PHASE 3 (STAGE 3 REPORT):
SURFACE WATER QUALITY AND CONTAMINANT LOAD ASSESSMENT FOR 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 studies at the Rum Jungle Mine Site in order to characterize current surface water and groundwater quality conditions at the site and thereby assist the NT Department of Resources (DoR) in developing a revised rehabilitation strategy.

The objectives of the current report are to:

- Evaluate surface water quality conditions in the East Branch of the Finniss River from August 2010 to the end of July 2011;
- Estimate contaminant loads in the river for that period; and
- Discuss the implications of these results with respect to developing a revised rehabilitation strategy for the Rum Jungle Mine Site.

Surface water quality

Surface water monitoring data were assessed in light of the 95% protection level trigger values from the current ANZECC water quality guidelines. These trigger values equate to ecologically low-risk levels of physicochemical indicators for sustained exposure and are concentrations that, if exceeded, would indicate a potential environmental problem.

Key conclusions from the assessment of surface water quality data are summarized as follows:

- Contaminant concentrations in shallow pit water were generally low but concentrations of Cu, Ni, and Zn (and sometimes Al) exceeded the trigger values from the ANZECC water quality guidelines; concentrations of Cu and Zn were higher in the Intermediate Open Pit than in the Main Open Pit due to additional loads from contaminated groundwater in the Copper Extraction Pad area;
- In the East Branch of the Finniss River, only Cu concentrations exceeded the trigger value from the ANZECC water quality guidelines during the high flow period from December to mid-April at gauges GS8150200 and GS8150097; flow-weighted Cu concentrations were 5 to 10 times higher than the 11 μg/L trigger value for this period and much lower concentrations were observed during peak flow periods; if Cu concentrations from the Rum Jungle Mine Site were lowered by implementing a revised rehabilitation strategy then water quality conditions in the river during high flow periods would likely not be a major source of concern;
- High concentrations of Cd, Cu, Mn, Ni, and Zn characterize the East Finniss Diversion Channel (EFDC) and the East Branch of the Finniss River near gauge GS8150200 during the period of receding river flows at the end of the wet season and throughout the subsequent dry season; any precipitates that accumulate along the river bed during this period are re-dissolved in the first flows of the following wet season and contribute to the ‘first flush’ of...
contaminants towards the main Finniss River; the ‘first flush’ of contaminants can be detrimental to aquatic ecology in the river and reducing its severity by establishing stringent post-rehabilitation water quality objectives (WQOs) for the dry season is considered a major priority.

**Contaminant Loads**

Contaminant loads in the East Branch of the Finniss River for 2010/2011 are representative of a very wet year that was characterized by record-high rainfall and river flow volumes. Key aspects of the load assessment for 2010/2011 are summarized as follows:

- The annual $\text{SO}_4$ load in the East Branch of the Finniss River for 2010/2011 was about 3,400 t (or about 10% lower than the average $\text{SO}_4$ load in the mid-1990s); this small discrepancy is related in part to errors and uncertainties in river flow data but also smaller loads from the flooded Open Pits due to an improvement in pit water quality that has occurred since the 1990s;
- Annual loads of dissolved metals in the East Branch of the Finniss River range from 5 t for Cu and Ni to 24 t for Mn; river-borne loads were generally conserved downstream and any small differences in loads at gauges GS8150200 and GS8150097 are ascribed to the precipitation of metals from the river;
- The total Cu load in the river is much higher than the dissolved Cu load due to high particulate loads that are related to fluvial erosion and surface losses from the mineralized overburden heaps; total and dissolved loads of Mn, Ni and Zn were comparable due to the high solubility of these metals under the near-neutral pH conditions that characterize the river during high flow periods;
- The annual $\text{SO}_4$ load from the Intermediate Open Pit accounted for less than 5% of the total load in the East Branch of the Finniss River; the Intermediate Open Pit was a larger source of metals to the river (e.g. 25% for copper) due to loads from untreated pit water and/or groundwater that discharges to the pit from the Copper Extraction Pad area.

**Recommendations**

The completion of a quantitative ecological risk assessment (ERA) for the East Branch of the Finniss River is recommended prior to finalizing any revised rehabilitation strategy. The following work is recommended prior to initiating this ERA:

- Assessment of surface water quality conditions and contaminant loads in the East Branch of the Finniss River for the 2011/2012 wet season in light of lower-than-average rainfall;
- Refinement of the preliminary contaminant load estimates from RGC (2012) using measurements of toe seepage and seepage water quality data collected in 2011/2012;
• Delineation of the metal plume in the Copper Extraction Pad area via the installation of five additional monitoring bores to the north of the EFDC (see Figure 3-9);
• Evaluation of the active water management strategy described in this report along with the five other alternative rehabilitation options outlined in RGC (2012).

Completion of this work will enable contaminant loads and current surface water quality conditions in the East Branch of the Finniss River to be well-constrained and thereby enable quantitative post-rehabilitation WQOs to be developed prior to implementing a more effective rehabilitation strategy for the Rum Jungle Mine Site.
PHASE 3 (STAGE 3 REPORT):
SURFACE WATER QUALITY AND CONTAMINANT LOAD ASSESSMENT FOR THE RUM JUNGLE MINE SITE, NT

Table of Contents

1 INTRODUCTION ............................................................................................................................ 1
   1.1 TERMS OF REFERENCE .............................................................................................................. 1
   1.2 PURPOSE & SCOPE ................................................................................................................... 2
2 BACKGROUND ............................................................................................................................. 3
   2.1 LOCATION & CLIMATE ................................................................................................................ 3
   2.2 HYDROLOGY ............................................................................................................................. 3
       2.2.1 Drainage Patterns ............................................................................................................ 3
       2.2.2 Annual Hydrologic Cycle .............................................................................................. 3
       2.2.3 Gauges along the East Branch of the Finniss River ........................................................ 4
       2.2.4 Outflow from the flooded Open Pits ................................................................................. 5
   2.3 SITE DESCRIPTION & HISTORY OF REHABILITATION ......................................................... 5
       2.3.1 Open Pits ......................................................................................................................... 5
       2.3.2 Overburden Heaps ........................................................................................................... 6
       2.3.3 Copper Extraction Pad ..................................................................................................... 7
       2.3.4 Old Tailings Dam area ..................................................................................................... 7
   2.4 GROUNDWATER MONITORING NETWORK ......................................................................... 8
   2.5 POST-REHABILITATION SUCCESS CRITERIA ..................................................................... 8
       2.5.1 Rum Jungle Rehabilitation Project, 1984/1985 ............................................................... 8
       2.5.2 Success criteria for an improved rehabilitation strategy ................................................ 10
3 SURFACE WATER MONITORING RESULTS, 2010/2011 WET SEASON ........................................... 12
   3.1 SEEPAGE FROM WASTE ROCK & SHALLOW BACKFILL MATERIALS ................................ 12
       3.1.1 Toe Seepage .................................................................................................................... 12
       3.1.2 Seepage Water Quality .................................................................................................. 12
   3.2 PIT WATER .................................................................................................................................. 13
       3.2.1 Outflow from the Intermediate Open Pit ........................................................................ 13
       3.2.2 Pit Water Quality ............................................................................................................ 13
   3.3 EAST BRANCH OF THE FINNISS RIVER .................................................................................. 15
       3.3.1 River flows at gauges GS8150200 & GS8150097 ........................................................... 15
       3.3.2 Water Quality .................................................................................................................. 15
LIST OF TABLES

Table 2-1  Historic loads in the East Branch of the Finniss River
Table 2-2  Trigger Values from the ANZECC water quality guidelines
Table 3-1  Selected ARD indicator species in seepage, 2010/2011
Table 3-2  Shallow pit water quality data for the Main and Intermediate Open Pits
Table 3-3  Surface water quality data for the East Branch of the Finniss River, 2010/2011
Table 4-1  Current and historic contaminant loads in the East Branch of the Finniss River
Table 4-2  Observed loads in the East Branch of the Finniss River and simulated loads from RGC (2012), 2010/2011
Table 4-3  Observed and simulated loads in the East Branch of the Finniss River, 2010/2011
Table 4-4a Wet and dry season contaminant concentrations in the East Branch of the Finniss River at gauge GS8150200, 2010/2011
Table 4-4b Wet and dry season contaminant concentrations in the East Branch of the Finniss River at the mid-station gauge, 2010/2011
Table 4-4c Wet and dry season contaminant concentrations in the East Branch of the Finniss River at gauge GS8150097, 2010/2011

LIST OF FIGURES

Figure 2-1  Location of the Rum Jungle Mine Site in northern Australia
Figure 2-2  Regional topography and drainage near the Rum Jungle Mine Site
Figure 2-3  Layout of the Rum Jungle Mine Site
Figure 2-4  Air photo of the Rum Jungle Mine Site after rehabilitation
Figure 2-5  Groundwater Monitoring Network
Figure 3-1  Electrical conductivity profiles for the flooded open pits
Figure 3-2  Instantaneous river flows and electrical conductivity measurements for the East Branch of the Finniss River, 2010/2011
Figure 3-3  Dissolved SO4 concentrations in the East Branch of the Finniss River, 2010/2011
Figure 3-4  Total nickel concentrations in the East Branch of the Finniss River, 2010/2011
Figure 3-5  Total zinc concentrations in the East Branch of the Finniss River, 2010/2011
Figure 3-6  Total manganese concentrations in the East Branch of the Finniss River, 2010/2011
Figure 3-7  Total copper concentrations in the East Branch of the Finniss River, 2010/2011
Figure 3-8  Total iron concentrations in the East Branch of the Finniss River, 2010/2011
Figure 3-9  Proposed monitoring bores near the East Finniss Diversion Channel

LIST OF APPENDICES

Appendix A  Historic surface water quality data for the East Branch of the Finniss River
LIST OF ACRONYMS & ABBREVIATIONS

ANZECC  Australia and New Zealand Environment Conservation Council
ARD    Acid rock drainage
As     Arsenic
bgs    below ground surface
Cd     Cadmium
Co     Cobalt
Cu     Copper
DoR    Department of Resources
EFDC   East Finniss Diversion Channel
ERA    Ecologic Risk Assessment
Mn     Manganese
Ni     Nickel
Pb     Lead
RGC    Robertson GeoConsultants Inc.
SO₄     Sulphate
SRK    SRK Consulting (Australasia) Pty. Ltd.
Zn     Zinc
PHASE 3 (STAGE 3 REPORT):
SURFACE WATER QUALITY AND CONTAMINANT LOAD ASSESSMENT FOR THE RUM JUNGLE MINE SITE, NT

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 of the site (Kraatz, 2004). In 2009, the Mining Performance Division of the Department of Resources (DoR) was tasked with developing a revised rehabilitation strategy 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 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, 2010). 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 subsequently recommended a second phase of work that would include additional drilling in areas that are under-represented in the existing bore network and was retained by the DoR to complete that work (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 Stage 2 involved the development of a numerical groundwater flow model and preliminary
contaminant load estimates for the Rum Jungle Mine Site (see RGC, 2012). Stage 3 comprised an assessment of surface water quality and contaminant loads in the East Branch of the Finniss River for 2010/2011. This report summarizes the results of this Stage 3 assessment work.

