.6</td>
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<td>June-83</td>
<td>Near SW toe of White's Overburden Heap</td>
<td>717738</td>
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<td>16.0</td>
<td>10 to 16</td>
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<td>69.15</td>
<td>Rum Jungle Complex</td>
<td>&lt;0.1</td>
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<td>Upgradient of mine site</td>
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<td>5</td>
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<td>718229</td>
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<td>Rum Jungle Complex</td>
<td>0.5</td>
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<td>RN022411</td>
<td>Oct-83</td>
<td>East of White's Overburden Heap (near drainage channel)</td>
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<td>0.3 to 1.5</td>
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<td>Laterite</td>
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1. bgs = below ground surface  
2. ags = above ground surface  
3. TOC = Top of casing  

Note: wtr = weathered
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<th>Northing (MGA94 Zone 56)</th>
<th>Total depth (m bgs)</th>
<th>Screened Interval (m bgs)</th>
<th>Stickup2 (m bgs)</th>
<th>TOC3 (m AHD 71)</th>
<th>Yield (L/s)</th>
<th>Screened lithology</th>
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1. bgs = below ground surface
2. ags = above ground surface
3. TOC = Top of casing
Note: wtr = weathered
### Table A-1b. Summary of historic monitoring bores in Dyson's area and in the Old Tailings Dam area

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<th>Bore ID</th>
<th>Installation Date</th>
<th>Location/description</th>
<th>Easting</th>
<th>Northing</th>
<th>Total depth (m bgs)</th>
<th>Screened Interval (m bgs)</th>
<th>Stickup (m ags)</th>
<th>TOC (m HAD 71)</th>
<th>Screened lithology</th>
<th>Yield (L/s)</th>
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<td>SW of Dyson's Overburden Heap near upper East Finniss River</td>
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<td>Clay</td>
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<td>RN023417</td>
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<td>SW of Dyson's Overburden Heap near upper East Finniss River</td>
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<td>8563327</td>
<td>2.1</td>
<td>0.3 to 0.8</td>
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<td>719141</td>
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<td>1.3 to 1.9</td>
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<td>64.54</td>
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<td>8563438</td>
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### Near the Old Tailings Dam area

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<th>Easting</th>
<th>Northing</th>
<th>Total depth (m bgs)</th>
<th>Screened Interval (m bgs)</th>
<th>Stickup (m ags)</th>
<th>TOC (m HAD 71)</th>
<th>Screened lithology</th>
<th>Yield (L/s)</th>
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<td>8564289</td>
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<td>75.32</td>
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1. bgs = below ground surface  
2. ags = above ground surface  
3. TOC = Top of casing  
Note: wtr = weathered
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<th>Bore ID</th>
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<th>Northing</th>
<th>Total depth</th>
<th>Screened Interval</th>
<th>Stickup2</th>
<th>TOC3</th>
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<th>Yield</th>
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<td>(m bgs)2</td>
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<td>'Open hole' bore near road bridge (now PMB9S/D)</td>
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<td>8563152</td>
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<td>8562457</td>
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<td>0.92</td>
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<td>1.7 to 2.5</td>
<td>0.77</td>
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<td>Clay</td>
<td>-</td>
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1. bgs = below ground surface
2. ags = above ground surface
3. TOC = Top of casing
Note: wtr = weathered
## Table A-2. Summary of bores installed in 2010

