REPORT NO. 183002/1

PHASE 2 REPORT - DETAILED WATER QUALITY REVIEW & PRELIMINARY CONTAMINANT LOAD ESTIMATES, RUM JUNGLE MINE SITE, NT

Submitted to:

Northern Territory Government
Department of Resources - Minerals and Energy

Prepared by:

Robertson GeoConsultants Inc.
Consulting Engineers and Scientists for the Mining Industry
www.robertsongeoconsultants.com

February 2011

REPORT NO. 183002/1

PHASE 2 REPORT - DETAILED WATER QUALITY REVIEW & PRELIMINARY CONTAMINANT LOAD ESTIMATES, RUM JUNGLE MINE SITE, NT

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

REPORT NO. 183002/1

PHASE 2 REPORT - DETAILED WATER QUALITY REVIEW & PRELIMINARY CONTAMINANT LOAD ESTIMATES, 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 East Finniss River. Rum Jungle was one of Australia's first major uranium mines and produced approximately 3,500 tonnes of uranium between 1954 and 1971. Acid rock drainage (ARD) and heavy metal mobilization at the site have led to significant environmental impacts on groundwater and the East Finniss River and localized concentrations of radioactive tailings that present a potential radiological hazard (Kraatz, 2004). From 1983 to 1986, Rum Jungle was rehabilitated under an $18.6 million cooperative agreement between the Commonwealth and Northern Territory Governments. Initial monitoring activities indicated that the rehabilitation program met its original objectives yet recent monitoring has documented a deterioration of the site's historic rehabilitation works. Today the contamination of local groundwater and the East Finniss River continues and the site is recognized as an ongoing environmental concern (Ryan et al., 2009).

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

In June 2010, RGC submitted an initial review of historic geochemical and hydrogeological data collected from the Rum Jungle mine site since the mid-1980s (RGC, 2010a). That review included a preliminary assessment of potential sources of ARD to receiving waters, current groundwater and surface water quality conditions at the site, and the identification of any data gaps that could hinder future rehabilitation planning. RGC (2010a) recommended a second phase of work at the Rum Jungle mine site that would include the development of a preliminary groundwater flow model and contaminant load balance for the site and additional drilling in areas that are under-represented in the existing bore network. RGC was subsequently retained by the DoR to complete this second phase of work under tender Q10-0385 and the current report summarizes the results of that phase.

1.2 STUDY OBJECTIVES & SCOPE OF WORK

The fundamental objective of RGC's study of the Rum Jungle mine site is to develop a contaminant load balance model that can explain the current groundwater and surface water quality conditions at the site and then be used to assist the DoR in further rehabilitation planning.

Phase 1 of this study involved an initial review of hydrogeological data to identify data gaps (RGC, 2010a) whereas Phase 2 involves a more detailed data review of the data available from historic records and collected in 2008/2009 and 2010. The specific objectives of Phase 2 study are as follows:

- Develop a hydrostratigraphic model for the Rum Jungle mine site that can assist in data visualization and conceptual model development (Task 1);
- Conceptualize groundwater flow at the site based on initial groundwater level data collected in 2010 (Task 2);
- Complete a detailed review of groundwater and surface water quality data collected from 2008 to 2010 (Task 3); and
- Develop a preliminary load balance for the mine site that accounts for contaminant fluxes from the mine site to the East Finniss River (Task 4).

Task 5 of Phase 2 involved completion of the 2010 drilling program (see RGC, 2010b). The completion of Tasks 1 to 5 will ultimately lay the groundwork for comprehensive routine monitoring during the remainder of the 2010/2011 Wet Season and more detailed load balance assessments in subsequent phases of the project. Note that groundwater quality data collected from bores installed in late 2010 are beyond the scope of this report (as are the pending radionuclide data).

1.3 ORGANIZATION OF REPORT

This body of this report is sub-divided into three main sections:

- Site Description & Background Information (Section 2)
- Site Hydrogeology (Section 3)
- Contaminant Load Estimates (Section 4)

Section 2 describes the location and layout of the historic Rum Jungle mine site and includes background information on site layout, historic mining operations, and previous rehabilitation works that is relevant to site hydrogeology.

Section 3 provides a detailed review of hydrogeological data provided to RGC by the DoR (and other stakeholders), including seepage/groundwater quality data, groundwater levels, and hydraulic testing data. The principal focus of this section is the development of a preliminary conception of groundwater flows at the mine site that will be refined during subsequent stages of the Rum Jungle project and subsequently used during development of a contaminant load balance for the site.

Section 4 provides preliminary estimates of contaminant loads from the mine site to the East Finniss River. These load estimates are intended to identify major contaminant loads delivered to the East Finniss River and thereby prioritize future monitoring activities.

2 SITE DESCRIPTION & BACKGROUND

2.1 LOCATION & CLIMATE

The historic Rum Jungle mine site is located in Australia's Northern Territory (NT) about 105 km by road south of Darwin near the township of Batchelor (Figure 2-1 and 2-2). Local climate is considered tropical/monsoonal with mean annual rainfall of about 1500 mm and a distinct wet period ('the Wet Season') that lasts from November to April. 90% or more of annual rainfall occurs during the Wet Season and no sustained rainfall is observed from May to October (i.e. 'the Dry Season'). Mean maximum temperatures range from 31°C in July to 37°C in October and savannah woodlands (predominantly *Eucalyptus* trees and various grass species) surround the mine site (Taylor et al., 2003).

2.2 SITE LAYOUT

The mine site features three waste rock piles (i.e. the White's, Intermediate, and Dyson's Overburden Heaps), the flooded White's and Intermediate Open Cuts, and the backfilled Dyson's Open Cut (see Figure 2-3). Other notable features shown in Figure 2-3 are the East Finniss Diversion Channel (EFDC), the former tailings dam area along Old Tailings Creek, and the former copper heap leach pad between the flooded Open Cuts.

2.3 HYDROLOGY

The mine site is located along the East Branch of the Finniss River (hereafter the 'East Finniss River') about 8.5 km upstream of its confluence with the West Branch of the Finniss River (Figure 2-2). Surface water enters the mine site via the upper East Finniss River and Fitch Creek. Before mining these creeks met near the NE corner of White's Overburden Heap and subsequently flowed eastward via the natural course of the East Finniss River. However, the original course of the East Finniss River ran through the White's and Intermediate ore bodies so flow was diverted to the EFDC during mining operations (see 'former river channel' and 'EFDC' in Figure 2-3).

Today, flows from the upper East Finniss River and Fitch Creek flow directly into the EFDC and into White's Open Cut near the former Acid Dam. Water then flows from White's Open Cut to the Intermediate Open Cut via a channel that roughly follows the original course of the East Finniss River. Outflow from the Intermediate Open Cut to the EFDC occurs near the western boundary of the mine site and combined flows from the Open Cuts and EFDC continues eastward via the natural course of the East Finniss River.

Flows in the East Finniss River downstream of the mine site are currently monitored at gauge GS8150200 (near the road bridge) and then again 5.6 km downstream at gauge GS8150097. Gauge GS8150200 drains an area of 53 km^2 that includes the flooded Open Cuts and Overburden Heaps but does not capture flows from the former tailings dam area (which drains via Old Tailings Creek). Gauge GS8150097 captures the additional flows from Old Tailings Creek and several small tributaries that do not drain the Rum Jungle mine site. Gauge GS8150097 has long been considered the principal compliance point for surface water monitoring at the Rum Jungle mine site so flows at this location have been recorded almost continuously since the 1960s (Davy, 1975). Gauge GS8150200 was established in 1991 to collect flow (and water quality data) during the 1993 to 1998 monitoring period and has been used ever since (see Lawton and Overall, 2002a).

Flows in the East Finniss River vary predictably in response to intra-annual variability in rainfall and typically vary by several orders-of-magnitude over the course of a single year. First flows at gauge GS8150200 are usually observed in early December in response to high-intensity rainfall events that often occur in the early Wet (Taylor et al., 2003). First flows at gauge GS8150097 usually occur 3 to 4 weeks after they are recorded at gauge GS8150200 due to 'wetting up' of the dry river bed between the gauges (Lawton and Overall, 2002a). Sustained flows at both gauges typically occur by mid-January and continue until the end of May with peak flows usually occurring in February or March. No appreciable flow is observed at gauges GS8150200 and GS8150097 from June to November due to minimal rainfall but small, often localized storm events do cause small flows that may not be recorded at the gauges.

From 1969 to 2001, annual flow volumes at gauge GS8150097 ranged from 7 to 10 billion liters (L) for relatively dry years (annual rainfall < 1000 mm) up to 65 billion L in 2000/2001 (the wettest year of this period). These annual flow volumes correspond to wet season flows of 400 to 600 L/s for relatively dry years to 4,000 L/s for wetter years. Mean annual flows at gauge GS8150097 are higher than at gauge GS8150200 due to inflows from several creeks (including Old Tailings Creek) and the discharge of groundwater from dolomite beds to the East Finniss River downstream of gauge GS8150200 (Davy, 1975; Lawton and Overall, 2002a).

2.4 LOCAL GEOLOGY

The historic Rum Jungle mine site is one of numerous polymetallic ore deposits that characterize the Rum Jungle Mineral Field (RJMF) of northern Australia. The RJMF itself is situated within the central to western part of the Pine Creek Orogen and features two dome-like Archean basement highs: the Rum Jungle Complex (to the north) and the Waterhouse Complex (to the south) (McCready et al., 2004).

The Rum Jungle and Waterhouse Complexes consist primarily of granitic intrusions that are now overlain by a Paleoproterozoic sequence of metasedimentary and subordinate metavolcanic rocks called the Mount Partridge Group (and repetitive clastic-carbonate sequences of the Namoona Group). From youngest to oldest, the three major formations of the Mount Partridge Group are the

Crater Formation, the Coomalie Dolomite, and the White's Formation (Table 2-1). Note that rocks of the entire Mount Partridge Group have been folded, faulted and metamorphosed to sub-greenschist facies but the original stratigraphic succession has been preserved (McCready et al., 2004). Brittle failure associated with deformation has produced a number of faults that follow the northeast-southwest structural trends of the Rum Jungle mine site. These faults (and the much larger Giant's Reef Fault) are shown in Figure 2-4. Also shown in Figure 2-4 is the occurrence of the Protorezoic Geolsec Formation that lies unconformably atop the Mount Partridge Group and consists of hematite quartzite breccia (or HQB) (Ahmad et al., 2006).