1.2 PURPOSE & SCOPE

The objectives of the current report are to:

- Evaluate surface water quality conditions in the East Branch of the Finniss River from August 2010 to the end of July 2011; and
- Estimate contaminant loads in the river for that period;
- Discuss the implications of these results with respect to developing a revised rehabilitation strategy for the Rum Jungle Mine Site.

Surface water quality data for 2010/2011 are evaluated in light of trigger values from the Australia and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines (ANZECC, 2000). These trigger values equate to ecologically low-risk levels of physicochemical indicators (such as dissolved metals) and are derived from biological dose-response data (see LPSDP, 2007). Water quality data for 2010/2011 are compared to the trigger values in order to identify the principal contaminants of concern near the Rum Jungle Mine Site prior to further rehabilitation planning.

Trigger values from the ANZECC water quality guidelines are also proposed as potential post-rehabilitation success criteria for the revised rehabilitation strategy being developed by the DoR. These trigger values are acknowledged to be rather stringent success criteria so the feasibility of their application is evaluated in this report.
2 BACKGROUND

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). The region is characterized by a tropical savannah-like climate and typically receives about 1500 mm of annual rainfall. 90% or more of rainfall occurs during a distinct wet season that lasts from November to April, as no sustained rainfall occurs from May to October. Total annual rainfall for the 2010/2011 wet season was 2,333 mm, or about 50% higher than the long-term average for the area (RGC, 2012).

2.2 HYDROLOGY

2.2.1 Drainage Patterns

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).

Unimpacted 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 central mine area and subsequently flowed eastward via the natural river course. During mining, the river was diverted to the East Finniss Diversion Channel (EFDC) to allow access to the Main and Intermediate ore bodies (see ‘former river channel’ and ‘EFDC’ in Figure 2-3).

Since rehabilitation, flows from the upper East Branch of the Finniss River and Fitch Creek have flowed 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 river course.

2.2.2 Annual Hydrologic Cycle

River flows in the East Branch of the Finniss River are closely related to rainfall and therefore highly-seasonal. The annual cycle in river flows can be divided into three distinct periods:

- The ‘build up’ period (from September to November); most of the rainfall that occurs during this period infiltrates to groundwater and raises the water table near the river; river flows are therefore intermittent during this period and typically related to runoff from localized thunderstorms;
• The high flow period (from December to mid-April); groundwater levels have risen substantially by this time of the year and sustained river flows are observed due to the consistency of rainfall in the catchment;

• The period of receding river flows (from mid-April to August); as rainfall decreases and ultimately ceases, river flows recede at the end of the wet season, the groundwater system near the river acts as a reservoir that can sustain river flows through the end of July; flows are nearly negligible in August and reflect small amounts of baseflow groundwater discharge.

The East Branch of the Finniss River is a non-perennial stream but there is a series of permanent pools along its bed that are maintained throughout the dry season by groundwater discharge from the Coomalie Dolostone (Davy, 1975). The largest of these pools are located downstream of the mine site and are surrounded by dense vegetation.

Smaller permanent pools are also located along the EFDC. Several of these pools are sustained by groundwater discharge from a finger of the Coomalie Dolostone that connects to the Main Open Pit and another pool is sustained by dry season seepage from the Intermediate Overburden Heap (RGC, 2012).

2.2.3 Gauges along the East Branch of the Finniss River

Flows in the East Branch of the Finniss River are currently monitored immediately downstream of the central mine area at gauge GS8150200 and then downstream at the new mid-station gauge and gauge GS8150097 (see Figure 2-2). Pertinent features of these gauges are summarized as follows:

• Gauge GS8150200 is located near the road bridge west of the Intermediate Open Pit and drains an area of 53 km² that includes the central mine reach and Dyson’s Area (which together occupy an area of about 0.6 km²); this gauge does not capture flows from Old Tailings Creek;

• The mid-station gauge is located about 2 km downstream of gauge GS8150200 on private property and captures additional flows from Old Tailings Creek and any groundwater discharge from the rehabilitated tailings area east of the river;

• Gauge GS8150097 is located about 4 km further downstream of the mid-station gauge (near the old rail bridge crossing) and captures flows from several tributaries that do not drain the Rum Jungle Mine Site; the total drainage area of this gauge is 71 km²;

Gauge GS8150097 was constructed in 1965 and has been operational for most of the time (Lawton and Overall, 2002a). Flows at this location were used to estimate contaminant loads in the East Branch of the Finniss River prior to initial rehabilitation works in the 1980s (Davy, 1975).

Gauge GS8150200 was built in December 1981 and operated initially until August 1988. The gauge was re-established in 1991 and has since been used to monitor surface water quality conditions in
the East Branch of the Finniss River immediately downstream of the mine site (see Lawton and Overall, 2002a for additional details).

The mid-station gauge was built in between gauges GS8150200 and GS8150097 as part of Phase 3 investigations. Validated flows are not yet available but this gauge will eventually be used as the principal compliance point for post-rehabilitation surface water quality monitoring.

### 2.2.4 Outflow from the flooded Open Pits

Total outflow from the flooded Open Pits is currently recorded at gauge GS8150212. This gauge is located at the point of outflow from the Intermediate Open Pit immediately upstream of gauge GS8150200 (Figure 2-3).

Outflow from the Intermediate Open Pit typically begins in the early wet season after first flows have been recorded in the East Branch of the Finniss River at gauge GS8150200 (Lawton and Overall, 2002a). This flow pattern is a result of the hydrological design incorporated into rehabilitation works in the 1980s, which facilitates early wet season flows in the upper East Branch of the Finniss River to enter the EFDC and not the Main Open Pit (Allen and Verhoeven, 1986).

Gauge GS8150212 was previously monitored from 1991 to 1998 along with inflows to Main Open Pit at gauge GS8150213. Flow monitoring at gauge GS8150212 was re-initiated in December 2010 as part of Phase 3 investigations.

### 2.3 SITE DESCRIPTION & HISTORY OF REHABILITATION

#### 2.3.1 Open Pits

Uranium mineralization at the Rum Jungle Mine Site was discovered in 1949. Uranium and polymetallic mineralization occurred in black pyritic/graphitic slates of the Whites Formation along its contact with the Coomalie Dolostone. Mineralization is comprised mainly of bornite (Cu$_5$FeS$_4$) and pyrite (FeS$_2$) with traces of Pb, Bi, Ni, Co, and Cu sulphides (Fraser, 1975).

The Main, Intermediate, Dyson’s, and Browns Oxide ore bodies are the principal deposits at the Rum Jungle Mine Site. The Main, Intermediate, and Dyson’s ore bodies were mined out by the early 1970s and each of these pits flooded with contaminated groundwater and seepage when mining operations ended (Davy, 1975). The Browns Oxide ore body has only been partially mined-out and the pit is currently de-watered by HAR Resources (the tenement holders of the mine lease).

Key features of the open pits at the Rum Jungle Mine Site are summarized as follows:

- The Main Open Pit was mined to about 105 m below ground surface (bgs) and then partially backfilled (to about 50 m) with tailings and other mine waste in the 1960s; the Main Open Pit remains flooded yet pit water quality conditions have been improved by treatment during
initial rehabilitation in 1985 and annual wet season flows from the East Branch of the Finniss River;

- The Intermediate Open Pit was mined to about 57 m bgs and also remains flooded; pit water from the Intermediate Open Pit was not treated to the same extent as water from the Main Open Pit but water quality conditions have improved by wet season flows from the East Branch of the Finniss River (via the Main Open Pit);

- 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 entirely with additional tailings removed from the Old Tailings Dam and leached low-grade ore and contaminated soils removed from the Copper Extraction Pad area (Allen and Verhoeven, 1986);

- The Browns Oxide Open Pit is relatively shallow compared to the other open pits and has not been backfilled; due to active de-watering, this pit represents a major discharge zone for groundwater and affects local groundwater flow fields in its vicinity (see RGC, 2012).

2.3.2 Overburden Heaps

Waste rock removed during mining of the Main, Intermediate, and Dyson’s ore bodies was stored above ground in three waste rock piles or ‘overburden heaps’ (see Figure 2-4). The heaps are well-established as the main sources of contaminants to receiving waters at the Rum Jungle Mine Site (see Davy, 1975; Allen and Verhoeven, 1986, Kraatz, 2004; RGC, 2012).

Waste rock geochemistry has recently been characterized in SRK (2012) and some pertinent results from that study are summarized as follows:

- Waste rock associated with the Intermediate ore body has the highest acid potential (~60 kg H₂SO₄/t); this waste rock is stored in the Intermediate Overburden Heap and was used to backfill shallow portions of Dyson’s Open Pit; high acid potential for this type of waste rock is consistent with highly-impacted toe seepage from the Intermediate Overburden Heap and Dyson’s (backfilled) Open Pit (see RGC, 2012);

- The acid potential of waste rock from the Main Overburden Heap is 26 kg H₂SO₄/t or less than half the acid potential of waste rock associated with the Intermediate ore body; the lower sulphide content of waste rock from this heap may explain lower concentrations of SO₄ and metals in seepage from this heap but the potential for heterogeneity in seepage water quality is high for this large heap (see RGC, 2012);

- Waste rock from Dyson’s Overburden Heap has an acid potential of 7 kg H₂SO₄/t; according to SRK (2012), this heap is characterized by a lower sulphide content than the other heaps due to the lower initial sulphide content of waste rock and/or more advanced oxidation of
waste rock; seepage from this heap is characterized by relatively high concentrations of \( \text{SO}_4 \) but low metal concentrations, which is consistent with the low sulphide content of waste rock.

Each of the Overburden Heaps was covered in 1984/1985 to reduce rainfall infiltration and oxygen transport within the heaps but the covers have deteriorated over the last 30 years (Taylor et al., 2003). Dyson’s Overburden Heap was also only partially-covered in the 1980s so waste rock is exposed near the edges of the heap. This has likely led to higher rainfall infiltration to this heap (see RGC, 2012) and the more advanced oxidation of waste rock due to greater oxygen availability within the heap (see SRK, 2012).