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Installation Date</th>
<th>Location/description</th>
<th>Easting (MGA94 Zone 56)</th>
<th>Northing</th>
<th>Total depth</th>
<th>Screened Interval</th>
<th>Stickup</th>
<th>TOC</th>
<th>Screened lithology</th>
<th>Yield</th>
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</thead>
<tbody>
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<td>PMB1a</td>
<td>Nov-10</td>
<td>In drainage channel from Dyson's (backfilled) Open Cut</td>
<td>719072</td>
<td>8563353</td>
<td>3.4</td>
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<td>69.68</td>
<td>Saprolite</td>
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<td>PMB1b</td>
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<td>Adjacent to braided channel south of Dyson's (backfilled) Open Cut</td>
<td>718974</td>
<td>8563405</td>
<td>3.7</td>
<td>2.2 to 3.7</td>
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<td>70.73</td>
<td>Alluvium</td>
<td>n.d.</td>
</tr>
<tr>
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<td>Bedrock beneath Dyson's area</td>
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<td>8563378</td>
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<td>12.7 to 18.7</td>
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<td>70.73</td>
<td>Rum Jungle Complex</td>
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<tr>
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<td>Saprolite (and some alluvium) near the head of EFDC</td>
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<td>8562971</td>
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<td>1.97 to 3.47</td>
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<td>Near Intermediate Overburden Heap</td>
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<td>Overburden</td>
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<td>Downgradient of Intermediate Open Cut near East Finniss River</td>
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<td>Near East Finniss River (formerly RN022108)</td>
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<td>In former copper heap leach area</td>
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1. bgs = below ground surface  
2. ags = above ground surface  
3. TOC = Top of casing  
Note: wtr = weathered
Appendix B

Calibration Data
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| 18-Jan-11  | 63.8  | 64.2  | 64.3 | 62.4 | 62.7 | 58.3 | 59.1 | 59.0 | -     | -     | 59.9  | 59.5  | 60.0  | 60.3  | 61.7  | 58.9  | 60.2  | 61.0  | 53.4  |
| 14-Feb-11  | 63.7  | 64.1  | 64.2 | 62.4 | 62.6 | 59.1 | 59.6 | 58.7 | 59.6  | 58.6  | 59.8  | 59.4  | 60.3  | 60.5  | 61.8  | 58.6  | 60.6  | 61.2  | 53.8  |
| 28-Feb-11  | 63.6  | 64.0  | 64.0 | 62.4 | 62.7 | 58.5 | 59.2 | 59.0 | 59.8  | 58.6  | 60.4  | 59.8  | 60.5  | 60.9  | 62.4  | 58.9  | 61.2  | -     | 53.8  |
| 15-Mar-11  | 63.6  | 64.1  | 63.5 | 62.4 | 62.7 | 58.6 | 59.2 | 59.0 | 59.5  | 58.7  | 60.3  | 59.8  | 60.3  | 60.7  | 62.1  | 58.8  | 60.7  | 61.2  | 53.6  |
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| 12-Apr-11  | 63.5  | 64.0  | 63.6 | 62.3 | 62.6 | 58.3 | 59.0 | 58.7 | 59.4  | 58.4  | 60.0  | 59.5  | 60.2  | 60.6  | 61.9  | 58.6  | 60.7  | 61.1  | 53.7  |
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| 9-May-11   | 63.3  | 63.9  | 63.6 | 62.0 | 62.5 | 57.9 | 58.7 | 58.4 | 57.5  | 58.0  | 59.3  | 58.9  | 59.3  | 59.7  | 60.8  | 58.2  | 59.5  | 60.6  | 53.0  |
| 6-Jun-11   | 63.3  | 63.9  | 63.4 | 61.8 | 62.0 | 57.8 | 58.5 | 58.2 | 56.6  | 57.9  | 59.1  | 58.7  | 58.9  | 59.2  | 60.0  | 57.9  | 58.9  | 60.1  | 52.7  |
| 8-Jul-11   | 63.3  | 63.9  | -    | 61.5 | 61.8 | 57.7 | 58.5 | 58.1 | 55.9  | 57.7  | 58.8  | 58.4  | 58.6  | 58.9  | 59.5  | 57.7  | 58.5  | 59.7  | -     |
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<td>62.3</td>
<td>71.0</td>
<td>69.0</td>
<td>61.9</td>
<td>66.7</td>
<td>77.3</td>
<td>77.8</td>
</tr>
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<td>22-Oct-11</td>
<td>-</td>
<td>58.0</td>
<td>57.3</td>
<td>59.4</td>
<td>57.2</td>
<td>53.9</td>
<td>65.9</td>
<td>65.9</td>
<td>67.2</td>
<td>62.6</td>
<td>62.0</td>
<td>70.8</td>
<td>68.7</td>
<td>61.6</td>
<td>66.3</td>
<td>77.0</td>
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</tbody>
</table>

All values in m AHD
Appendix C

Calibrated Parameters
### Table C1. Calibrated parameters for the Overburden Heaps and Dyson's (backfilled) Open Pit