The Rum Jungle mine site is situated in a triangular area of the RJMF that is defined by the Giant's Reef Fault to the south and by east-trending ridges of the Crater Formation to the north (Figure 2-4). This triangular area is known as The Embayment and it lies on the shallow-dipping limb of a northeast-trending, southwest plunging asymmetric syncline cut by northerly faults (shown in an idealized cross-section with a northwest and southeast trend in Figure 2-5). Each of the polymetallic ore deposits within The Embayment occurs within the White's Formation near its contact with the Coomalie Dolomite and is strongly associated with fault zones (and hence structurally-controlled). Specifically, ore has been deposited in carbonaceous slates by selective replacement along shear zones that intersect local faults (Ahmad et al., 2006).

Note that the Rum Jungle Complex (and all Proterozoic sediments and metasediments) have undergone *in situ* lateritization since the early Mesozoic era and Tertiary period and hence deeply-weathered soil profiles characterize much of the Rum Jungle mine site. The site also features Quaternary soils and alluvium but no sedimentological record of the (South Australian) Permo-Carboniferous glaciation is apparent in the study area.

2.5 MINE UNITS

2.5.1 *White's Open Cut/Overburden Heap*

White's ore body was discovered in 1949 and is one of the largest in the RJMF (Barrie, 1982). The ore body occurs in a layered series of near vertical zones of uranium-copper (U-Cu), copper-cobalt-nickel (Cu-Co-Ni), and lead-cobalt (Pb-Co) that extend to 180 m below ground surface (Davy, 1975). Pitchblende (UO_2) and associated secondary uranium minerals are common in the U-Cu zone (which extends to a depth of 180 m) whereas chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), digenite (Cu_9S_5), bornite (Cu_5FeS_4), and covellite (CuS) characterize the Cu-Co zone (Ahmad et al., 2006). Mineralization is hosted by black shale of the White's Formation near its contact with the Coomalie Dolomite and is bounded by to the west by a northeast-striking, south-dipping fault and to the east by graphitic shale.

Overall, White's ore body was mined at a grade of 2.7% Cu and 0.27% U_3O_8 (Ahmad et al., 2006). White's ore body was initially mined underground from 1950 to 1953 and then by open cut methods until 1958. White's Open Cut had reached a depth of about 120 m or so when mining operations ceased. At that time, pit de-watering was discontinued and the pits were allowed to fill with groundwater and, in the case of White's Open Cut, surface water from the East Finniss River (Allen and Verhoeven, 1986). White's Open Cut was then partially backfilled with tailings in the late 1960s and hence the pit is much shallower today than when initially mined out (i.e. 50 to 60 m; Tropical Water Solutions, 2008).

White's Overburden Heap is the largest (33 ha) of the waste rock piles at the Rum Jungle mine site and consists of material removed during mining of White's ore body in the 1950s. The heap is mainly comprised of pyritic slates and shales together with a small proportion of dolomite (10 to 15%) and contains about 3% sulphur in the form of heavy metal sulphides (Davy, 1975).

2.5.2 Intermediate Open Cut/Overburden Heap

Unlike the White's ore body (which was comprised of a suite of different metal-bearing sulphides), the Intermediate ore body consisted predominantly of copper sulphide mineralization hosted in granitic schist (Davy, 1975). Chalcopyrite ($CuFeS_2$) was the main copper-sulphide minerals but lesser amounts of chalcocite (Cu_2S) and bornite (Cu_5FeS_4) were also present in the mineralized zone. Moreover, the ore body was covered by extensive capping of oxidized ore that contained malachite ($Cu_2CO_3(OH)_2$) and various other copper-bearing minerals (Anderson et al., 1966). Due to the prevalence of copper-sulphide minerals, the Intermediate ore body was mined exclusively for copper by open cut methods.

Overburden/waste rock removed during mining the Intermediate ore body was placed in a heap adjacent to the EFDC. Less is known about the waste rock contained in Intermediate Overburden Heap than the White's and Dyson's Overburden Heaps because detailed information on the ore body itself is lacking. However, Davy (1975) suggests that the Intermediate Overburden Heap contains primarily pyritic graphitic shale and identified large amounts of pyrite and the occasional pile of nickel, iron, and cobalt-bearing minerals on the heap before site rehabilitation.

2.5.3 Former copper heap leach area

High-grade ore from the Intermediate Overburden Heap was treated by froth flotation whereas copper from sub-grade ore (and the oxidized capping) was later extracted via heap leaching on a pad located between the White's and Intermediate Open Cuts (Davy, 1975). The heap leach procedure involved piling sulphide and oxide ore into separate piles atop a 'non-permeable' pad and then spraying the ores with a highly-acidic (pH 2) mixture of raffinate, barren liquor, and water from

White's Open Cut to dissolve soluble copper in the ore pile (Davy, 1975). After percolating through the pile, the pregnant liquor was thought to drain from the heap primarily via a series of lined channels and culverts yet the process was rather inefficient and significant losses via seepage occurred. The extent to which seepage could have altered bedrock or unconsolidated material beneath the former heap leach pad is unknown at this time but some alteration is likely.

2.5.4 Dyson's Landform & Overburden Heap

Dyson's ore body was located on the southern slopes of a small hill rising to the north of the East Finniss River and was mined by open cut methods in 1957/1958 (Davy, 1975). The ore body occurred as a vertical lens that was 60 m long and 8 m wide and extended to a depth of 100 m below ground surface. Mineralization was hosted within a narrow zone of strongly-sheared carbonaceous shale of the White's Formation at its contact with the Coomalie Dolomite and consisted almost entirely of a uranium-bearing mineral with no copper, lead, cobalt, or nickel present (Spratt, 1965).

Only the first 50 m or so of Dyson's ore body was mined and the material removed was deposited on the hillslope adjacent to the mine (forming Dyson's Overburden Heap). This overburden material is comprised mainly of black graphitic shale and dolomite/breccia that occurs in the area around Dyson's ore body. Note that below a depth of 27 m, the black graphitic shale in this area becomes strongly pyritic and contains appreciable amounts of pitchblende. According to Davy (1975), Dyson's Overburden Heap contains up to 2 to 3% pyrite (or 0.2 million tons), which is consistent with recent field observations (Fawcett Mine Rehabilitation Services, 2007; RGC, 2010b).

Note that from 1961 to 1965, tailings were discharged into Dyson's Open Cut and these tailings now lie beneath layers of additional tailings, heap leach material, and contaminated soils placed during subsequent rehabilitation in the 1980s (see Section 3.4.3 for further description).

2.6 HISTORIC REHABILITATION WORKS

An air photo of the Rum Jungle mine site taken prior to rehabilitation in the 1980s is shown in Figure 2-6. Some minor clean-up operations had been completed in the late 1970s but this photo essentially illustrates the major features of the site as they existed when mining operations ceased in the 1960s. For instance, note that Dyson's Open Cut had not yet been backfilled at the time this photo was taken. An air photo of the site taken in 2009 is shown in Figure 2-7 for comparison.

When mining ceased in the 1960s, Territory Enterprises Pty Ltd. (the company that had conducted mining operations at the site) was under no obligation to remediate existing environmental impacts at the site or prevent further impact. Instead, the mine site was left as it was with sulfide-bearing waste rock essentially exposed to atmospheric conditions within the various mine waste units. According to Kraatz (1998), the resulting generation of sulfuric acid and associated release of heavy metals from waste rock in the Overburden Heaps resulted in the destruction of all flora and fauna in the East Finniss River for 8.5 km downstream of the site and reduced bio-diversity in the Finniss River for a further 15 km downstream. Growing concern over the ongoing environmental impact from historic mine wastes lead to a minor clean-up operation in the late 1970s although most of the cleanup measures were aimed at the aesthetics of the Rum Jungle mine site (and hence did not reduce the generation of pollutants at the site).

In 1979, a working group from the Commonwealth Government and the Northern Territory Administration was established at this time to develop more comprehensive rehabilitation strategies at the Rum Jungle mine site (Pidsley, 2002). In 1982, financial arrangements between the Commonwealth and NT Governments set in place an $18.6 million program that entailed rehabilitation of the Rum Jungle mine site from 1982 to 1986 and subsequent monitoring from 1986 to 1988 (Allen and Verhoeven, 1986). In addition to aesthetic improvements to the site, the objectives of the rehabilitation program were to reduce the quantities of copper, zinc, and manganese reaching the East Finniss River, improve the condition of water in the White's and Intermediate Open Cuts, and reduce the public health hazard related to radioactive ores at the site (Allen and Verhoeven, 1986). These objectives were achieved via the following treatment measures:

- Treatment of acid water contained with the White's and Intermediate Open Cut and re-establishment of wet-season flushing through the Open Cuts;
- Capping of acid-generating material with low-permeability clays and pore-breaking layers to restrict the ingress of water and oxygen;
- Re-shaping of 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 'tailings dam' and East Finniss River floodplain) and copper heap leach material in Dyson's Open Cut.

Brief descriptions of historic rehabilitation of the Overburden Heaps, the treatment of contaminated waters in White's and Intermediate Open Cuts, the backfilling of Dyson's Open Cut, and rehabilitation work in the former tailings dam and copper heap leach areas are provided in the sub-sections below. Note that these descriptions are intended to provide context to subsequent discussions of water quality and contaminant loads to groundwater and surface water at the mine site and hence are not comprehensive.

2.6.1 Overburden Heaps

White's Overburden Heap was rehabilitated in 1983/1984 while the Intermediate and Dyson's Overburden Heaps were rehabilitated two years later in 1986 (Allen and Verhoeven, 1986).