2.3.3 Copper Extraction Pad

Copper from sub-grade ore (and the oxidized capping) from the Intermediate ore body was extracted via heap leaching on a pad located between the Main and Intermediate Open Pits. The heap leach procedure involved piling sulphide and oxide ore into separate piles atop a low-permeable pad and then spraying the ores with a highly-acidic mixture of raffinate, barren liquor, and water from Main Open Pit to dissolve soluble copper in the ore pile (Andersen, 1966).

Pregnant liquor was intended to drain from the heap primarily via a series of lined channels and culverts but the process was inefficient and seepage losses were substantial (Davy, 1975). These losses led to significant impacts on groundwater between the Main and Intermediate Open Pits and this impacted groundwater ultimately filled the pits when de-watering ceased in the 1960s.

Spent heap leach material and soils that had been contaminated during the leaching process were removed during rehabilitation in the 1980s and used to backfill shallow portions of Dyson’s Open Pit. Some heap leach material and contaminated soils remain in the Copper Extraction Pad area and deep groundwater in this area is characterized by very high concentrations of dissolved copper (see RGC, 2012).

2.3.4 Old Tailings Dam area

Slurried tailings were discharged to an almost flat area to the north of the Main Open Pit during mining operations. Drainage from this area formed a small creek called ‘Old Tailings Creek’ that eventually discharged to the East Branch of the Finniss River (Watson, 1979). Perimeter walls were later 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 were later removed from this area and placed in Dyson’s Open Pit during site rehabilitation in the 1980s (Allen and Verhoeven, 1986).

The Old Tailings Dam area was limed and re-shaped to control drainage after the removal of tailings and contaminated subsoil. A one-layer cover was also installed to enable the establishment of vegetation. Residual amounts of tailings do remain in this area and likely represent a diffuse source of contaminants to local groundwater (RGC, 2012).
2.4 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 (Figure 2-5). The historic 'RN' bores were either installed as production bores during mining operations or during previous groundwater investigations (e.g. Appleyard, 1983; Salama, 1985). The 'PMB' bores were installed in 2010 to augment the existing network of monitoring bores (see RGC, 2011a).

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. Additional bores installed in 2010 are located mainly near the former Copper Extraction Pad area or north of the central mine reach but several bores were also installed in Dyson’s Area (see Figure 2-5).

Groundwater levels and groundwater quality conditions in a selection of bores are currently monitored routinely by the DoR. These data were described in detail in RGC (2012) and descriptions are not repeated here. Pertinent groundwater quality data are, however, discussed as necessary in this report in the context of describing contaminant sources and loads to the East Branch of the Finniss River.

2.5 POST-REHABILITATION SUCCESS CRITERIA

2.5.1 Rum Jungle Rehabilitation Project, 1984/1985

From 1969 to 1984, contaminant loads to the East Branch of the Finniss River were very high (see Table 2-1). The main contaminant sources at that time were seepages from waste rock in the uncovered overburden heaps, spent heap leach material in the Copper Extraction Pad area, and flows of highly-impacted pit water to the East Branch of the Finniss River (Ritchie and Bennett, 2003).

Table 2-1.

<table>
<thead>
<tr>
<th>Source or Gauge</th>
<th>Annual contaminant loads (in t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow, Mm³</td>
</tr>
<tr>
<td>Before rehabilitation (1969 to 1984)</td>
<td></td>
</tr>
<tr>
<td>EBFR at gauge GS8150097</td>
<td>31</td>
</tr>
<tr>
<td>After rehabilitation (mid-1990s)</td>
<td></td>
</tr>
<tr>
<td>To the Main Open Pit</td>
<td>14</td>
</tr>
<tr>
<td>From the Intermediate Open Pit</td>
<td>14</td>
</tr>
<tr>
<td>EBFR at GS8150200</td>
<td>34</td>
</tr>
<tr>
<td>EBFR at GS8150097</td>
<td>40</td>
</tr>
</tbody>
</table>

Note: Pre-rehabilitation loads (from 1969 to 1984) from Lawson and Overall (2002a) and references therein
Contaminant loads to the East Branch of the Finniss River were reduced by the following treatment measures undertaken in 1984/1985:

- Treatment of acidic water contained in the Main and Intermediate Open Pits and re-establishment of wet-season flushing through the open pits;
- Capping of acid-generating material with low-permeability clays and capillary break layers to restrict the ingress of water and oxygen;
- Re-shaping of the overburden heaps and construction of soil conservation works to facilitate water drainage, minimize ponding, and prevent erosion; and
- Placement and covering of radioactive material (from the ‘Old Tailings Dam’ and floodplain of the East Branch of the Finniss River) and spent ore from the Copper Extraction Pad area in Dyson’s Open Pit.

Post-rehabilitation success criteria for the Rum Jungle Rehabilitation Project included a series of water quality objectives (WQOs) that were based on National Health and Medical Research Council (NHMRC) drinking water guidelines (see Allen and Verhoeven, 1986). Copper (Cu), manganese (Mn), and zinc (Zn) concentrations were considered the principal contaminants of concern so reducing loads of these metals was prioritized.

WQOs established for the Rum Jungle Rehabilitation Project were not particularly stringent but they were achieved by improving pit water quality in the Main and Intermediate Open Pits and reducing seepage from the overburden heaps (Kraatz, 2004). SO_4 and metal loads to the East Branch of the Finniss River were, however, still substantial after rehabilitation and surface water quality conditions in the East Branch of the Finniss River remained adversely affected as a result (see RGC, 2011 and plots of historic water quality data in Appendix A of this report).

Some key aspects of the post-rehabilitation loads from Table 2-1 are summarized as follows:

- Ten years after rehabilitation, about 3,500 to 4,000 t of SO_4 and considerable metal loads reported to the East Branch of the Finniss River from the Rum Jungle Mine Site each year; 50 to 75% of these annual loads were likely related to waste rock seepage from the Main and Intermediate Overburden Heaps;
- Loads from the Intermediate Open Pit have historically been higher than loads to the Main Open Pit; this implies additional loads from deep, untreated water at the bottoms of the pits and/or the discharge of highly-contaminated groundwater from the former Copper Extraction Pad area to the Intermediate Open Pit;
- Total Cu loads in the East Branch of the Finniss River are typically higher than dissolved loads due to high particulate loads of these metals during high flow periods; total and
dissolved loads of Mn, Ni, and Zn are comparable in magnitude due to high solubility of these metals at near-neutral pH conditions.

**2.5.2 Success criteria for an improved rehabilitation strategy**

Improving surface water quality conditions in the East Branch of the Finniss River will likely be the main objective of further rehabilitation measures undertaken at the Rum Jungle Mine Site. This improvement could be achieved by further reducing contaminant loads to the river via a number of alternative rehabilitation options. Some conceptual rehabilitation options were outlined in RGC (2012) and SRK (2012) but no quantitative success criteria for post-rehabilitation performance have yet been proposed.

We recommend that the Australia and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines be used to develop site-specific water quality objectives (WQOs) that could be included as success criteria for rehabilitation performance.

ANZECC trigger values equate to ecologically low-risk levels of physicochemical indicators for sustained exposure (LPSDP, 2007). Trigger values from the ANZECC water quality guidelines are derived from biological dose-response data and are concentrations that, if exceeded, would indicate a potential environmental problem. A selection of ANZECC trigger values that are relevant to the East Branch of the Finniss River is provided in Table 2-2.

### Table 2-2.

**Selected ANZECC Trigger Values for Freshwater**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>99%</th>
<th>95%</th>
<th>90%</th>
<th>80%</th>
<th>Guideline (livestock)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₄, mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,000</td>
</tr>
<tr>
<td>Al</td>
<td>27</td>
<td>55</td>
<td>80</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>As</td>
<td>0.8</td>
<td>13</td>
<td>42</td>
<td>140</td>
<td>-</td>
</tr>
<tr>
<td>Cd*</td>
<td>0.06</td>
<td>0.2</td>
<td>0.4</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>Cu*</td>
<td>1.0</td>
<td>1.4</td>
<td>1.8</td>
<td>2.5</td>
<td>-</td>
</tr>
<tr>
<td>Mn</td>
<td>1200</td>
<td>1900</td>
<td>2500</td>
<td>3600</td>
<td>-</td>
</tr>
<tr>
<td>Ni*</td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>17</td>
<td>-</td>
</tr>
<tr>
<td>Pb*</td>
<td>1</td>
<td>3.4</td>
<td>5.6</td>
<td>9.4</td>
<td>-</td>
</tr>
<tr>
<td>Zn*</td>
<td>2.4</td>
<td>8</td>
<td>15</td>
<td>31</td>
<td>-</td>
</tr>
</tbody>
</table>

All metal/metalloid concentrations expressed in μg/L

*Trigger values for hardness of 30 mg/L CaCO₃
A trigger value for SO₄ is not provided in the current ANZECC water quality guidelines so the 2,000 mg/L value in Table 2-2 represents a concentration that is considered suitable for livestock to drink without chronic health effects (and was taken from a previous version of the guidelines). The 80%, 90%, 95%, and 99% protection levels represent the percentage of freshwater species that would be preserved at the indicated metal (or metalloid) concentration.

Trigger values for metals (and Cd, a metalloid) are indicative of the bioavailable fraction of the total metal/metalloid content of surface water. The bioavailable fraction represents the concentration of those metal species present in surface water that can cross biological membranes and can be difficult to determine without extensive study and speciation modeling (Twining et al., 2002; LPSDP, 2007). For the purpose of this report, dissolved concentrations were considered a reasonable approximation of the bioavailable fraction of a metal in the East Branch of the Finniss River.

The guiding principle relevant to the selection of water quality criteria for Australian mine sites is the limitation of metal (or other contaminant) species that are causing toxic effects to local aquatic ecology. According to LPSDP (2007), the 95% protection level is often assigned to waterways near mine sites in Australia (see shaded values in Table 2-2). Dissolved metal concentrations observed in surface water at the Rum Jungle mine site are therefore compared to trigger values for this protection level throughout this report. Trigger values for Co and Fe have not been developed due to a lack of available information on these metals (LPSDP, 2007).