<table>
<thead>
<tr>
<th>Description</th>
<th>Recharge mm</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
<th>Layer 4</th>
<th>Layer 5</th>
<th>Layer 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Layer 1 (waste rock &amp; tailings)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate Overburden Heap</td>
<td>593</td>
<td>5.8E-05</td>
<td>2.8E-06</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Overburden Heap</td>
<td>593</td>
<td>5.8E-05</td>
<td>2.8E-06</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyson's (backfilled) Open Cut</td>
<td>474</td>
<td>2.0E-07</td>
<td>1.0E-07</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyson's Overburden Heap</td>
<td>1186</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
<td>0.25</td>
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</tr>
</tbody>
</table>

### Table C2. Calibrated parameters for the bedrock aquifer

<table>
<thead>
<tr>
<th>Description</th>
<th>Recharge mm</th>
<th>Layer 2</th>
<th>Layer 3</th>
<th>Layer 4</th>
<th>Layer 5</th>
<th>Layer 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rum Jungle Complex</strong></td>
<td></td>
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</tr>
<tr>
<td>Beneath the Main Overburden Heap at RN022082D</td>
<td>237</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
<td>0.075</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
</tr>
<tr>
<td>Uprgradiment of Main Overburden Heap at RN025165 &amp; RN025167</td>
<td>237</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
<td>0.020</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
</tr>
<tr>
<td>Near Fitch Creek at at RN022083</td>
<td>237</td>
<td>5.8E-05</td>
<td>2.8E-05</td>
<td>0.020</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
</tr>
<tr>
<td>In Dyson's Area (backfilled Overburden Heap)</td>
<td>237</td>
<td>5.8E-05</td>
<td>2.8E-05</td>
<td>0.075</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
</tr>
<tr>
<td>Alluvium/granite near Fitch Creek &amp; East Branch of Finniss River</td>
<td>237</td>
<td>5.8E-05</td>
<td>2.8E-05</td>
<td>0.020</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
</tr>
<tr>
<td>Near mid-point gauge station at PMB21</td>
<td>119</td>
<td>5.8E-06</td>
<td>2.8E-06</td>
<td>0.020</td>
<td>5.8E-06</td>
<td>2.8E-07</td>
</tr>
<tr>
<td>Between the Main and Intermediate Overburden Heaps</td>
<td>24</td>
<td>2.0E-07</td>
<td>1.0E-07</td>
<td>0.075</td>
<td>2.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td><strong>Coomalie Dolostone</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North of Main Open Cut at RN021107</td>
<td>949</td>
<td>1.5E-04</td>
<td>1.5E-05</td>
<td>0.010</td>
<td>1.5E-04</td>
<td>1.5E-05</td>
</tr>
<tr>
<td>Small block that isolates the Main Open Pit</td>
<td>474</td>
<td>1.0E-04</td>
<td>1.0E-05</td>
<td>0.020</td>
<td>1.0E-04</td>
<td>1.0E-05</td>
</tr>
<tr>
<td>Large block towards the East Branch of the Finniss River</td>
<td>474</td>
<td>1.0E-04</td>
<td>1.0E-05</td>
<td>0.020</td>
<td>1.0E-04</td>
<td>1.0E-05</td>
</tr>
<tr>
<td>Higher elevation area to the northeast</td>
<td>474</td>
<td>7.2E-05</td>
<td>8.0E-06</td>
<td>0.020</td>
<td>7.2E-05</td>
<td>8.0E-06</td>
</tr>
<tr>
<td>North of the Old Tallings Creek</td>
<td>474</td>
<td>9.8E-06</td>
<td>1.4E-06</td>
<td>0.020</td>
<td>9.8E-06</td>
<td>1.4E-06</td>
</tr>
<tr>
<td>Upgradiment of central mine area at RN022085</td>
<td>474</td>
<td>1.0E-05</td>
<td>1.0E-05</td>
<td>0.010</td>