Rehabilitation consisted primarily of covering the Overburden Heaps with a three layer cover system designed to reduce infiltration to less than 5% of incident rainfall and therefore restrict the movement of pollutants from the Heaps. The cover system included:

- A compacted clay layer (minimum thickness 255 mm) as a moisture barrier;
- A moisture retention zone (minimum thickness 250 mm) to support vegetation and prevent drying of the clay layer; and
- An erosion protection layer (minimum thickness 150 mm) to also restrict moisture loss during the dry.

A subsoil drainage system was also constructed to intercept groundwater at the interface between the original ground surface and underside of the Overburden Heap in the areas where the springs had been observed (i.e. on the northeastern and southwestern sides of the heap). Seepages from the northeastern toe of White's Overburden Heap were collected via a drainage channel that drains to the head of the EFDC whereas seepages from the southwestern toe of White's Overburden Heap were captured by Wandering Creek and subsequently delivered to the EFDC. Note that these same drainage features characterize the site although Wandering Creek now also receives water from a creek that originates near the Water Retention Pond located near the Brown's Oxide Open Cut (see Figure 2-6).

In addition to being covered, the White's and Intermediate Overburden Heaps were also re-shaped and outfitted with engineered drainage structures that could quickly and safely dispose of stormwater to the EFDC (Allen and Verhoeven, 1986). Note that the batters of Dyson's Overburden Heap were not-reshaped and that a cover system was only installed on the top surface of the heap (Kraatz, 2004).

2.6.2 White's and Intermediate Open Cuts

Mining from White's Open Cut ceased in 1958 and the Intermediate Open Cut was mined from 1963 to 1964 (Davy, 1975). When mining from White's Open Cut ceased, pit de-watering was discontinued and the pits were allowed to fill with contaminated surface water/groundwater (Allen and Verhoeven, 1986). Tailings and other mine wastes were later disposed of into White's Open Cut in the late 1960s which resulted in extremely poor water quality in White's Open Cut by the late-1970s when initial rehabilitation attempts were made (Davy, 1975).

During site rehabilitation in 1984/1985, contaminated water from White's Open Cut was pumped out and treated with lime to raise the pH of the water (and consequently precipitate dissolved metals). The treated (and hence less dense water) was returned to the surface of the pit with minimal turbulent mixing, thereby establishing a lower density layer on top of the denser untreated water. The treated pit water layer in White's Open Cut was low in heavy metals and initially extended to a depth of about 20 m. Given the lower level of contaminants in Intermediate Open Cut and the smaller volume involved, this pit water was first treated *in situ* with lime and the aid of an aeration mixing device. The settled precipitate was subsequently removed by a sludge pump.

Today, the White's and Intermediate Open Cuts are connected by a channel that roughly follows the former channel of the East Finniss River. Flow between the Open Cuts occurs when the water level in White's Open Cut (which still receives water from the upper East Finniss River) reaches a certain level during the early Wet. By design, early flows in the upper East Finniss River flow into the EFDC before beginning to flow into White's Open Cut (Lawton and Overall, 2002a). Flow to the Intermediate Open Cut then occurs when the evaporative drawdown volume in White's Open Cut has been replenished by flow from Upper East Finniss River. In 1997/1998 (the last time flows to and from the Open Cuts were recorded), outflow from the Intermediate Open Cut occurred one week after inflow to White's Open Cut began but the lag period depends on river flow in the upper East Finniss River and can be prolonged by a month or so.

2.6.3 Dyson's Open Cut

Dyson's Open Cut had been used for tailings disposal during mining operations and was later selected as the disposal site for materials removed from the former tailings dam and copper heap leach areas during site rehabilitation in the 1980s (Allen and Verhoeven, 1986). These materials included tailings, contaminated soils, and low-grade ores that were identified as being particularly susceptible to oxidation (and hence the release of metals) if left exposed at surface.

Tailings from the former tailings dam area (and copper launders from the former heap leach area) were placed first atop the original tailings and hence lie at the bottom of the Open Cut. A 1 m thick rock blanket was then constructed on a geotextile fabric layer over the tailings to capture any pore water released during their consolidation. The rock layer was also extended up the face of the original Open Cut above the level of the tailings to capture groundwater inputs from the northern and western sides of the pit. The rock layer is connected to a subsoil drainage system that provides a drainage path for pore water. The sub-soil drain commences on the western-most corner of the pit and extends along the southwestern and southeastern (downslope) sides of the Open Cut at the toe of the batter slope.

Copper heap leach material and contaminated soils were placed in alternating layers over the rock blanket and then compacted. The layer thicknesses of the copper heap leach material and contaminated soils were 1000 mm and 300 mm, respectively. The backfilled Open Cut was then covered with a system similar to the one used for White's Overburden Heap (see description above).

Given the nature of materials placed in Dyson's Open Cut though a slightly thicker cover system was designed to further restrict rainfall infiltration.

2.6.4 Former tailings dam area

During mining operations, slurried tailings were discharged to an almost flat area to the north of White's Open Cut (Figure 2-5). Drainage from this area formed a small creek called 'Old Tailings Creek' that eventually discharged to the East 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 during site rehabilitation in the 1980s.

Following the removal of tailings and contaminated subsoil, the tailings dam area was limed and re-shaped to control drainage. A one-layer cover was installed to enable the establishment of vegetation (which included native tree and shrub species). Note that tailings do remain exposed in the former tailings dam area and hence represent a potential (albeit diffuse) source of contamination to local groundwater and the East Finniss River (Fawcett Mine Rehabilitation Services, 2007; RGC, 2010a).

2.6.5 Former copper heap leach area

Rehabilitation of this area involved removal of the heap leach pile itself plus copper launders and the worst contaminated sub-soils in the area and the placement of these materials in Dyson's Open Cut. A subsoil drainage system and four-layer cover system were installed over the former copper heap leach area to deal with the highly-mobile and toxic metals that remained in the near-surface zones under the pile and in the area surrounding the heap. The current condition of the cover/drain system is not well-known at this time but some contaminated material like remains in this area.

2.7 PREVIOUS SITE INVESTIGATIONS & MONITORING

2.7.1 Routine monitoring after rehabilitation

Upon completion of the rehabilitation program in the early 1980s, the Rum Jungle Monitoring Committee (RJMC) was established and it assumed responsibility for implementation of the 1986 to 1988 monitoring program. Subsequent monitoring at the Rum Jungle mine site was conducted from 1988 to 1993 (see Kraatz, 1998) and from 1993 to 1998 (see Pidsley, 2002). Surface water monitoring was also conducted routinely in the late 1980s and early 1990s (e.g. Henkel, 1991a,b).

2.7.2 Recent sampling activities

In 2007, a database of historic monitoring data was developed by the Supervising Scientist Division of DEWHA (see Lowry and Staben, 2007). The aim of database development was to compile groundwater monitoring data from various sources and subsequently provide these data to stakeholders in a consistent and documented format, datum, and projection (Lowry and Staben, 2007). During data compilation, the limitations of historic monitoring data became apparent. Specifically, groundwater monitoring data had not been collected since 1988 and hence no time series data was available to document any changes in groundwater quality that could have occurred in the 25 years since rehabilitation. Moreover, no comprehensive surface water monitoring had taken placed since the late 1990s. Additional groundwater and surface water quality data were therefore collected in 2008/2009 to provide a snapshot of current conditions at the Rum Jungle mine site and thereby enable any changes in water quality since rehabilitation to be identified (Ryan et al., 2009).

Groundwater sampling was conducted at the beginning and end of the 2008/2009 Wet by the Environmental Research Institute of the Supervising Scientist (ERISS) and the then NT Department of Regional Development, Primary Industry, Fisheries, and Resources. The bores sampled were selected based on their proximity to potential contaminant sources or specific hydrogeologic features (i.e. faults, rock types, etc.) and the length of the historic monitoring record (Ryan et al., 2009). Samples of seepage and water from the East Finniss River were also collected at the time of groundwater sampling. Water quality data collected in 2008/2009 were discussed briefly in Ryan et al. (2009) and reviewed in RGC (2010a) but detailed interpretation of water quality data was not provided in either report. Hence a detailed review of these data (and some additional data from tenement holders of Browns Oxide mine site) is provided in Sections 3 and 4 of this report.

3 SITE HYDROGEOLOGY

3.1 MONITORING BORE NETWORK

The locations of 103 bores installed prior to 2010 are shown in Figure 3-1a. Each of the bores in Figure 3-1a has been classified as shallow (<5 m), intermediate (5 to 15 m), or deep (>15 m) based on its installation depth. Coordinates and construction details for the historic bores are provided in Table 3-1.

Most of the historic monitoring bores are shallow (<5 m in depth) and are often clustered together near one of the major mine waste units or along the principal drainages of the site. In 2010, 27 additional monitoring bores were installed at the mine site to augment the existing bore network and fill gaps that existed in certain areas of the site (i.e. north of the Open Cuts and in the former heap leach area). The locations of these bores are shown in Figure 3-1b and construction details are provided in Table 3-2 (see also Appendix A).

3.2 HYDROSTRATIGRAPHIC UNITS

3.2.1 Overburden Units

Most of the Rum Jungle mine site is covered with a veneer of overburden soils which typically consist of clayey sand that are interspersed with mottled zones of ferruginous sandy clays. In proximity of the East Finniss River and its larger tributaries the shallow soils are predominantly comprised of riverine sands and gravels.

The shallow soils in the upland areas are typically dry during most of the year but may provide significant ‘shallow subsurface flow’ during high precipitation events when the groundwater levels rise close to ground surface.

Sediments in the various side drainages draining towards the East Finniss River tend to be coarser-grained (sandy) and provide a conduit for shallow groundwater flow (including highly contaminated seepage from the various overburden heaps). However, while these side drainages may sustain groundwater flow for much of the year the capacity of these shallow units to transmit groundwater flow is limited by their shallow depth (typically <2m) and limited width (typically only a few meters wide).