Hardness-modified trigger values for Cd, Cu, Ni, Pb, and Zn were determined in order to account for the reduced bioavailability of these species at higher water hardesses (LPSDP, 2007). Hardness-modified trigger values were calculated for individual samples using the standardized trigger values from Table 2-2 and algorithms provided in ANZECC (2000). Hardness values for the East Branch of the Finniss River typically range from 50 to 75 mg/L CaCO₃ during high flow periods and can be over 1,000 mg/L CaCO₃ in the dry season so hardness-modified trigger values are usually higher than the standardized trigger values.
3 SURFACE WATER MONITORING RESULTS, 2010/2011 WET SEASON

3.1 SEEPAGE FROM WASTE ROCK & SHALLOW BACKFILL MATERIALS

3.1.1 Toe Seepage

Toe seepage from the overburden heaps and shallow backfill in Dyson’s (backfilled) Open Pit has been monitored routinely by DoR personnel since early 2012. Flows are measured via a series of temporary weirs constructed near the mine waste units. Field pH and EC measurements are collected during the seepage surveys to ensure that flows are representative of seepage and not runoff after a rainfall event.

Seepage monitoring data for the 2011/2012 wet season are beyond the scope of this report and will be discussed in a subsequent phase of the Rum Jungle project.

3.1.2 Seepage Water Quality

Baseflow seepage water quality data from August 2010 and the 2010/2011 wet season are summarized in Table 3-1.

<table>
<thead>
<tr>
<th>Source</th>
<th>Date</th>
<th>pH</th>
<th>EC</th>
<th>SO4</th>
<th>Al</th>
<th>Fe</th>
<th>Cd</th>
<th>Cu</th>
<th>Co</th>
<th>Mn</th>
<th>Ni</th>
<th>Pb</th>
<th>U</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<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></td>
<td></td>
</tr>
<tr>
<td>Baseflow seepage from the overburden heaps</td>
<td>Main 6-Aug-10</td>
<td>3.7</td>
<td>6000</td>
<td>5190</td>
<td>12900</td>
<td>4800</td>
<td>22.2</td>
<td>4400</td>
<td>5180</td>
<td>11100</td>
<td>3840</td>
<td>28.7</td>
<td>568</td>
<td>7140</td>
</tr>
<tr>
<td></td>
<td>Dyson’s 6-Aug-10</td>
<td>3.7</td>
<td>4520</td>
<td>2710</td>
<td>87600</td>
<td>5800</td>
<td>2.0</td>
<td>157</td>
<td>395</td>
<td>5060</td>
<td>1240</td>
<td>0.2</td>
<td>1170</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>Intermediate 6-Aug-10</td>
<td>3.3</td>
<td>12600</td>
<td>13800</td>
<td>169000</td>
<td>349000</td>
<td>211.0</td>
<td>34900</td>
<td>74700</td>
<td>84300</td>
<td>64900</td>
<td>26.8</td>
<td>1840</td>
<td>156000</td>
</tr>
<tr>
<td>Wet season seepage from Dyson’s Overburden Heap</td>
<td>16-Mar-11</td>
<td>4.3</td>
<td>1106</td>
<td>579</td>
<td>9020</td>
<td>2740</td>
<td>0.5</td>
<td>4630</td>
<td>3100</td>
<td>7380</td>
<td>2590</td>
<td>2.4</td>
<td>155</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>13-Apr-11</td>
<td>4.2</td>
<td>1356</td>
<td>766</td>
<td>14900</td>
<td>1880</td>
<td>0.7</td>
<td>5040</td>
<td>4110</td>
<td>9770</td>
<td>3380</td>
<td>22.8</td>
<td>224</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>10-May-11</td>
<td>4.2</td>
<td>1579</td>
<td>1020</td>
<td>11800</td>
<td>560</td>
<td>0.8</td>
<td>3800</td>
<td>6340</td>
<td>14900</td>
<td>4930</td>
<td>5.1</td>
<td>217</td>
<td>257</td>
</tr>
<tr>
<td>Wet season seepage from Dyson’s (backfilled) Open Pit</td>
<td>16-Mar-11</td>
<td>3.4</td>
<td>2872</td>
<td>1730</td>
<td>17000</td>
<td>11300</td>
<td>1.7</td>
<td>27300</td>
<td>18400</td>
<td>39900</td>
<td>15500</td>
<td>6.8</td>
<td>1030</td>
<td>705</td>
</tr>
<tr>
<td></td>
<td>13-Apr-11</td>
<td>3.4</td>
<td>3051</td>
<td>1900</td>
<td>18900</td>
<td>9920</td>
<td>2.0</td>
<td>29600</td>
<td>20500</td>
<td>41800</td>
<td>16300</td>
<td>7.0</td>
<td>1070</td>
<td>792</td>
</tr>
<tr>
<td></td>
<td>10-May-11</td>
<td>3.4</td>
<td>4041</td>
<td>2940</td>
<td>26400</td>
<td>9700</td>
<td>2.9</td>
<td>35700</td>
<td>32600</td>
<td>72400</td>
<td>25700</td>
<td>9.6</td>
<td>1700</td>
<td>1170</td>
</tr>
</tbody>
</table>

Shaded concentrations exceed the trigger value from the ANZECC water quality guidelines

Seepages are highly-acidic (pH<4.5) and characterized by high concentrations of SO4 and dissolved metals due to the oxidation of sulphide-containing waste rock in the heaps and Dyson’s (backfilled) Open Pit. Some key observations regarding seepage water quality are summarized as follows:

- Toe seepage from the Intermediate Overburden Heap is characterized by the highest concentrations of SO4 and dissolved metals (i.e. Cu, Co, Mn, Ni, and Zn); these high concentrations are consistent with the high sulphide content of waste rock in this heap (SRK,
2012); the representativeness of this seepage water quality data to the entire heap does, however, remain unclear and will be re-evaluated when additional data is available;

- Many of the metals that are elevated in seepage from the Intermediate Overburden Heap are also elevated in seepage from Dyson’s (backfilled) Open Pit; this is related to the use of waste rock and leached material from the Intermediate ore body to backfill the shallow portions of the pit; deeper portions of the pit have been backfilled with tailings that are submerged throughout the year and hence not actively oxidized;

- Toe seepage from the Main Overburden Heap is less concentrated than seepage from the Intermediate Overburden Heap; possible explanations include the dilution of toe seepage by shallow groundwater, the lower sulphide content of waste rock, and/or heterogeneity in seepage water quality from this very large heap (see RGC, 2012);

- SO$_4$ and metals concentrations in seepage from Dyson’s Overburden Heap are typically lower than seepages from the Main and Intermediate Overburden Heaps and Dyson’s (backfilled) Open Pit; these lower concentrations reflect in part the lower initial 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); also possible is the more advanced oxidation of waste rock due to only partial covering during rehabilitation and hence greater oxygen availability within the heap (see SRK, 2012).

In March 2012, a series of water samples were collected from all of the major seepage areas at the site. Also completed was a detailed survey of seepage water quality conditions along the EFDC during the period of receding river flows in April 2012. Data from these seepage surveys are not yet available but will be discussed during subsequent phases of the project.

### 3.2 Pit Water

#### 3.2.1 Outflow from the Intermediate Open Pit

First flows from the Intermediate Open Pit (at gauge GS8150212) occurred on December 29 or about one week after first flows in the East Branch of the Finiss River at gauge GS8150200. Outflow from the Intermediate Open Pit ceased on June 2. Total flow for 2010/2011 was 15 Mm$^3$ or about 20% of the flow observed at gauge GS8150200 from August 2010 to the end of July 2011 (see below).

#### 3.2.2 Pit Water Quality

Untreated water remains in the deepest portions of both open pits (Lawton and Overall, 2002; Tropical Water Solutions, 2008). High concentrations of SO$_4$ and metals in this water are representative of the highly-impacted groundwater and seepage that filled the pits after de-watering ceased (and still resides beneath the Copper Extraction Pad).
Wet season flows from the upper East Branch of the Finniss River have gradually depleted the open pits of untreated pit water over the last 25 years so the majority of pit water is generally characterized by relatively low concentrations of $SO_4$ and metals (see Figure 3-1 and RGC, 2012).

Current water quality data for the Main and Intermediate Open Pits are summarized in Table 3-2. These data are for surface water samples collected from the east and west sides of the open pits by HAR Resources in 2010 and 2011. Samples collected on February 24 are considered representative of shallow pit water quality during the high flow period of 2010/2011. Pit water quality at this time is dominated by surface water flow from the upper East Branch of the Finniss River.

### Table 3-2.

**Pit water quality data for the Main and Intermediate Open Pits**

<table>
<thead>
<tr>
<th>Date</th>
<th>SO4</th>
<th>Al</th>
<th>Co</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
<th>U</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Open Pit (western side)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-Aug-10</td>
<td>64</td>
<td>5</td>
<td>66</td>
<td>66</td>
<td>33</td>
<td>45</td>
<td>50</td>
<td>420</td>
<td>790</td>
</tr>
<tr>
<td>17-Sep-10</td>
<td>67</td>
<td>5</td>
<td>53</td>
<td>54</td>
<td>22</td>
<td>32</td>
<td>50</td>
<td>120</td>
<td>690</td>
</tr>
<tr>
<td>5-Oct-10</td>
<td>63</td>
<td>5</td>
<td>40</td>
<td>48</td>
<td>20</td>
<td>22</td>
<td>50</td>
<td>370</td>
<td>460</td>
</tr>
<tr>
<td>24-May-11</td>
<td>11</td>
<td>120</td>
<td>130</td>
<td>48</td>
<td>48</td>
<td>180</td>
<td>180</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>23-Aug-11</td>
<td>29</td>
<td>96</td>
<td>110</td>
<td>110</td>
<td>120</td>
<td>120</td>
<td>50</td>
<td>34</td>
<td>1300</td>
</tr>
<tr>
<td><strong>Main Open Pit (eastern side)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-Aug-10</td>
<td>63</td>
<td>5</td>
<td>67</td>
<td>67</td>
<td>32</td>
<td>47</td>
<td>50</td>
<td>410</td>
<td>780</td>
</tr>
<tr>
<td>17-Sep-10</td>
<td>64</td>
<td>6.1</td>
<td>34</td>
<td>55</td>
<td>58</td>
<td>25</td>
<td>34</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>5-Oct-10</td>
<td>63</td>
<td>5</td>
<td>40</td>
<td>48</td>
<td>19</td>
<td>23</td>
<td>50</td>
<td>120</td>
<td>440</td>
</tr>
<tr>
<td>24-Feb-11</td>
<td>33</td>
<td>340</td>
<td>740</td>
<td>77</td>
<td>150</td>
<td>410</td>
<td>1200</td>
<td>180</td>
<td>220</td>
</tr>
<tr>
<td><strong>Intermediate Open Pit (western side)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-Aug-10</td>
<td>63</td>
<td>15</td>
<td>72</td>
<td>44</td>
<td>46</td>
<td>45</td>
<td>100</td>
<td>50</td>
<td>290</td>
</tr>
<tr>
<td>17-Sep-10</td>
<td>68</td>
<td>13</td>
<td>46</td>
<td>39</td>
<td>39</td>
<td>47</td>
<td>70</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>24-Feb-11</td>
<td>15</td>
<td>11</td>
<td>30</td>
<td>35</td>
<td>34</td>
<td>110</td>
<td>110</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>5-Oct-11</td>
<td>68</td>
<td>110</td>
<td>120</td>
<td>52</td>
<td>53</td>
<td>46</td>
<td>59</td>
<td>50</td>
<td>140</td>
</tr>
<tr>
<td><strong>Intermediate Open Pit (eastern side)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12-Aug-10</td>
<td>65</td>
<td>12</td>
<td>61</td>
<td>42</td>
<td>43</td>
<td>42</td>
<td>82</td>
<td>50</td>
<td>210</td>
</tr>
<tr>
<td>17-Sep-10</td>
<td>69</td>
<td>12</td>
<td>55</td>
<td>40</td>
<td>47</td>
<td>76</td>
<td>50</td>
<td>110</td>
<td>290</td>
</tr>
<tr>
<td>5-Oct-10</td>
<td>67</td>
<td>12</td>
<td>25</td>
<td>34</td>
<td>33</td>
<td>45</td>
<td>57</td>
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<td>100</td>
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<td>24-May-11</td>
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<td>140</td>
<td>36</td>
<td>37</td>
<td>72</td>
<td>71</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>23-Aug-11</td>
<td>32</td>
<td>46</td>
<td>64</td>
<td>44</td>
<td>43</td>
<td>63</td>
<td>84</td>
<td>41</td>
<td>97</td>
</tr>
</tbody>
</table>