<td>1.0E-05</td>
<td>1.0E-05</td>
</tr>
<tr>
<td>Beneath the Intermediate Overburden Heap</td>
<td>474</td>
<td>5.0E-06</td>
<td>1.0E-06</td>
<td>0.020</td>
<td>5.0E-06</td>
<td>1.0E-06</td>
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<tr>
<td><strong>Whites Formation</strong></td>
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<tr>
<td>Near Browns Oxide pit at RN023060</td>
<td>119</td>
<td>5.0E-05</td>
<td>5.0E-05</td>
<td>0.020</td>
<td>5.0E-05</td>
<td>5.0E-06</td>
</tr>
<tr>
<td>Near the Intermediate Overburden Heap at PMB8 &amp; PMB6</td>
<td>119</td>
<td>5.0E-05</td>
<td>5.0E-06</td>
<td>0.020</td>
<td>5.0E-06</td>
<td>5.0E-06</td>
</tr>
<tr>
<td>Near the former copper extraction pad</td>
<td>237</td>
<td>5.0E-06</td>
<td>1.0E-06</td>
<td>0.020</td>
<td>5.0E-06</td>
<td>1.0E-06</td>
</tr>
<tr>
<td>West of Main Open Cut at RN025544</td>
<td>48</td>
<td>2.0E-07</td>
<td>2.0E-07</td>
<td>0.075</td>
<td>2.0E-07</td>
<td>2.0E-07</td>
</tr>
<tr>
<td>In Dyson's Area, beneath pit &amp; south of</td>
<td>237</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>0.020</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>North of the backfilled pit</td>
<td>237</td>
<td>1.0E-06</td>
<td>1.0E-06</td>
<td>0.020</td>
<td>5.0E-07</td>
<td>5.0E-07</td>
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<tr>
<td><strong>Geolsec Formation</strong></td>
<td></td>
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<tr>
<td>In Dyson's Area at RN023790</td>
<td>237</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>0.020</td>
<td>5.0E-08</td>
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<tr>
<td>In Dyson's Area NW of block at RN023790</td>
<td>237</td>
<td>1.0E-06</td>
<td>1.0E-06</td>
<td>0.020</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>SW of backfilled pit at RN02236</td>
<td>356</td>
<td>2.0E-06</td>
<td>1.0E-06</td>
<td>0.020</td>
<td>5.0E-07</td>
<td>5.0E-07</td>
</tr>
<tr>
<td>SW of backfilled pit at RN023790</td>
<td>356</td>
<td>4.0E-07</td>
<td>4.0E-07</td>
<td>0.075</td>
<td>4.0E-07</td>
<td>4.0E-07</td>
</tr>
<tr>
<td>2 blocks adjacent to Coomalie Dolostone</td>
<td>48</td>
<td>5.0E-08</td>
<td>5.0E-08</td>
<td>0.020</td>
<td>5.0E-08</td>
<td>5.0E-08</td>
</tr>
<tr>
<td>Block to the north of Main Open Cut</td>
<td>24</td>
<td>2.0E-07</td>
<td>2.0E-07</td>
<td>0.020</td>
<td>2.0E-07</td>
<td>2.0E-07</td>
</tr>
<tr>
<td>Block to the south of Main Open Cut</td>
<td>24</td>
<td>4.0E-07</td>
<td>4.0E-07</td>
<td>0.020</td>
<td>4.0E-07</td>
<td>4.0E-07</td>
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<tr>
<td><strong>Fault zone</strong></td>
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<tr>
<td>Between the Main and Intermediate Open Pits</td>
<td>237</td>
<td>1.0E-03</td>
<td>1.0E-03</td>
<td>0.100</td>
<td>1.0E-03</td>
<td>1.0E-03</td>
</tr>
</tbody>
</table>
Appendix D

Sensitivity Analysis Results
Figure D1. Simulated groundwater flow fields for the base case calibration.
Figure D2. Simulated groundwater flow field and water levels for Sensitivity Run 1.
Figure D3. Simulated groundwater flow field and water levels for Sensitivity Run 2.
Figure D4. Simulated groundwater flow field and water levels for Sensitivity Run 3.
Figure D5. Simulated groundwater flow field and water levels for Sensitivity Run 4.
Figure D6. Simulated groundwater levels for the base calibration and Sensitivity Run 5.
Figure D7. Simulated groundwater levels for the base calibration and Sensitivity Run 6.