The alluvial sediments of the East Finniss River are significantly deeper (and wider) than those of the side drainages and therefore have the greatest potential for groundwater flow. A preliminary review of existing exploration holes suggests that coarse-grained alluvial sediments were encountered to a maximum depth of 20m near the historic East Finniss River channel between the White’s and Intermediate Open Cuts (see Figure 2-3). In December 2010, highly permeable soils (possibly of alluvial origin) were encountered in borehole PMB11 to a maximum depth of 37m. Air lift testing in this hole yielded about 8 L/s suggesting a very high hydraulic conductivity for these deep sediments. At this point it is unclear whether these deep sediments are of natural origin (potentially deep sinkholes in-filled with river sediments?) or whether they are related to mining activity.

These highly permeable alluvial sediments of the East Finniss River may represent an important hydrostratigraphic unit at the Rum Jungle mine site, in particular considering its potential as a conduit for highly contaminated seepage from the former heap leach area (see below). Additional review of historic borehole logs is recommended to better delineate the spatial extent of this alluvial unit.

3.2.2 Bedrock Units

Groundwater flow at the Rum Jungle mine site occurs predominantly in partially weathered and/or fractured bedrock. As a first approximation, the bedrock aquifer can be subdivided by lithology into the following hydrostratigraphic units (from youngest to oldest):

- hematitic quartz breccia (Geolsec Formation);
- pelites, shales and schist (White's Formation);
- dolostone and tremolite schist (Coomalie Dolomite);
- sandstone and conglomerate (Crater Formation); and
- granitoid (Rum Jungle Complex).

A description of the geologic complexities of these units (and their provenance) is beyond the scope of this report but an overview of their occurrence was provided in Section 2.4 (see Figure 2-3) and a detailed description can be found in Ahmad et al. (2006).

Table 3-3 summarizes the hydraulic testing data available to date for the different bedrock lithologies present at the Rum Jungle mine site. It should be cautioned that the hydraulic testing completed to data is incomplete and not necessarily representative for each unit. Bedrock aquifers characteristically show significant heterogeneity due to the dominant influence of secondary porosity, i.e. fractures, bedding planes, dissolution channels and/or faults. The number of hydraulic tests completed to date may not be sufficient to cover the likely range of permeabilities that can be expected for these bedrock units. Furthermore, many of the hydraulic tests are slug tests (in particular in the lower yielding granitic bedrock) which tend to be representative of only a small area near the bore. Nevertheless, the following preliminary conclusions can be drawn with respect to the hydraulic properties of the different bedrock lithologies encountered at Rum Jungle mine site (in order of importance).

Coomalie Dolomite

The Coomalie Dolomite unit is comprised of recrystallized dolostone and tremolite schist with some brecciated zones along faulting. The Coomalie Dolomite unit represents the most permeable bedrock unit on the site. Air lift yields typically range from 1-10 L/s but can reach 50-60 L/s where significant structures and/or dissolution channels are encountered. Pumping tests and dewatering of a trial pit (on the Browns Oxide mine site) in the Coomalie dolomite suggested transmissivities in the range of 100 to 1,000 m^2/d which represent ‘effective’ hydraulic conductivity (K) values ranging from about $1*10^{-4}$ to $3*10^{-3}$ m/s. Historic and recent drilling suggests that the shallow, weathered dolostone is typically more permeable, likely due to development of secondary porosity (i.e. natural karst formation and/or dissolution by acidic mine drainage). However, very high yields have also been found at greater depth associated with highly permeable structures (e.g. at RN22108 now converted to PMB9D, see below).

White’s Formation

The White’s Formation is comprised of calcareous and carbonaceous (“black”) shales and schist, amphibolite dikes and quartzite. The White’s Formation shows moderately high bedrock permeability. Air lift tests in the White’s Formation typically range from 0.1 to 2 L/s but can reach 10-20 L/s along major structures (at the Browns Oxide project). Hydraulic testing in the White’s Formation suggests typical transmissivity values of 20 to 100 m^2/d which correspond to K values in the order of $1*10^{-5}$ to $1*10^{-4}$ m/s. Note that the majority of hydraulic testing in the White’s Formation is limited to the upper partially weathered zone (say <20m bgs). No hydraulic testing data is available for tight bedrock at greater depth in the White’s Formation.

Rum Jungle Complex

The Rum Jungle Complex is comprised of metamorphosed granite (granitoid). The granitic bedrock of the RJC generally has a much lower permeability than the meta-sediments at the Rum Jungle mine site. Air lift tests in bedrock of the RJC typically range from 0.05 to 0.5 L/s. Hydraulic testing in the RJC is primarily limited to slug testing in relatively shallow, partially weathered granitic bedrock and suggests local K values in the order of $5*10^{-7}$ to $1*10^{-5}$ m/s. Bedrock permeability at greater depth (say > 20m) in the RJC has not been tested but is believed to be very low permeability ($<10^{-7}$ m/s).

Note that the low-permeability granitoid of the Rum Jungle Complex encloses the moderately to highly permeable meta-sediments of the Coomalie Dolomite and the White’s Formation to the southeast and northwest of the Rum Jungle mine site. Impacted groundwater from the Rum Jungle mine site is expected to remain contained within these more permeable sediments since the granitoid to the northwest (i.e. downgradient) of the Rum Jungle site represents a natural barrier to groundwater flow.

Geolsec Formation

The Geolsec Formation is comprised of hematitic quartzite brecchia. Hydraulic testing in the Geolsec formation is very limited but most boreholes completed in this formation did not produce any significant air lift yield suggesting low bedrock permeability.

This bedrock unit is therefore tentatively classified as an aquitard with very limited groundwater flow. However, additional hydraulic testing will be needed to better quantify its hydraulic properties.

Crater Formation

The Crater Formation is comprised of sandstone and conglomerate. Bedrock of the Crater Formation is only observed in a narrow band to the north of the Rum Jungle site. Little is known about the hydraulic properties of this bedrock unit since no drilling or hydraulic testing data is available for this unit.

This bedrock unit is not considered to be an important aspect of the groundwater flow regime at the Rum Jungle mine site.

3.2.3 Structural Controls

Limited information is available on the hydraulic properties of structural features that characterize the Rum Jungle mine site. The Giant's Reef Fault is considered a barrier to groundwater flow due to the presence of the Rum Jungle Complex on its southeastern flank, whereas high bore yields (20 L/s at TPB3) suggest that the major fault intersecting the Brown's Oxide deposit is highly transmissive (Water Studies, 2002; Coffey, 2005). Similarly, the numerous NE-trending faults that cross-cut the site (roughly perpendicular to the Giant's Reef Fault) may also be highly-transmissive although no hydraulic testing of these features has been completed.

However, the relatively high permeability of these NE-trending faults is inferred from the very high yield of bore PMB14 (which yielded at least 40 L/s during an airlift test conducted during drilling). Specifically, all of this water discharged from two small (10 to 20 cm wide), sand-filled fractures that occurred at around 17.5 m bgs and could be primary or secondary in nature (i.e. related to dolomite dissolution due to contaminant loading).

3.3 Groundwater Flow Field

Figure 3-2 shows geodetic groundwater level data collected in January 2011 and inferred contours of the groundwater table. Note that contours in that figure are based primarily on data from the January 2011 survey supplemented with data from August 2010 (e.g. on the Browns Oxide property).

The inferred direction of groundwater flow is illustrated by arrows. Blue arrows indicate the movement of clean (unimpacted) groundwater whereas red arrows indicate the movement of highly impacted groundwater. Orange arrows indicate the movement of moderately impacted groundwater (see below).

Groundwater flow generally follows surface topography, i.e. flows from the topographic highs surrounding the mine site towards the East Finniss River channel. Hydraulic gradients are generally steeper in the low-permeability bedrock units (RJC and Geolsec formations) and much flatter in the more permeable Coomalie dolomite and White's formation.

Significant groundwater inflow to the site is inferred to occur from the northeast where the highly permeable Coomalie dolomite extends further north. Several historic production bores in this area were used to exploit this clean source of groundwater flow.

Owing to the relatively low permeability of the granitic bedrock underlying the White's Overburden Heap, seepage from the White's heap has resulted in some localized mounding of the groundwater table in this area. Consequently, seepage from the White's Overburden Heap is observed at shallow depth year-round and discharges near the toe of the White's Heap (in particular along the northeast and southwest side) during most of the wet season.

Note that a similar mounding of groundwater levels is not evident from the existing bores in vicinity of the Intermediate Overburden Heap, likely due to the higher bedrock permeability of the underlying White's Formation.

Groundwater flow in the highly impacted former heap leach area between the White's and the Intermediate Open Cuts appears to be in a southwesterly direction (i.e. from the White's Open Cut towards the Intermediate Open Cut). Note that groundwater flow appears to be aligned with the main NE-SW trending structure connecting the two historic ore deposits (to be confirmed with future water level monitoring).

Highly impacted groundwater from the former heap leach area appears to flow towards the flooded Intermediate Open Cut and from there towards the East Finniss River (at PMB9D). Highly impacted groundwater in the Coomalie dolomite immediately to the north of the former heap leach area (e.g. at PMB12 and PMB16) flows in a westerly direction towards the East Finniss River but may also recharge the Intermediate Open Cut (to be confirmed).

Moderately impacted groundwater in the Coomalie dolomite located further north of the flooded Open Cuts (at PMB14 and PMB17) flows in a westerly direction towards the East Finniss River.

Note that the groundwater flow field depicted in Figure 3-2 represents a snapshot in time (at the beginning of the wet season in mid-January 2011). Historic monitoring of groundwater levels in selected monitoring bores at Rum Jungle (e.g. at RN22081) has shown significant seasonal fluctuations (ranging from 2 to 4 m per year). Seasonal water level monitoring across the Rum Jungle mine site using the expanded network of monitoring bores will be required to determine the seasonal variation in groundwater flow (planned for 2011 wet). This water level monitoring program will have to include monitoring of geodetic water levels in the two flooded Open Cuts to determine the interaction of the pit water bodies with the surrounding bedrock aquifer(s).

It should also be pointed out that very limited information was available about groundwater levels on the west side of the East Finniss River. Of particular interest is the Browns Oxide mine site which could potentially influence the groundwater flow field due to pit dewatering and/or seepage from the tailings storage facility and/or water retention dam. It is important that selected monitoring bores on the Browns Oxide property be included in the water level program for the Rum Jungle mine site (unless this information is available from the operators of the Browns Oxide mine site).