Shaded concentrations exceed the trigger value from the ANZECC water quality guidelines.
3.3 EAST BRANCH OF THE FINNIS RIVER

3.3.1 River flows at gauges GS8150200 & GS8150097

Hourly mean flows in the East Branch of the Finniss River at gauges GS8150200 and GS8150097 are shown in Figure 3-2 with daily rainfall at the Rum Jungle Mine Site. These flow data have been validated by EnviroTech Monitoring and are considered reliable for the purpose of this report. Flow data for the mid-station gauge are not yet available.

Intermittent flows were observed at gauge GS8150200 during the build-up to the wet season in November and early December 2010 but sustained flows did not occur until December 22. First flows at gauge GS8150097 occurred about two weeks earlier on December 7. Flows begin to recede in mid-April due to less rainfall and were nearly negligible by August 2011.

River flows in the East Branch of the Finniss River increased substantially during four periods of particularly high rainfall (see Figure 3-2). The highest flows during the 2010/2011 wet season were observed in mid-February when 438 mm of rainfall occurred over a 5-day period. Instantaneous river flows during this period reached 160 m³/s at gauge GS8150200 and 400 m³/s at gauge GS8150097.

Annual flow volumes for the 2010/2011 wet season were 69 Mm³ at gauge GS8150200 and 120 Mm³ downstream at GS8150097. Higher flows at gauge GS8150097 are primarily due to inflows from Old Tailings Creek and several other tributaries that feed into the East Branch of the Finniss River downstream of the mid-station gauge. Some groundwater discharges to the river downstream of gauge GS8150200 as well but flows are relatively small in comparison to annual surface water flow volumes (RGC, 2012).

3.3.2 Water Quality

pH, water temperature, and electrical conductivity (EC) of the East Branch of the Finniss River were measured continuously at gauges GS8150200 and GS8150097 in conjunction with flow. Some of these data sets are incomplete or contain errors so only EC data for gauge GS8150200 are shown in Figure 3-2.

204 water samples were collected from gauges GS8150200 and GS8150097 from August 2010 to the end of July 2011 (using auto samplers) and analyzed for major ion content and total metal concentrations. Ten grab samples were also collected by EMU staff from gauges GS8150200, GS8150097, and the mid-station gauge during the 2010/2011 wet season:

- One sample was collected from each gauge during the ‘build-up’ to the wet season;
- Six samples were collected during the period of sustained river flow from the beginning of January to mid-April; and
Three samples were collected during the period of recessional flows from April to the end of June.

Grab samples were analyzed for major ions and concentrations of total and dissolved metals (see Figure 3-2 for sampling dates). Concentrations of \( \text{SO}_4 \) and a selection of total and dissolved metals in grab samples from the East Branch of the Finniss River are provided in Table 3-3 and time trends for \( \text{SO}_4 \) and selected metals are shown in Figures 3-3 to 3-8.

### Table 3-3.

**Contaminant concentrations in grab samples from the East Branch of the Finniss River, 2010/2011**

<table>
<thead>
<tr>
<th>Gauge</th>
<th>( \text{SO}_4 ) (mg/L)</th>
<th>As (Diss. Total)</th>
<th>Cd (Diss. Total)</th>
<th>Co (Diss. Total)</th>
<th>Cu (Diss. Total)</th>
<th>Fe (Diss. Total)</th>
<th>Mn (Diss. Total)</th>
<th>Pb (Diss. Total)</th>
<th>Ni (Diss. Total)</th>
<th>Zn (Diss. Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First flush</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EFDC</td>
<td>1210</td>
<td>6 -</td>
<td>8.8</td>
<td>8.4</td>
<td>4540</td>
<td>4560</td>
<td>6910</td>
<td>12200</td>
<td>&lt;200</td>
<td>1600</td>
</tr>
<tr>
<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><strong>Build Up</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS8150200</td>
<td>373</td>
<td>0.6</td>
<td>0.9</td>
<td>1.8</td>
<td>1.9</td>
<td>778</td>
<td>812</td>
<td>244</td>
<td>466</td>
<td>20</td>
</tr>
<tr>
<td>GS8150097</td>
<td>159</td>
<td>0.6</td>
<td>1.0</td>
<td>0.2</td>
<td>0.2</td>
<td>31</td>
<td>38</td>
<td>22</td>
<td>39</td>
<td>20</td>
</tr>
<tr>
<td><strong>High flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS8150200</td>
<td>62</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>108</td>
<td>113</td>
<td>89</td>
<td>145</td>
<td>98</td>
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<tr>
<td>GS8150097</td>
<td>40</td>
<td>0.4</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
<td>45</td>
<td>47</td>
<td>55</td>
<td>112</td>
<td>91</td>
</tr>
<tr>
<td><strong>Receding flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS8150200</td>
<td>267</td>
<td>0.4</td>
<td>0.4</td>
<td>1.4</td>
<td>1.5</td>
<td>45</td>
<td>47</td>
<td>50</td>
<td>63</td>
<td>59</td>
</tr>
<tr>
<td>GS8150097</td>
<td>169</td>
<td>0.3</td>
<td>0.4</td>
<td>0.9</td>
<td>1.0</td>
<td>301</td>
<td>298</td>
<td>62</td>
<td>74</td>
<td>38</td>
</tr>
<tr>
<td><strong>Dry Season</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS8150200</td>
<td>1110</td>
<td>1.1</td>
<td>1.2</td>
<td>9.6</td>
<td>10.2</td>
<td>3770</td>
<td>3840</td>
<td>938</td>
<td>1220</td>
<td>20</td>
</tr>
<tr>
<td>GS8150097</td>
<td>309</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>10</td>
<td>10</td>
<td>16</td>
<td>19</td>
<td>20</td>
</tr>
</tbody>
</table>

Note: Shaded concentrations exceed the trigger value from the ANZECC water quality guidelines
- \( ^a \) Data from sample collected on August 6, 2010
- \( ^b \) Data from sample collected on December 10, 2010
- \( ^c \) Flow-weighted average concentrations for the high flow period
- \( ^d \) Flow-weighted average concentrations for the receding flow period
- \( ^e \) Data from sample collected on June 29, 2011

Key trends in the surface water quality data for the East Branch of the Finniss River are summarized as follows:

- Contaminant concentrations are higher at gauge GS8150200 than downstream at gauge GS8150097; lower concentrations downstream reflect the dilution of contaminants in the river by inflows of surface water from Old Tailings Creek and several other tributaries downstream of the mid-station gauge.
Contaminant concentrations in the East Branch of the Finniss River are high during the early ‘build up’ period as water in the river channel at this time represents a mixture of dry season seepage and/or river water that has re-dissolved residual metal salts from the previous wet season; no representative water quality data for the ‘first flush’ of the 2010/2011 wet season are available (as the first samples were not collected until December after several rainfall events of close to 50 mm had occurred in October); Cu, Ni, and Zn concentrations in the samples from December exceeded ANZECC trigger values;

Contaminant concentrations decrease during the period of sustained river flow from December to mid-April due to dilution by flows of unimpacted river water from upstream; concentrations are particularly dilute during periods of intense rainfall due to high surface runoff; Cu concentrations at gauge GS8150200 and GS8150097 exceeded the ANZECC trigger value throughout the wet season; Zn concentrations at gauge GS8150200 exceeded the ANZECC trigger value;

Contaminant concentrations in the river generally remain low until mid-April when flows in the river begin to recede and concentrations increase towards dry season levels due to a lack of dilution (see Figure 3-3b); surface water quality conditions in the East Branch of the Finniss River were poorest at the end of June 2011 and high concentrations likely persist throughout the subsequent dry season; Cd, Cu, Ni, Mn, and Zn concentrations all exceeded the ANZECC trigger values at gauge GS8150200 at this time (and Al and Co concentrations were very high);

Contaminant concentrations downstream at gauge GS8150097 are much lower than at gauge GS8150200 during the period of receding flow; surface water quality improves downstream of gauge GS8150200 as dissolved metals precipitate due to the discharge of well-buffered groundwater from the Coomalie Dolostone to the river (either directly or via standing pools of water); precipitated material consists of sulphate and metal salts that will be re-dissolved in the first flows of the 2011/2012 wet season;

Total concentrations of Cu, Pb, and Fe are higher than dissolved concentrations of these metals; the discrepancy is particularly apparent during the wet season when particulate loads of these metals are highest (see Section 4.2.3).

Surface water quality conditions will be discussed further in the next section in the context of describing contaminant loads from the Rum Jungle Mine Site.
4 DISCUSSION

4.1 ANNUAL CONTAMINANT LOADS

Annual loads of SO\(_4\) and selected metals from the flooded open pits and in the East Branch of the Finniss River for 2010/2011 are summarized in Table 4-1. Also provided in Table 4-1 are average contaminant loads from 1993 to 1998 from RGC (2011).