One of the key aspects of the hydrogeology at Rum Jungle is the hydraulic connection between the flooded open cuts (which still contain highly contaminated water at depth) and the surrounding bedrock aquifer units, in particular the highly permeable Coomalie Dolomite. In the last quarter of 2008, Compass Resources (tenement holders of the Browns Oxide mine site) pumped down the water level in the Intermediate Open Cut by a total of 10 m for its mine water supply. Figure 3-3 shows the observed changes in water levels (and EC) for selected monitoring bores in the general vicinity of the Intermediate Open Cut.

The monitoring data collected during this large-scale ‘pumping test’ indicates a very good hydraulic connection between the Intermediate Open Cut and RN22108 (now refurbished as nested bores PMB9S/D). The groundwater level decline in this open hole mimicked the decline in the open water level of the Intermediate Open Cut (Figure 3-3). Furthermore, groundwater quality in this open bedrock hole significantly deteriorated during this drawdown period, with EC values increasing from ~400 uS/cm to about 2,500 uS/cm. This increase in EC in RN22108 was likely caused by a decreased contribution of very dilute surface water from the Intermediate Open Cut and an increased contribution of deep (highly contaminated) groundwater.

Note that monitoring bore RN22107, screened in the Coomalie dolomite but located a greater distance away (about 500 m northeast of the Intermediate Open Cut), also responded to the pit dewatering although the drawdown was more subdued (only about 1m). This drawdown test confirms that the Intermediate Open Cut is well connected to the surrounding bedrock aquifer.

At this point it is unclear whether a similar good hydraulic connection exists between the White’s Open Cut and the surrounding bedrock aquifer. The White’s Open Cut does not border the highly permeable Coomalie Dolomite (only the moderately permeable White’s formation) but intersects the same NE-SW trending main fault which is inferred to be highly transmissive. A similar large-scale drawdown test (as performed in the Intermediate Open Cut) would be required in the White's Open Cut to better assess the hydraulic connection of the White's Open Cut with the local bedrock aquifer(s).

3.4 SEEPAGE WATER QUALITY

Highly-contaminated seepages from sulphide-bearing waste rock are well-established as the major source of contaminants to groundwater (and surface water) at the Rum Jungle mine site. The purpose of this section is to describe the geochemical characteristics of these seepages and how they differ from one another.

Seepage water quality data are provided in Table 3-4. 'Dissolved' metals concentrations in Table 3-4 represent the metals content of un-acidified water after filtration through a 0.45 µm membrane.

3.4.1 Dyson's Area

Dyson's area is characterized by two drainage features that ultimately deliver contaminants to the upper East Finniss River (either at surface or via the shallow sub-surface). One of these features is an engineered (or rip-rap) channel that collects surface runoff from the tops of Dyson's (backfilled) Open Cut and the nearby Overburden Heap. This channel eventually runs along the western toe of Dyson's Overburden Heap and hence may collect some additional waste rock seepage from the Overburden Heap before discharge to the upper East Finniss River occurs. The exact proportion of surface runoff to waste rock seepage is not known at this time but the former is more likely to dominate volumetrically (whereas the latter likely contributes a larger contaminant load).

The second drainage feature in Dyson's area represents a braided channel that originates along the southern batter of Dyson's (backfilled) Open Cut (near bore RN023790) and terminates in the upper East Finniss River channel. The source of water to this channel is a series of drains that are believed to be directly connected to the sub-surface drainage layers that were built into the landform during the process of backfilling. These drains can be identified at surface by covered concrete manholes. The extent of the braided channel itself is most obvious from the extent of 'dieback' in this area, as most vegetation in the vicinity has been killed off by exposure to acidic, metal-laden seepage (see below).

In April 2009, water samples were collected from the braided channel that originates from Dyson's (backfilled) Open Cut (at site 11) and from near the southern toe of Dyson's Overburden Heap (at site 9) (see Figure 4-1 for locations) (Jones and Turner, 2010). A seepage sample was also collected at site 9 in August 2010, as was a sample from a rip-rap channel atop Dyson's (backfilled) Open Cut.

The samples collected at site 11 represents seepage from within Dyson's (backfilled) Open Cut whereas the sample from site 9 represents waste rock seepage from Dyson's Overburden Heap.

Samples from both mine waste units in Dyson's area were highly-acidic (pH 3.1 or less) and characterized by high concentrations of SO_4 and Mg (Table 3-4). Seepage from Dyson's Overburden Heap though is characterized by much higher concentrations of Al, Fe, and U and lower concentrations of Cu, Co, Ni, and Zn than seepage from Dyson's (backfilled) Open Cut. Higher concentrations of Cu, Co, Ni, and Zn in seepage from Dyson's (backfilled) Open Cut reflects the highly-contaminated soils, tailings, and copper launders that were used to backfill the Open Cut whereas low concentrations of these metals (and high U concentrations) are consistent with the absence of these metals in Dyson's ore body (and the occurrence of pitchblende in Dyson's Overburden Heap; see Section 2.2.4).

3.4.2 White's Overburden Heap

Seepage from White's Overburden Heap was collected at sites 4 and 5 in April 2009 and again at site 5 in August 2010. The samples collected in April 2009 represent seepage during the late stages of the 2008/2009 Wet, whereas the sample collected in August 2010 represents baseflow seepage (i.e. collected when water levels are lowest at the site).

Seepage from White's Overburden Heap is highly-acidic (pH 3.5 to 4.0) and characterized by high concentrations SO_4, Mg, and various dissolved metals (Table 3-4). Note that seepage from White's Overburden Heap is less acidic and contains much lower concentrations of Al and Fe than seepage from Dyson's Overburden Heap but is characterized by higher concentrations of Cu, Co, Ni, and Zn. The suite of elevated metals in seepage from White's Overburden Heap is consistent with mineralization in White's ore body, which was mined for uranium, copper, cobalt, nickel, and lead and not just uranium as Dyson's ore body was (see Section 2.2).

3.4.3 Intermediate Overburden Heap

In August 2010, a water sample was collected from the seepage face that characterizes the northwestern face of the Intermediate Overburden Heap (i.e. adjacent to the EFDC). The acidity of seepage from the Intermediate Overburden Heap is comparable to other seepages at the mine site but SO_4 concentrations are much higher by comparison (i.e. 13,800 mg/L vs. 5,200 mg/L or less; see Table 3-4). Seepage from the Intermediate Overburden Heap is also characterized by very high concentrations of nearly every dissolved metal in the suite (Table 3-4).

Most metals concentrations are comparable to those observed in seepage from Dyson's (backfilled) Open Cut which could be explained by the presence of similar materials in both mine waste units. Zn concentrations in seepage from the Intermediate Overburden Heap are particularly high in comparison to seepage from White's Overburden Heap and seepages in Dyson's area. In general, seepage from the Intermediate Overburden Heap appears to be the most concentrated seepage at the Rum Jungle mine site and likely represents a particularly important source of these metals to local groundwater and the East Finniss River (via the EFDC).

3.5 GROUNDWATER QUALITY

Groundwater quality data were available for a select number of monitoring bores routinely monitored by HAR Resources (operators of Browns Oxide mine site) since 2008 and from ERISS studies completed in 2009 and 2010 (Ryan et al., 2009; Jones and Turner, 2010). Additional data was also available from sampling campaigns conducted by the NT Department of Resources Environmental Monitoring Unit from August to October, 2010.

Samples for previous ERISS studies were collected at the beginning and end of the 2008/2009 Wet from a selection of monitoring bores across the site. HAR Resources also routinely monitors water quality in the White's and Intermediate Open Cuts, the East Finniss River at gauges GS8150200 and GS8150097, and in a selection of monitoring bores on their property and within the boundaries of the Rum Jungle mine site. Data for the following bores were incorporated into the current report:

- RN022107 (near northwestern edge of White's Open Cut)
- RN022108 (west of the Intermediate Open Cut near the road bridge)
- RN023140 (north of Old Tailings Creek)
- RN023790 (near the southern toe of Dyson's (backfilled) Open Cut)
- RN023137 (in the headwaters of the wet season creek that flows from Browns Oxide mine site)
- RN022085 (southwest of Intermediate Overburden Heap)
- RN022083 (between White's Overburden Heap and Fitch Creek)
- RN022084 (near southwest toe of White's Overburden Heap)

Groundwater quality data incorporated into this report are provided in Appendix B. In addition to data collected over the last 2 to 3 years, historic groundwater quality data for a selection of monitoring bores were available from the database compiled by Lowry and Staben (2007) (see Figures 3-6 to 3-12). Note that metals concentrations shown in these figures are 'total' concentrations and that some of the data plotted in the figures were flagged as suspect in the database and hence the figures are intended only to provide a broad perspective on historic trends in groundwater quality over the 25 years since site rehabilitation. Also note that there is a lack of groundwater quality data for a 20 year period between 1998 and 2008 and hence time trends are not continuous. After a brief description of background conditions, groundwater quality data in Dyson's area, in the vicinity of the flooded Open Cuts, and near the White's and Intermediate Overburden Heaps are discussed separately in the sub-sections below. The mine site was subdivided in this manner in part for ease of discussion but also because the extent to which each area is connected is not yet apparent.

3.5.1 Background conditions

Groundwater quality data for the following bores are considered representative of background conditions near the Rum Jungle mine site:

- Bore RN023140 (screened in schist north of Old Tailings Creek)
- Bore RN022085 (screened in the Coomalie Dolomite upgradient of the site)

Bores RN023140 and RN022085 are routinely sampled by HAR Resources and hence a multi-year record of groundwater quality is available whereas bore RN025168 has been sampled twice since 2009. The pH of groundwater from bores RN023140 and RN022085 is typically neutral to slightly alkaline (pH 7 to 8) and EC values typically ranged from 350 to 500 uS/cm. HCO_3 is the predominant anion in groundwater from these bores as SO_4 concentrations are very low (i.e. 1 to 4 mg/L). This suggests that groundwater is not only unimpacted by ARD but that groundwater contains very low levels of naturally-occurring SO_4. Dissolved metal concentrations in bores RN023140 and RN022085 are typically very low although Mn concentrations in groundwater from the latter are somewhat elevated due to natural conditions in Coomalie Dolomite. Data from several bores installed in 2010 will offer additional information on background water quality in the Rum Jungle Complex (and the Coomalie Dolomite) but these data are still pending (and should be discussed in subsequent reports).

As mentioned in section 2.6.4, tailings were once disposed of into the relatively flat area north of White's Open Cut along Old Tailings Creek. In addition to bore RN023140 (which is representative of background water quality conditions), bores RN023302, RN023304, RN022547, and RN022548 are all located in the vicinity of the former tailings dam area. Note that bores RN023304, RN022547, and RN022548 are located in a relatively high-elevation area to the northeast of Old Tailings Creek whereas bore RN023302 is located close to the confluence between Old Tailings Creek and the East Finniss River. Groundwater from bores RN023304, RN022547, and RN022548 is essentially unimpacted by ARD as EC levels are close to background and metals concentrations are very low.

Groundwater from bore RN023304 is characterized by circum-neutral pH conditions but SO_4 concentrations are much higher than background levels (i.e. 600 mg/L). Elevated SO_4 concentrations in bore RN023304 are a clear indication that groundwater from this bore is affected by ARD although metals concentrations remain low and the source of ARD products is not certain at this time.

Preliminary descriptions of the groundwater flow field for the mine site suggest groundwater currently flows from the northwest across the site towards the Open Cuts and Overburden Heaps and hence elevated contaminant concentrations in bore RN023304 could reflect a historic TDS plume pulled into the area during historic pumping of this production bore or some localized oxidation of tailings that were not removed during the rehabilitation program in the 1980s (see Fawcett Mine Rehabilitation Services, 2007). Groundwater is only modestly impacted though and hence the former tailings dam area likely represents a relatively minor (and diffuse) source of contaminants to groundwater downgradient near the East Finniss River.

3.5.2 Dyson's Area

Dyson's Area features the Giant's Reef Fault and a series of NE-trending faults (see Figure 2-4). Dyson's Overburden Heap lies to the south of the Giant's Reef Fault and hence is underlain exclusively by granites of the Rum Jungle Complex. Dyson's (backfilled) Open Cut lies between two of the NE-trending faults in black shale of the White's Formation.

Most of the bores in Dyson's Area are clustered together near the southern toe of Dyson's Overburden Heap along the upper East Finniss River channel (Figure 3-1). Groundwater flow in this area is likely limited to shallow deposits of saprolite and/or alluvium associated with the Upper East Finniss River (meaning that most water infiltrating in this area likely moves laterally towards the river channel and not downward into the Rum Jungle Complex). This is supported by groundwater quality data from bores RN023413 and RN023419 (which are both screened in shallow, fine-grained alluvium). Groundwater from both is highly-acidic (pH<3) and characterized by SO_4, Mg, and metals concentrations that are essentially identical to (if not higher than) seepage from Dyson Overburden Heap. This suggests that the majority of the contaminant load from Dyson's Overburden Heap is delivered to the East Finniss River via shallow groundwater/seepage.

The other bores in the Dyson's area are located north of the Giant's Reef Fault closer to Dyson's (backfilled) Open Cut and are screened deeper in bedrock. Note that the occurrence of the different bedrock units in this area is structurally-controlled by the NE-trending faults that ultimately intersect the Giant's Reef Fault to the south. Groundwater quality near the western toe of Dyson's (backfilled) Open Cut (at bores RN023792 and RN022036) is characterized by near-background concentrations of SO_4/dissolved metals and hence appears to be completely unimpacted by ARD. This suggests that Dyson's (backfilled) Open Cut is not a source of ARD products to deep groundwater in this area or that contaminants are preferentially transported towards the Giant's Reef Fault via the NE-trending fault that lies east of these bores. Note that groundwater further west of these bores (at bore RN023793) does appear to be impacted by ARD but contaminants are most likely related to a nearby drainage channel at surface.

Groundwater from bore RN023790 also appears to be very modestly impacted by ARD but the contamination is limited to conservatively-transported species and water quality is consistent year-round. This suggests only a weak connection between relatively deep groundwater from this bore and the nearby braided channel that runs at surface from the southern toe of Dyson's (backfilled) Open Cut towards the upper East Finniss River. Note that bore PMB1b is screened in the braided channel and hence a quantitative description of this sub-surface contaminant load will be provided when data from that bore is available.

Historic groundwater quality shown in Figure 3-6 indicate that SO_4 concentrations in Dyson's Area are similar today as they were in the mid-1980s and metals concentrations remain very low in groundwater. This suggests that groundwater quality in this area of the site is relatively stable and that most contamination is limited to shallow groundwater near the main drainage features in this area. For this reason, Dyson's area is a low-priority in terms of future groundwater monitoring although the area likely delivers a small, chronic contaminant load to the upper East Finniss River that can be well-characterized by samples from bores RN023413 and RN023419 and bore PMB1b.

3.5.3 Near the Overburden Heaps

The White's and Intermediate Overburden Heaps are well-established as the main sources of ARD products to groundwater at the Rum Jungle mine site yet the complexity of groundwater flow fields around the heaps has hindered a detailed description of how the extent of ARD impact varies around the heaps (and what the implications to future contaminant transport are). The purpose of this section is to provide such a description and enable some preliminary conception of contaminant transport in this critical area of the site.

White's Overburden Heap straddles the Giant's Reef Fault with the southern part of the heap built atop low-permeability granite of the Rum Jungle Complex and northern part built atop the Crater Formation. Bores RN022082S/D are screened in the Rum Jungle Complex directly beneath White's Overburden Heap whereas the following bores are screened in the Rum Jungle Complex near the perimeter of the heap:

- Bore RN022083 (eastern toe near Fitch Creek)
- Bore RN022084 (southwestern toe near Wandering Creek)
- Bores RN025172 and RN030004 (near the southwestern toe)
- Bore RN022039 and RN022081 (near northwestern toe)
- Bores RN022037 and RN025173 (closer to the Intermediate Overburden Heap)

Note that the Rum Jungle Complex in each of these bores (except bore RN022082D) is weathered to some extent. Also note that bore PMB4 was recently installed in the Rum Jungle Complex near the EFDC but groundwater quality data is not yet available.

Groundwater from bore RN022082S is highly-impacted by seepage from the overlying waste rock. Specifically, groundwater from bore RN22082S is highly-acidic (pH 4) and SO_4 concentrations were consistently around 7,000 mg/L in 2008/2009. Most metals concentrations are also very high but Cu concentrations in groundwater are noticeably lower than in seepage from the eastern toe of the heap. In the deeper Rum Jungle Complex screened by bore RN22082D, contaminant concentrations are comparable to those observed in bore RN22082S but this similarity could be ascribed to a poor seal between the bores. Regardless, groundwater in bedrock beneath White's Overburden Heap is characterized by a TDS/metals plume yet the low permeability of the Rum Jungle Complex likely limits contaminant transport in deep groundwater beyond this area.

Note that groundwater quality in the Rum Jungle Complex near White's Overburden Heap has generally improved since the mid-1980s due to rehabilitation at that time. Specifically, SO_4 and dissolved metals are substantially lower today than they were in 1984/1985 when the heap was covered to reduce infiltration (see Figure 3-7). Specifically, SO_4 concentrations in bores RN22082S/D typically ranged from 20,000 to 50,000 mg/L before site rehabilitation and 'total' Cu concentrations often spanned a similar range. Since rehabilitation SO_4 concentrations have decreased to less than 25% of pre-rehabilitation levels and dissolved metals concentrations (such as Cu and Zn) have decreased by at least an order-of-magnitude (and done so near exponentially). The decrease in metals concentrations is consistent with reduced contaminant loads to deep groundwater and hence has important implications regarding the rate of deep groundwater recharge via seepage. Detailed analysis of deep groundwater recharge is beyond the scope of this report.

Groundwater from bore RN022083 is moderately-acidic (pH 6.0 to 6.5) and characterized by high EC levels and SO_4 concentrations. Contamination appears to be limited primarily to conservatively-transported species and some of the more mobile metals (like Zn and Mn). Elevated Al, Cu, and Co concentrations are also observed in the occasional sample but concentrations are typically orders-of-magnitude less than groundwater that is considered highly-impacted by seepage from White's Overburden Heap (i.e. at bore RN022411). Overall, this suggests that a TDS plume extends east from White's Overburden Heap and past bore RN022083 towards Fitch Creek but that the leading edge of a metals plume still resides closer to the heap. Note from Figure 3-8 that groundwater quality in this area has not improved since the 1980s and hence it seems reasonable to conclude that the area features a rather immobile TDS plume that resides in rather impermeable granite of the Rum Jungle Complex. Regardless, groundwater in the area east of White's Overburden Heap is not considered a priority area at this time and hence no additional bores were proposed in this area as part of the 2010 drilling program.

Recall that wet-season seepage from the southwestern toe of White's Overburden Heap is collected by Wandering Creek and subsequently delivered to the EFDC. Bores RN022084, RN022417, and RN029997 are each located close to Wandering Creek near the southwestern toe of White's Overburden Heap. Note that bore RN022417 is screened in quartz gravels immediately above the Rum Jungle Complex and not in the Rum Jungle Complex as the other bores are. Groundwater from each of these bores is highly-acidic (pH 3.6 to 5.2) and characterized by very high concentrations of Mg (2,000 to 2,500 mg/L), SO_4 (9,000 to 11,000 mg/L), and nearly every dissolved metal in the suite. The particularly high metals concentrations in bores RN022084and RN029997 are related to their proximity to a seepage face that characterizes the southwestern batter of White's Overburden Heap during the Wet whereas slightly lower concentrations at bore RN022417 reflects some dilution and/or metals attenuation along a flowpath that originates near the toe of the heap.