Loads for 2010/2011 were estimated from annual flow volumes from August 2010 to end the end of July 2011 and flow-weighted SO\(_4\) and metal concentrations described in Section 3.3.2. Flow-weighted SO\(_4\) concentrations from the 204 samples collected from the East Branch of the Finniss River were used to estimate annual SO\(_4\) loads.

Table 4-1.

Current and historic contaminant loads in the East Branch of the Finniss River

<table>
<thead>
<tr>
<th>Source or Location</th>
<th>Flow, Mm(^3)</th>
<th>Annual Loads, t</th>
<th>Source or Location</th>
<th>Flow, Mm(^3)</th>
<th>Annual Loads, t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SO(_4)</td>
<td>Cu</td>
<td></td>
<td>Mn</td>
</tr>
<tr>
<td>Post-rehabilitation loads (mid-1990s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To the Main Open Pit</td>
<td>14</td>
<td>608</td>
<td>0.6 (3.0)</td>
<td>2.0 (2.1)</td>
<td>0.5 (0.8)</td>
</tr>
<tr>
<td>From the Intermediate Open Pit</td>
<td>14</td>
<td>1128</td>
<td>3.0 (3.6)</td>
<td>11.9 (12.2)</td>
<td>3.7 (1.5)</td>
</tr>
<tr>
<td>EBFR at gauge GS8150200 (“road bridge”)</td>
<td>34</td>
<td>3672</td>
<td>5.3 (14.3)</td>
<td>24.3 (26.8)</td>
<td>5.3 (5.9)</td>
</tr>
<tr>
<td>EBFR at gauge GS8150097 (“rail bridge”)</td>
<td>40</td>
<td>3864</td>
<td>5.2 (12.4)</td>
<td>23.0 (25.3)</td>
<td>4.8 (5.5)</td>
</tr>
<tr>
<td>Loads for 2010/2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From the Intermediate Open Pit</td>
<td>15</td>
<td>219</td>
<td>1.6 (1.6)</td>
<td>5.7 (6.1)</td>
<td>0.8 (0.8)</td>
</tr>
<tr>
<td>EBFR at gauge GS8150200 (“road bridge”)</td>
<td>69</td>
<td>3426</td>
<td>6.2 (9.6)</td>
<td>16.4 (17.1)</td>
<td>5.5 (6.2)</td>
</tr>
<tr>
<td>EBFR at gauge GS8150097 (“rail bridge”)</td>
<td>120</td>
<td>3337</td>
<td>5.8 (12.7)</td>
<td>16.1 (18.4)</td>
<td>4.6 (4.6)</td>
</tr>
</tbody>
</table>

Note: ‘Total’ loads (i.e. particulate plus dissolved loads) are bracketed

Dissolved metal concentrations were not available for the 204 samples collected in 2010/2011 so flow-weighted total and dissolved concentrations from the grab samples were used instead. Flow-
weighted total metal concentrations from the grab samples are about 10 to 20% higher than the flow-weighted average from the more frequently-collected samples. This implies that metal loads for 2010/2011 could be over-estimated by proportion (see Section 4.2.1).

Key observations regarding loads for 2010/2011 are summarized as follows:

- The annual SO₄ load in the East Branch of the Finniss River for 2010/2011 was about 3,400 t; the SO₄ load downstream at gauge GS8150097 was essentially identical within the uncertainties ascribed to flows and weighted SO₄ concentrations in the river; this implies that any SO₄ load delivered to the East Branch of the Finniss River between these gauges via discharging groundwater is relatively insignificant;

- Annual loads of dissolved metals range from 5 t for Cu and Ni to 24 t for Mn; river-borne loads were conserved downstream and any small differences in loads at gauges GS8150200 and GS8150097 are ascribed to the precipitation of metals in the river and/or minor uncertainties in flow volumes; total Cu and Fe loads are much higher than dissolved loads of these metals (see Section 4.2.3);

- The annual SO₄ load from the Intermediate Open Pit accounted for less than 5% of the total load in the East Branch of the Finniss River at gauge GS8150200; the Intermediate Open Pit was a larger source of metals (e.g. 25% for Cu) than SO₄ to the river due to loads from untreated pit water and/or groundwater that discharges to the pit from the Copper Extraction Pad area.

The annual SO₄ load to the East Branch of the Finniss River for 2010/2011 was about 10% lower the average SO₄ load from 1993 to 1998. This reduction is likely caused by smaller loads from the flooded Open Pits due to an improvement in pit water quality that has occurred since the 1990s. It should be noted, however, that the discrepancy in sulphate loads is relatively small and may, at least in part, be due to errors and/or uncertainties in river flow data. The improvement in pit water quality is related to the perennial flushing of deep, untreated water from the pits to the East Branch of the Finniss River and is particularly evident from the reduction in Mn loads at gauge GS8150200 since the mid-1990s (see Table 4-1).

4.2 CONTAMINANT SOURCES

The main sources of dissolved contaminants to the East Branch of the Finniss River are as follows:

- Seepage from waste rock stored in the overburden heaps (Main, Intermediate, Dyson’s);

- Seepage from a mixture of waste rock, heap leach material, and contaminated soils used to backfill shallow portions of Dyson’s Overburden Heap;

- Highly-impacted groundwater from the former Copper Extraction Pad area and/or untreated pit water at the bottoms of the open pits.
The majority of SO$_4$ and dissolved metals in the East Branch of the Finniss River are derived from waste rock seepage or seepage from shallow backfill material in Dyson’s Open Pit that can be reasonably well-simulated with seepage water quality and calibrated recharges from RGC (2012). Loads from RGC (2012) accounted for the majority of the observed SO$_4$ and metal loads at gauge GS8150200 for 2010/2011. Ni and Zn loads are particularly well-explained by simulated seepage loads but SO$_4$, Cu, and Mn loads are under-estimated.

Under-estimation of SO$_4$ and metal loads in the East Branch of the Finniss River by simulated seepage loads from RGC (2012) is related in part to unaccounted loads from the flooded open pits. Loads from these sources were not included in the simulated load estimates reported in RGC (2012) because surface water flows from the open pits are not modeled or representative water quality data could not be assigned to groundwater flows. Adding observed loads from the flooded open pits for 2010/2011 to the simulated loads from RGC (2012) does, however, allow 73% of the observed SO$_4$ load in the river and about 80 to 90% of dissolved metal loads to be explained (see Table 4-3).

**Table 4-3.**

**Observed and simulated loads in the East Branch of the Finniss River, 2010/2011**

<table>
<thead>
<tr>
<th>Source or location</th>
<th>SO$_4$</th>
<th>Cu</th>
<th>Mn</th>
<th>Ni</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed loads at gauge GS8150200</td>
<td>3426</td>
<td>6.2</td>
<td>16.4</td>
<td>5.5</td>
<td>7.8</td>
</tr>
<tr>
<td>Simulated loads* + loads at gauge GS8150212</td>
<td>2494</td>
<td>5.2</td>
<td>14.8</td>
<td>5.0</td>
<td>6.9</td>
</tr>
<tr>
<td>Simulated/observed:</td>
<td>0.73</td>
<td>0.84</td>
<td>0.90</td>
<td>0.91</td>
<td>0.88</td>
</tr>
</tbody>
</table>

* From RGC (2012)

The small discrepancy in dissolved metal loads that remains can be explained by a combination of the following factors:

- Calibrated recharges for the Main and Intermediate Overburden Heaps from RGC (2012) could be too low (i.e. more than 25% of net rainfall infiltrated to the heaps in 2010/2011);
- The limited seepage water quality data that are available are unrepresentative of seepage from the overburden heaps and shallow backfill materials in Dyson’s Open Pit (either due to spatial heterogeneity or changes over time);
- Observed loads in the East Branch of the Finniss River are over-estimated by 10 to 20% due to the use of total and dissolved metal concentrations in grab samples (see Section 4.1);
Some of these uncertainties could be reduced when the numerical groundwater flow model is recalibrated and additional measurements of toe seepage and seepage water quality data for 2011/2012 are available.

Total annual loads of Cu (and Fe) in the East Branch of the Finniss River are substantially higher than dissolved loads (see Table 4-1). Higher total loads in the river could be related to the discharge of impacted groundwater from the Copper Extraction Pad area to the EFDC and/or high particulate loads of Cu during peak flow periods due to fluvial erosion and surface losses from the overburden heaps.

The importance of physical erosion processes on Cu loads was highlighted by field measurements of sheet erosion from the Old Tailings Dam and Main Overburden Heap provided in Davy (1975). Specifically, that study concluded that:

- About 1 cm of tailings (or 400 t) was typically eroded from the Old Tailings Dam during an average wet season and a significant amount of this material ended up in the East Branch of the Finniss River or deposited along its floodplain;
- Particulate loads of Cu were negligible in early, low flow runoff from the Main Overburden Heap but represented about 50% of the total load of Cu carried from the Main Overburden Heap at the peak of a storm event.

These pre-rehabilitation erosion and surface loss rates do not apply today as the Old Tailings Dam area has been reclaimed and the overburden heaps have been covered but the same processes likely still occur at the site (albeit at reduced rates). These processes could explain in part the consistently higher concentrations of total Cu in the river during high flow periods in the 1990s (see Appendix A) and in surface water monitoring data for 2010/2011 (see Table 3-3).

Each of the alternative rehabilitation options outlined in RGC (2012) is expected to reduce any surface losses and hence particulate loads can be expected to be reduced in tandem with dissolved loads (after any residual contaminants are flushed to the river). Loads from diffuse sources (and any potential loads from the Copper Extraction Pad area) are not expected to be reduced and surface water quality in the East Branch of the Finniss River could therefore be adversely affected after rehabilitation.

The numerical groundwater flow model for the mine site (and historical evidence) suggests that groundwater discharges to the EFDC from the north (see RGC, 2012). For 2010/2011, the average rate of groundwater discharge from this area was 3.4 L/s during the high flow period from December to April (and peaked at 5 L/s in March). At these flows, discharging groundwater would have to contain about 80 mg/L Cu to account for the Cu load in the East Branch of the Finniss River that cannot be explained by seepage loads.
Very high metal concentrations characterize groundwater in the Copper Extraction Pad area (i.e. 500 mg/L at bore PMB23) and local groundwater flow fields between this area and the EFDC are not well-constrained (RGC, 2012). Additional loads from the Copper Extraction Pad area cannot, therefore, be ruled out without additional information on groundwater quality conditions north of the EFDC.

The installation of five additional monitoring wells along the road north of the EFDC is therefore recommended to further delineate the metal plume near the former Copper Extraction Pad area (see proposed locations in Figure 3-9). Data from these bores would enable any potential loads from groundwater in the Copper Extraction Pad area to be assessed prior to further rehabilitation.