This dilution/attenuation trend is also apparent in bores located further west of White's Overburden Heap. For instance, bores RN022037 and RN025173 are both characterized by elevated levels of conservatively-transported species but groundwater is only slightly acidic and metals concentrations are much lower than in groundwater closer to the heap. These data are consistent with rather weak hydraulic gradients in this area and the presence of a residual TDS plume that extends from White's Overburden Heap to the eastern toe of the Intermediate Overburden Heap. This implies the westward transport of contaminants towards the Intermediate Overburden Heap (and not vice versa). Contaminants from the Intermediate Overburden Heap likely move northwest towards Wandering Creek and/or the EFDC (near the location of bores PMB5 and PMB6). This conception of contaminant transport is consistent with the identification of highly-impacted groundwater at bore RN023057 in 2009 and historic data from other nearby bores (i.e. RN023058 and RN023059; see Figure 3-10). Additional description of contaminant loads/transport in this area will be provided when data from bores PMB5 and PMB6 become available. At this time though is seems unlikely that contaminants are being transported beyond the lease boundary as Wandering Creek is expected to intercept shallow groundwater sampled by bores RN023058 and RN023059. That being said, contaminated groundwater has been identified at bore TPB2 so the issue should be re-visited once a better conception of hydraulic gradients and groundwater flows in this area has been developed.

3.5.4 Near the Flooded Open Cuts

This sub-section discusses groundwater quality near the flooded Open Cuts, in the former heap leach area, and the area north of these features/areas closer to the Old Tailings Dam area. This area is of particular significance to contaminant transport towards the East Finniss River and hence it was the principal focus of the 2010 drilling program. As data from the new bores is not yet available, the focus of this section is to provide some context as to why the characterization of groundwater quality in this area has been prioritized and what data gaps the new bores have effectively filled.

The White's and Intermediate Open Cuts are prominent features of the site and have likely affected groundwater flow fields in their vicinity for decades since they were allowed to flood. This is due to their behavior as constant head boundaries and hence as either a source or sink for groundwater depending on how pit water levels vary in relation to water levels in surrounding aquifers. Moreover, as pit waters used to be highly-contaminated they could have acted as significant sources of contaminants to local groundwater. Groundwater quality near the flooded Open Cuts (at bores RN022543 and RN022544) and immediately downgradient (at bore RN022107) is clearly impacted by ARD and has been for decades (see Figure 3-11). Whether groundwater contamination is ongoing or residual in nature is not well understood at this time though. For instance, groundwater from bore RN022544 (screened relatively deep near the eastern perimeter of White's Open Cut) is characterized by circum-neutral pH values but contains elevated concentrations of SO_4 (3,000 to 5,000 mg/L) and some dissolved metals (i.e. Mn and U in particular). These levels of ARD indicator species are not representative of current water quality conditions at the surface of White's Open Cut but instead reflect dense, highly-contaminated water that currently resides at the bottom of the Open Cut (or resided throughout the water column in the Open Cut prior to treatment). According to Tropical Water Solutions (2008), this layer of dense, highly-contaminated waters in White's Open Cut is currently restricted to the bottom-most 5 m of the water column (which is slightly deeper than the screened interval of bore RN022544) (see Figure 4-2).

The hydraulic connection between White's Open Cut and local groundwater is not known at this time but historic groundwater quality data shown in Figure 3-11 indicate that groundwater from bore RN022544 was highly-impacted by ARD in the 1980s and has not improved considerably over the last 25 years. Hence it seems likely that groundwater in this area was contaminated prior to the treatment of water in White's Open Cut and that the contamination of groundwater is not ongoing. In other words, groundwater to the east of White's Open Cut is characterized by a residual TDS (and possibly metals plume). This type of residual contaminant plume may also characterize groundwater to the north of White's Open Cut at bore RN022107. Bore RN022107 is screened in the rather permeable Coomalie Dolomite and is characterized by high concentrations of SO_4 and a suite of dissolved metals that are indicative of highly-contaminated groundwater. However, the consistency of water quality in this bore (as in bore RN022544) may be indicative of contamination primarily in the past. This implies weak hydraulic gradients in this area of the mine site have limited contaminant transport downgradient despite the high permeability of the Coomalie Dolomite (which could be supported by pending data from bores recently installed in the area).

Bores RN023516 and RN022108 are located less than 100 m from the western edge of the Intermediate Open Cut (Figure 3-1). Bore RN022108 is an ‘open hole’ in the Coomalie Dolomite whereas bore RN023516 is screened in fine-to-medium grained sand associated with the nearby East Finniss River. Groundwater from bore RN023516 is relatively unimpacted with respect to metals yet SO_4 concentrations are elevated. Groundwater from bore RN022108 is also relatively unimpacted as SO_4 concentrations are typically about 100 to 300 mg/L and metals concentrations are usually at or below their respective detection limits. Prior to rehabilitation though, this bore was highly-impacted by ARD (i.e. SO_4 concentrations of 2,000 to 3,500 mg/L and high concentrations of Cu, Co, Mn, Ni, and Zn; see Figure 3-12). Hence groundwater quality in this area appears to have improved along with water quality in the Intermediate Open Cut (which is consistent with its close hydraulic connection to the Open Cut). Note, however, that field EC readings collected by RGC in August 2010 suggest that highly-impacted groundwater could remain at the very bottom of this bore. This hypothesis is supported by the significant increase in EC observed in this open hole during drawdown of the water level in the Intermediate Open Cut in late 2008 (see section 3.3 and Figure 3-3). This bedrock bore was retrofitted with a set of nested piezometers (i.e. bores PMB9S/D) during the 2010 drilling program (see Appendix A). RGC believes that further discussion regarding the presence of highly-contaminated groundwater in the deeper Coomalie Dolomite is undertaken once more reliable data is available from these nested bores.

Another likely source of contaminants in this area is the oxidation of heap leach material and/or contaminated soils that remain between the two Open Cuts (and close to the former location of the East Finniss River channel). Groundwater quality in the former heap leach area is poorly characterized due to the lack of monitoring bores in the area (i.e. only bore RN023054 is located in the area and screened in weathered black shale to 2.6 m). Groundwater from bore RN023054 is rather unique in that it features much higher Cu concentrations than would be expected based on only moderately-elevated SO_4 concentrations (and EC levels). This is consistent with the local oxidation of residual heap leach material in this area and not necessarily the transport of impacted groundwater from upgradient. Note that four new bores were installed in the former heap leach area in 2010 (see Appendix A) and RGC recommends that further attention is given to water quality conditions in this area once that data is available.

3.5.5 Downgradient of the mine site

Detailed water quality surveys conducted in the mid-1990s show that EC and SO_4 concentrations in the East Finniss River increase immediately downstream of gauge GS8150200 (see Figure 3-4). Specifically, EC and SO_4 concentrations in the river increased within the first 900 m or so downstream of gauge GS8150200. In April 1994, maximum EC/SO_4 levels in the river occurred about 900 m downstream of gauge GS8150200 at site SW23, whereas in April 1995, maximum levels were observed 700 m downstream at site SW24. Flow data for April 1994 is unavailable whereas flow in April 1995 for gauge GS8150097 are shown in Figure 4-5a of the next section. Both surveys were conducted during a period of recessional flow at the end of the Wet (Lawton and Overall, 2002a). Another water quality survey conducted in June 1995 under true baseflow conditions showed no increase in EC/SO_4 levels downstream of gauge GS8150200 (likely due to a decrease in groundwater levels below that of the East Finniss River).

Lawton and Overall (2002a) ascribed the increases in EC/SO_4 levels observed downstream of gauge GS8150200 in April 1994 and April 1995 to the discharge of high-EC groundwater to the East Finniss River. This is a plausible scenario as groundwater is known to discharge to the river further downstream yet the EC/SO_4 levels necessary to account for the increase in the river implies the presence of contaminated groundwater in this area. Prior to installation of bore PMB16, bore RN023139 was the only bore located in the vicinity of the East Finniss River (see Figure 3-1) yet the water quality in this 'open-hole' bore appears to reflect surface water quality in the East Finniss River (rather than conditions in the bedrock aquifer) (Figure 3-13). Specifically, EC and SO_4 concentrations in samples from bore RN023139 increase in response to the pulse of contaminated surface water that moves downstream in the East Finniss River during the early wet season. Highly-impacted groundwater was recently identified near the East Finniss River (at bore PMB16) and hence supports the assertion that a contaminant load from groundwater to the river should be incorporated into future contaminant load assessments (and can explain historic variations in surface water quality downstream of gauge GS8150200).

4 SURFACE WATER QUALITY & CONTAMINANT LOADS

High annual loads of contaminants to the East Finniss River are well-established from previous reports (e.g. Henkel, 1991a,b; Lawton and Overall, 2002a; Ritchie and Bennett, 2003) yet the additional flow and surface water quality data now available enable some refinement of these loads at this time. The purpose of this section is therefore to characterize surface water quality at the mine site and then develop a preliminary contaminant load balance for the mine site by incorporating available flow data from operational and historic flow gauges.

4.1 DATA SOURCES & QA/QC

4.1.1 Flow data

The following is a list of selected flow gauges that have operated at the historic Rum Jungle mine site:

- GS8150209: flow at the head of the EFDC (near White's Overburden Heap)
- GS8150210: flow from Wandering Creek to the EFDC
- GS8150211: flow in the EFDC opposite the Intermediate Overburden Heap
- GS8150212: outflow from the Intermediate Open Cut
- GS8150213: inflow to White's Open Cut
- GS8150214: flows to the East Finniss River from Copper Creek
- GS8150200: East Finniss River immediately downstream of mine site
- GS8150097: East Finniss River 5.6 km downstream of mine site

The locations of these gauges are shown in Figure 4-1. Hourly river flow data were available from the Department of Natural Resources, Environment, the Arts and Sport (NRETAS) from 1993 to 1998 for gauges GS8150213 and GS8150212, from 1981 to 2008 for gauge GS8150200, and from 1965 to 2009 for gauge GS8150097. According to NRETAS, flows for gauges GS8150200 and GS8150097 are based on rating curves developed over a wide range of flow conditions and hence the data are reliable. Flows at gauges GS8150212 and GS8150213 were collected from 1993 to 1998 to determine annual flow volumes to and from the flooded Open Cuts (Lawton and Overall, 2002a). These flow data are less reliable than data for gauges GS8150200 and GS8150097 though and hence are interpreted with caution.