4.3 IMPLICATIONS FOR REHABILITATION

4.3.1 Contaminants of Concern

The majority of observed metal loads in the river in 2010/2011 can be explained by seepage loads from the overburden heaps and Dyson’s (backfilled) Open Pit. Loads from each of these sources are expected to be significantly reduced by the implementation of a more effective rehabilitation strategy for the site and therefore a considerable improvement in surface water quality downstream of the site is anticipated.

Loads from diffuse groundwater discharge or the discharge of impacted groundwater from the Copper Extraction Pad area to the East Branch of the Finniss River are not expected to be decreased by the conceptual rehabilitation options outlined in RGC (2012). Metals loads from these sources are, however, relatively small and any SO₄ loads from the flooded open pits or Copper Extraction Pad area report to the East Branch of the Finniss River during high flow periods when dilution is highest.

In 2010/2011, SO₄ concentrations in the East Branch of the Finniss River at gauge GS8150200 only reached half of the 2,000 mg/L guideline concentration for livestock at the end of the wet season and during the subsequent dry season (see Table 4-4a). Downstream at the mid-station gauge and gauge GS8150097, SO₄ concentrations in the river were much lower than the guideline concentration during this low flow period (see Table 4-4b). High SO₄ concentrations immediately downstream of the mine site are therefore not considered a major source of concern (as any rehabilitation strategy that reduces metal loads would also reduce the SO₄ load).

Cd, Cu, Mn, Ni, and Zn are considered the principal contaminants of concern near the Rum Jungle Mine Site. Cu is of particular concern because concentrations of this metal consistently exceed the trigger value from the ANZECC water quality guidelines during the high and low flow periods (see Table 4-4). At gauge GS8150200, concentrations of Cd, Mn, Ni, and Zn exceeded trigger values from the ANZECC water quality guidelines during lower flow periods when dilution is minimal. Al and Co concentrations are also high at this time and are considered contaminants of concern.
Dissolved metal concentrations were substantially lower downstream at the mid-station gauge (see Table 4-4b). Only Cu, Ni, and Zn concentrations exceeded the trigger values from the ANZECC water quality guidelines at the end of the wet season at this location. Flow-weighted concentrations are not yet available at the mid-station gauge but this gauge still seems most likely to be used as a compliance point for post-rehabilitation surface water monitoring.

Table 4-4a.

Dry and wet season contaminant concentrations in the East Branch of the Finniss River at gauge GS8150200, 2010/2011

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Dry Season</th>
<th>Wet Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed Concentration</td>
<td>Trigger Value</td>
</tr>
<tr>
<td>SO₄, mg/L</td>
<td>1110</td>
<td>2000</td>
</tr>
<tr>
<td>Cd</td>
<td>9.6</td>
<td>2</td>
</tr>
<tr>
<td>Co</td>
<td>3770</td>
<td>n/a</td>
</tr>
<tr>
<td>Cu</td>
<td>938</td>
<td>13</td>
</tr>
<tr>
<td>Mn</td>
<td>6400</td>
<td>1900</td>
</tr>
<tr>
<td>Ni</td>
<td>3280</td>
<td>104</td>
</tr>
<tr>
<td>Pb</td>
<td>0.1</td>
<td>40</td>
</tr>
<tr>
<td>Zn</td>
<td>5360</td>
<td>76</td>
</tr>
</tbody>
</table>

Metals/metalloid concentrations in μg/L
Shaded concentrations are higher than the trigger value from the ANZECC water quality guidelines.
Table 4-4b.
Dry and wet season contaminant concentrations in the East Branch of
the Finniss River at the mid-station gauge, 2010/2011

<table>
<thead>
<tr>
<th>Gauge GS8150097</th>
<th>Dry Season</th>
<th>Wet Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contaminant</td>
<td>Observed Concentration</td>
</tr>
<tr>
<td></td>
<td>SO₄, mg/L</td>
<td>567</td>
</tr>
<tr>
<td></td>
<td>Cd</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Co</td>
<td>276</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Mn</td>
<td>747</td>
</tr>
<tr>
<td></td>
<td>Ni</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Zn</td>
<td>295</td>
</tr>
</tbody>
</table>

Metals/metalloid concentrations in μg/L

Shaded concentrations are higher than the trigger value from the ANZECC water quality guidelines.

No flow data is available for this gauge so wet season concentrations cannot be determined.
### Table 4-4c.

Dry and wet season contaminant concentrations in the East Branch of the Finniss River at gauge GS8150097, 2010/2011

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Dry Season</th>
<th>Wet Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed Concentration</td>
<td>Trigger Value</td>
</tr>
<tr>
<td>SO₄, mg/L</td>
<td>309</td>
<td>2000</td>
</tr>
<tr>
<td>Cd</td>
<td>0.2</td>
<td>4</td>
</tr>
<tr>
<td>Co</td>
<td>10</td>
<td>n/a</td>
</tr>
<tr>
<td>Cu</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>Mn</td>
<td>56</td>
<td>1900</td>
</tr>
<tr>
<td>Ni</td>
<td>64</td>
<td>199</td>
</tr>
<tr>
<td>Pb</td>
<td>0.1</td>
<td>106</td>
</tr>
<tr>
<td>Zn</td>
<td>51</td>
<td>145</td>
</tr>
</tbody>
</table>

Metals/metalloid concentrations in μg/L

Shaded concentrations are higher than the trigger value from the ANZECC water quality guidelines.

#### 4.3.2 Post-Rehabilitation Water Quality Objectives

Surface water monitoring data for 2010/2011 were assessed in light of the 95% protection level trigger values from the ANZECC water quality guidelines. The key conclusions from this assessment are summarized as follows:

- During the high flow period from December to mid-April, Cu concentrations in the East Branch of the Finniss River exceeded the trigger value from the ANZECC water quality guidelines at gauges GS8150200 and GS8150097;
- During the period of receding flow and the subsequent dry season, Cd, Cu, Mn, Ni, and Zn concentrations in the East Branch of the Finniss River exceeded the trigger values from the ANZECC water quality guidelines at gauges GS8150200 and GS8150097.

These exceedances highlight the importance of developing flow-specific WQOs for the East Branch of the Finniss River that could be used to evaluate post-rehabilitation performance. Trigger values from the ANZECC water quality guidelines may provide the basis for developing site-specific WQOs but it is strongly recommended that a quantitative ecological risk assessment (ERA) for the East Branch of the Finniss River be completed prior to finalizing any revised rehabilitation strategy.
The fundamental objective of the ERA is to evaluate the current ecological conditions in the East Branch of the Finniss River and provide a set of post-rehabilitation WQOs that would ensure adequate protection of the local aquatic ecology. Analysis of surface water monitoring data for 2011/2012 will assist in developing a range of potential contaminant levels to be evaluated and hence is recommended prior to initiating the ERA.

4.3.3 Alternative Rehabilitation Scenario

A series of alternative rehabilitation options were conceptualized in RGC (2012) for purposes of discussion. The list of options was not considered comprehensive and other options were outlined in SRK (2012). The rehabilitation options included one or more of the following measures:

- Collecting and treating waste rock seepage;
- Re-covering the overburden heaps and Dyson’s (backfilled) Open Pit; and
- Re-locating waste rock into the open pits (under water) to limit further oxidation.

Each of these options is expected to improve surface water quality conditions in the East Branch of the Finniss River by reducing contaminant loads from the various sources of ARD at the Rum Jungle Mine Site. Factors such as cost, reducing radiological hazards, long-term physical stability, and/or site aesthetics were not considered in RGC (2012) but will likely influence the selection of a preferred rehabilitation option.

An additional rehabilitation option is proposed here based on results of the surface water quality and load balance assessment for 2010/2011. This option represents an active water management strategy that involves the following measures:

- Re-locating waste rock from the Intermediate Overburden Heap to the Main Open Pit;
- Diverting the East Branch of the Finniss River to the Main Open Pit during low flow periods;
- Controlling outflow from the Intermediate Open Pit to the East Branch of the Finniss River during high flow periods;
- Constructing a wetland along the EFDC.

Diverting the East Branch of the Finniss River to the Main Open Pit involves constructing a dam at the head of the EFDC (near the weir structure). This dam would have the opposite effect as the current hydrological design, as any dry season seepage from the Main Overburden Heap and early wet season flows in the river would accumulate behind this dam and be gravity-fed to the Main Open Pit.

Diverting dry season flows in the East Branch of the Finniss River to the Main Open Pit (and re-locating the Intermediate Overburden Heap) would eliminate the annual ‘first flush’ of contaminants that can be detrimental to aquatic ecology downstream of the mine site. Moreover, any contaminants
from seepage would be attenuated in the Main Open Pit and only report to the East Branch of the Finniss River during the high flow period after passing through both pits.

The wetland to be constructed as part of this scenario would essentially be an extension of the swampland that characterizes Fitch Creek near the former Sweetwater Dam and would attenuate any sub-surface loads from the Main Overburden Heap and/or Copper Extraction Pad area to the EFDC. Alternatively, the wetland could be constructed and then the entire EFDC could be backfilled in order to leave the area as it appeared prior to mining operations. The key is that a wetland system capable of attenuating metal loads (via reduction and precipitation of metals in acidic seepage) be in place to ensure negligible post-rehabilitation loads from these sources to the East Branch of the Finniss River.

Potential cost savings is a major benefit of this rehabilitation option as it involves limited earthmoving costs, eliminates the need for a water treatment plant, and may not require re-covering of the Main Overburden Heap or the waste units in Dyson’s Area. It is therefore recommended that this alternative rehabilitation approach be considered along with the five other options outlined in RGC (2012).
5 CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Surface water

Surface water monitoring data for 2010/2011 were assessed against the 95% protection level trigger values from the ANZECC water quality guidelines. ANZECC trigger values equate to ecologically low-risk levels of physicochemical indicators for sustained exposure and are concentrations that, if exceeded, would indicate a potential environmental problem (LPSDP, 2007).

Key conclusions from the assessment of 2010/2011 surface water monitoring data are summarized as follows:

- Contaminant concentrations in shallow pit water in 2010/2011 were generally low but concentrations of Cu, Ni, and Zn (and sometimes Al) exceeded the trigger values from the ANZECC water quality guidelines; concentrations of Cu and Zn were notably higher in the Intermediate Open Pit than in the Main Open Pit (likely due to loads from contaminated groundwater in the Copper Extraction Pad area);
- In the East Branch of the Finniss River, only Cu concentrations exceeded the trigger value from the ANZECC water quality guidelines during the high flow period from December to mid-April; flow-weighted dissolved Cu concentrations were 5 to 10 times higher than the trigger value (11 μg/L) but much lower concentrations were observed in the river during peak flow periods; Cu concentrations are expected to be substantially lowered by implementing a revised rehabilitation strategy and hence wet season water quality conditions in the river are not considered a major source of concern (after implementation of any of the proposed rehabilitation options);
- Very high concentrations of Cd, Cu, Mn, Ni, and Zn characterize the EFDC and the East Branch of the Finniss River near gauge GS8150200 during the period of receding river flows at the end of the wet season and throughout the subsequent dry season; some precipitates that accumulate along the river bed during this period are re-dissolved in the (acidic) first flows of the following wet season and contribute to the ‘first flush’ of contaminants towards the main Finniss River; the ‘first flush’ of contaminants can be particularly detrimental to aquatic ecology and reducing its severity by establishing stringent post-rehabilitation WQOs for the dry season (and subsequent “first flush”) is considered a priority;
5.1.2 Contaminant loads

Contaminant loads from the flooded Open Pits and in the East Branch of the Finniss River for 2010/2011 were estimated from annual flow volumes and flow-weighted contaminant concentrations. Key aspects of this load assessment are summarized as follows:

- The annual SO$_4$ load in the East Branch of the Finniss River for 2010/2011 was about 3,400 t (or about 10% lower than the average SO$_4$ load in the mid-1990s); this small discrepancy is attributed in part to smaller loads from the flooded Open Pits due to an improvement in pit water quality that has occurred since the 1990s but may also be partly explained by errors and uncertainties in river flow data;

- Annual loads of dissolved metals in the East Branch of the Finniss River range from 5 t for Cu and Ni to 24 t for Mn; river-borne loads were generally conserved downstream and any small differences in loads at gauges GS8150200 and GS8150097 are ascribed to the precipitation of metals from the river and/or minor uncertainties in flow volumes;

- The total Cu load in the river is much higher than the dissolved Cu load due primarily to high particulate loads of this metal that are related to physical erosion and surface losses from the overburden heaps; surface losses from the Intermediate Overburden Heap may be particularly high due to the poor condition of its northern batter (which terminates in the EFDC); total and dissolved loads of Mn, Ni and Zn were comparable due to the high solubility of these metals under near-neutral pH conditions in the river;

- The annual SO$_4$ load from the Intermediate Open Pit accounted for less than 5% of the total load in the East Branch of the Finniss River at gauge GS8150200; the Intermediate Open Pit was a larger source of metals (e.g. 25% for Cu) than SO$_4$ to the river due to loads from untreated pit water and/or highly impacted groundwater that discharges to the pit from the Copper Extraction Pad area.

5.2 Recommendations

We recommend that a quantitative ecological risk assessment (ERA) be completed prior to finalizing a revised rehabilitation strategy for the Rum Jungle Mine Site.

The following work is recommended prior to initiating an ERA:

- Assessment of surface water quality conditions and contaminant loads in the East Branch of the Finniss River for 2011/2012 in light of lower than average rainfall for that year;

- Refinement of the preliminary contaminant load estimates from RGC (2012) using more detailed measurements of toe seepage and seepage water quality data collected during the 2011/2012 wet season;
• Delineation of the contaminant plume near the former Copper Extraction Pad via the installation of five additional monitoring bores to the north of the EFDC (see Figure 3-9);
• Further evaluation of the active water management strategy described in this report along with the five other alternative rehabilitation options outlined in RGC (2012).

Completion of this work will enable contaminant loads and current surface water quality conditions in the East Branch of the Finniss River to be well-constrained and thereby enable the DoR to develop quantitative post-rehabilitation success criteria prior to implementing a more effective rehabilitation strategy for the Rum Jungle Mine Site.

6 CLOSURE

Robertson GeoConsultants Inc. (RGC) is pleased to submit this report entitled Phase 3 (Stage 3 Report): Surface Water Quality and Contaminant Load Assessment for the Rum Jungle Mine Site, NT.

This report was prepared by Robertson GeoConsultants Inc. for the use of the NT Department of Resources and prior consent by the Department should be given 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    Dr. Christoph Wels, M.Sc., P.Geo.
Senior Geochemist    Principal & Senior Hydrogeologist
7 REFERENCES


Appleyard, S. (1983), Groundwater investigations at Rum Jungle April to December 1983. Water Division; Department of Transport and Works.


RGC (2012), Phase 3 (Stage 2 Report) - Groundwater Flow Model for the Rum Jungle Mine Site, NT, April 2012.

SRK (2012), Geochemical Characterisation of Waste at the former Rum Jungle Mine Site, March 2012.


Figure 2-4. Air photo with pertinent features of the Rum Jungle Mine Site
Figure 3-1. Electrical conductivity profiles for the Main and Intermediate Open Pits
Figure 3-2. River flows and field EC measurements for the East Branch of the Finniss River.
Figure 3-3a. Dissolved SO₄ concentrations in the East Branch of the Finnis River, 2010/2011 Wet Season
Figure 3-3b. Dissolved SO₄ concentrations in the East Branch of the Finniss River, 2010/2011 Wet Season
Figure 3-3c. Dissolved SO$_4$ concentrations in the East Branch of the Finniss River, 2010/2011 Wet Season
Figure 3-4. Total nickel concentrations in the East Branch of the Finniss River, 2010/2011 Wet Season
Figure 3-5. Total zinc concentrations in the East Branch of the Finniss River, 2010/2011 Wet Season

- **'Build Up'**
  - Receding river flows
  - (increasing Zn concentrations at GS8150200)

- **High Flow Period**
  - (low Zn concentrations)
Figure 3-6. Total manganese concentrations in the East Branch of the Finnis River, 2010/2011 Wet Season
Figure 3-7. Total copper concentrations in the East Branch of the Finniss River, 2010/2011 Wet Season

- 'Build Up' High Flow Period (low dissolved Cu, high total Cu)
- Particularly high total Cu at peak flows

Data points for:
- Gauge GS8150200
- Mid-Station Gauge
- Gauge GS8150097
Figure 3-8. Total iron concentrations in the East Branch of the Finniss River, 2010/2011 Wet Season

- ‘Build Up’ (low dissolved Fe, high total Fe)
- Receding river flows
- Particularly high total Fe under peak flow conditions
Proposed Monitoring Bore
Near the East Finniss Diversion Channel
Rum Jungle Mine Site
SCALE

LEGEND

Geological Formation
White Formation
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
Proposed Monitoring Bore

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

FIGURE: 3-9

CLIENT: Department of Resources NT Government
PROJECT: Flow Modelling & Contaminant Load Balance


APPENDIX A

Historic surface water quality
**Figure A-1a. EC and SO₄ concentrations in the East Branch of the Finniss River at gauge GS8150097, 1990/1991**

<table>
<thead>
<tr>
<th>Date</th>
<th>EC or concentration (mg/L or uS/cm)</th>
<th>Dissolved SO₄</th>
<th>Electrical Conductivity</th>
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<tr>
<td>14-Jun-91</td>
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</tbody>
</table>

- After the 'first flush', contaminant concentrations decrease in response to sustained river flows.
- Contaminant concentrations diluted during peak flow.
- Contaminant concentrations increased during period of receding flows.
- Period of receding river flow interrupted (dilution occurs).
- High contaminant concentrations throughout the dry season.
Figure A-1b. Zn concentrations in the East Branch of the Finniss River at gauge GS8150097, 1990/1991.
Figure A-1c. Mn concentrations in the East Branch of the Finniss River at gauge GS8150097, 1990/1991.
Fluvial erosion and surface losses from the heaps cause high particulate loads of Cu in the river during high flow periods.
Figure A-2a. EC and SO₄ concentrations in the East Branch of the Finniss River at gauge GS8150097, 1991/1992
Figure A-2b. Zn concentrations in the East Branch of the Finnis River at gauge GS8150097, 1991/1992

- **Dissolved Zn**
- **Total Zn**

‘Total’ and ‘dissolved’ Zn concentrations are nearly equivalent throughout the year.

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**East Branch of the Finnis River at gauge GS8150097**

Date

- 30-Dec-91
- 15-Jan-92
- 30-Jan-92
- 15-Feb-92
- 30-Feb-92
- 15-Mar-92
- 30-Mar-92
- 14-Apr-92
- 29-Apr-92
- 14-May-92
- 29-May-92
- 13-Jun-92

Concentration (mg/L)

- Dissolved Zn
- Total Zn

Flow (Mm³)

- 0.0
- 2.5
- 5.0
- 7.5
- 10.0

River Flow

Flow (Mm³) vs. Concentration (mg/L)

1.0

0.0
Figure A-2c. Mn concentrations in the East Branch of the Finniss River at gauge GS8150097, 1991/1992.
Figure A-3a. EC measurements and SO$_4$ concentrations in the East Branch of the Finniss River at gauge GS8150097, 1992/1993
Figure A-3b. Zn concentrations in the East Branch of the Finniss River at gauge GS8150097, 1992/1993.
Figure A-3c. Mn concentrations in the East Branch of the Finiss River at gauge GS8150097, 1992/1993
Figure A-3d. Ni concentrations in the East Branch of the Finniss River at gauge GS8150097, 1992/1993.
Figure A-3e. Fe concentrations in the East Branch of the Finniss River at gauge GS8150097, 1992/1993.
Figure A-3f. Cu concentrations in the East Branch of the Finniss River at gauge GS8150097, 1992/1993
Contaminant concentrations decrease in response to sustained flows throughout the wet season. Contaminant concentrations diluted by higher flows that occur during the wet season. Higher flows during recessional flow period cause flushing.
Contaminant concentrations decrease in response to sustained flows throughout the wet season. Higher flows during recessional flow period cause flushing. Zn concentrations remain low throughout the wet season.

Figure A-4b. Zn concentrations in the East Branch of the Finniss River at gauge GS8150097, 1994/1995
Figure A-4c. Mn concentrations in the East Branch of the Finnis River at gauge GS8150097, 1994/1995

Mn concentrations remain low throughout the wet season (‘total’ and ‘dissolved’ concentrations nearly equivalent)

Occasional flushing of contaminants during intermittent high flow periods
Figure A-4d. Ni concentrations in the East Branch of the Finniss River at gauge GS8150097. 1994/1995
Figure A-4e. Fe concentrations in the East Branch of the Finniss River at gauge GS8150097, 1994/1995
Figure A-4f. Cu concentrations in the East Branch of the Finniss River at gauge GS8150097, 1994/1995

‘Total’ Cu concentrations are much higher than ‘dissolved’ Cu concentrations due to higher particulate Cu loads related to fluvial erosion and surface losses.