Spot measurements of flow at the other gauges listed were collected at eight different times during the 1989/1990 and 1990/1991 wet seasons. Note that these flows were measured before the Copper

Creek culvert was blocked, meaning that most of the outflow from White's Open Cut did not enter the Intermediate Open Cut but instead was delivered to the East Finniss River downstream of gauge GS8150200 via Copper Creek (Henkel, 1991a,b). Hence flows recorded at gauge GS8150212 and GS8150200 during this period cannot be compared directly to more recent flow data. Flow data from the other gauges in operation from 1989 to 1991 are valuable though as they enable some constraint of contaminant loads from the White's and Intermediate Overburden Heaps. Specifically, gauge GS8150209 captures flows from Fitch Creek and the upper East Finniss River plus any seepage collected by the drainage system that runs along the western toe of White's Overburden Heap whereas gauge GS8150210 captures seepage flows from the northern toe of White's Overburden Heap before they enter the EFDC via Wandering Creek. Also important is gauge GS8150211 (located about 700 m downstream of gauge GS8150209 in the EFDC). This gauge is located across from the Intermediate Overburden Heap and hence captures seepage flows from this heap to the EFDC upstream of the outflow from the Intermediate Open Cut (at gauge GS8150212) and flows from Wandering Creek.

Some additional flow data were available for a gauge located along the upper East Finniss River downstream of Dyson's area. These data were collected in 2008/2009 for the purpose of surface water studies conducted by ERISS but continuous measurements were not collected throughout the Wet Season (Ryan et al., 2009). Flows at this gauge are therefore interpreted with some caution and mainly in tandem with data from gauge GS8150213 (which represents the proportion of flow from the upper East Finniss River that enters White's Open Cut via the former Acid Dam area).

4.1.2 Water quality data

Surface water quality data collected by NRETAS from 1991 to 2001 are summarized as follows:

- From 1991 to 1995, daily composite samples of surface water from the East Finniss River at gauges GS8150200 and GS8150097
- From 1993 to 1998, flow-weighted samples of surface water to and from the flooded Open Cuts (at gauges GS8150213 and GS8150212) and from the East Finniss River at gauges GS8150200 and GS8150097
- From 1999 to 2001, flow-weighted samples of surface water from the East Finniss River at gauge GS8150097

Also available were spot water quality samples collected from gauges GS8150209, GS8150210, GS8150211, GS8150212, GS8150213, GS8150214, GS8150200, and GS8150097 at eight different times over the 1989/1990 and 1990/1991 wet seasons.

According to Lawton and Overall, (2002a), flow-weighted samples were collected from an 80-L plastic container that received pumped 500-mL aliquots from the river at intervals determined by river flow. Specifically, samples were collected after a pre-set volume of water had passed the station since the previous reading (meaning that each sample collected was representative of a specific volume). Daily composite samples were collected using a Sigma auto-sampler with a 24-bottle carousel and comprised three individual aliquots taken at eight hour intervals.

EC measurements and the concentrations of SO_4, Ca, Mg, Cu, Fe, Mn, Ni, and Zn were available for each sample collected from 1991 to 2001 whereas samples collected from 1989 to 1991 were only analyzed for SO_4, Cu, Mn, and Zn concentrations (see Appendix B). Note that 'total' and 'dissolved' metals concentrations are reported for surface water samples. Recall that 'dissolved' concentrations represent the metals content of un-acidified water after filtration through a 0.45 μm membrane whereas the 'total' concentration represents this 'dissolved' fraction plus any metals released from suspended solids upon sample acidification.

Because samples collected from 1989 to 2001 were not analyzed for a full suite of major ions and metals, these data could not be checked via a CBA but the data do appear to be of rather high quality and are considered reliable. Moreover, as these samples are flow-weighted they are particularly useful for estimating contaminant loads via surface water [see Lawton and Overall (2002a) and Section 4.3 of this report). Note that flow-weighted mean contaminant concentrations for gauges GS8150212, GS8150213, GS8150200, and GS8150097 provided in Table 4-1 were determined from monthly flow-weighted means determined for each gauge (but not provided in this report).

In addition to data collected by NRETAS from 1991 to 2001, surface water quality data collected by HAR Resources from 2008 to 2010 was also available for the following water courses/bodies:

- Upper East Finniss River upstream of Dyson's area
- White's & Intermediate Open Cuts
- East Finniss Diversion Channel (EFDC) upstream of gauge GS8150200 (at HAR Site 1)
- Creek flowing to EFDC from Browns Oxide mine site
- East Finniss River immediately downstream of mine site at gauge GS8150200
- East Finniss River 5.6 km downstream of mine site at gauge GS8150097

Water quality data collected from 2008 to 2010 by HAR Resources are provided in Appendix B with surface water quality data from the 2008/2009 ERISS studies. Each of the samples collected by HAR Resources was analyzed for a full suite of major ions and metals but flow data was not collected at the time of sample collection. Also, many of the samples were collected during the 2009/2010 wet season when only flow data from gauge GS8150097 is available from NRETAS. Note that data collected by HAR Resources was screened using the same procedure described in Section 3.4 and none of the data were excluded from interpretation.

4.2 SURFACE WATER QUALITY

4.2.1 Unimpacted surface water entering mine site

Unimpacted surface water enters Rum Jungle via the upper East Finniss River and Fitch Creek. The upper East Finniss River enters the Rum Jungle mine site from the east and flows past Dyson's area before being diverted to White's Open Cut or into the EFDC (see Section 2.3.2). Fitch Creek enters the Rum Jungle mine site from the south and flows past White's Overburden Heap before it too is diverted into the EFDC near the former Sweetwater Dam (Figure 2-3).

Samples from the upper East Finniss River and Fitch Creek upstream of the Rum Jungle mine site were collected in April 2009 as part of a wet season sampling campaigns conducted by ERISS (Ryan et al., 2009; Jones and Turner, 2010). These samples were collected during a period of high flow at the mine site and hence reflect relatively dilute water quality conditions. These data indicate that unimpacted surface water near the Rum Jungle mine site is characterized by circum-neutral pH conditions and very low concentrations of ARD indicator species like Mg, SO_4 and dissolved metals. SO_4 concentrations, for instance, were less than 1 mg/L in both Fitch Creek and the upper East Finniss River and EC levels typically ranged from 100 to 125 µS/cm (or about one-third of background EC levels for groundwater).

In summary, the geochemical characteristics of unimpacted surface water entering the Rum Jungle mine site via Fitch Creek and the upper East Finniss River are summarized as follows:

- Circum-neutral (if not slightly alkaline) pH conditions (i.e. pH 7 to 8)
- EC values of 50 to 125 µS/cm
- SO_4 concentrations of less than 5 mg/L
- 'Dissolved' and 'total' Cu, Co, Ni, Pb, U, and Zn concentrations of less than 10 µg/L but substantially higher levels of Al, Fe, and Mn (i.e. up to 2,000 µg/L for Fe)

Another source of relatively unimpacted surface water to the Rum Jungle mine site is from a small creek that flows to the EFDC immediately upstream of gauge GS8150200. Flows in the creek represent the controlled discharge of treated water from the Water Retention Pond near the Brown's Oxide Open Cut (and not natural creek flows). Hence due to treatment, water in the creek is characterized by circum-neutral pH conditions and typically low concentrations of SO_4 and metals although elevated contaminant levels are sometimes apparent. In August 2010, flows of 5 to 6 L/s were observed in the creek (or 80% of the flow in the EFDC) so this creek does represent a source of relatively clean water to the EFDC during periods of baseflow (see Appendix B).

4.2.2 Upper East Finniss River downstream of Dyson's area

Immediately downstream of Dyson's area (at site 9), the upper East Finniss River is slightly more acidic (pH 6.4) and SO_4 and metals concentrations (Co, Mn, and Ni in particular) are appreciably higher than upstream. Surface water at this location is therefore impacted by seepage from Dyson's area but the effect on surface water quality is diminished by dilution. Further downstream near Dyson's gauge, contaminant levels are slightly higher than at site 9. Note that samples from sites 9 and 10 were collected during a high flow period in 2009 when the dilution of seepage from Dyson's area by clean water from upstream is highest.

4.2.3 Flooded Open Cuts

When mining from White's Open Cut ceased in 1958, pit de-watering was discontinued and the pit were allowed to fill with groundwater and contaminated surface water (Allen and Verhoeven, 1986). Initially, water in White's Open Cut was acidic (pH 4.8) and characterized by SO_4 concentrations of less than 200 mg/L and Cu and Mn concentrations of less than 5 mg/L throughout the water column (see data for 1959 in Table B10). Tailings (and raffinate) were later discharged to White's Open Cut from 1965 to 1971 and water quality in White's Open Cut deteriorated rapidly as a consequence. By 1969, the pH of water in White's Open Cut was less than 3 and SO_4/metals concentrations were an order-of-magnitude higher than in 1959. By 1974, water quality had deteriorated further and some stratification within the water column was apparent (Davy, 1975).

Water quality in the Intermediate Open Cut was also very poor in the 1970s and 1980s but this pit was not used for tailings disposal or the containment of treatment plant wastes. Instead, the Intermediate Open Cut received contaminants from the discharge of highly-contaminated groundwater originating from White's Open Cut and/or the copper heap leach area or via surface flows from White's Open Cut (Davy, 1975). By the early 1980s, water quality in both Open Cuts was extremely poor and leakage from the pits represented a major source of contaminants to the nearby EFDC. For instance, Davy (1975) observed that a large limestone cavern in the EFDC seeped water that originated from White's Open Cut throughout the year. Note that this is consistent with field measurements collected in August 2010, which showed that some of the large pools in the EFDC were characterized by very different pH and EC values despite their proximity to one another. In other words, some of the pools may be hydraulically-connected to the White's Open Cut whereas others could be sustained by groundwater discharge from less-impacted areas that surround the EFDC.

In 1985, some thought went into whether to pump-and-treat water from both the White's and Intermediate Open Cuts. Ultimately, the worse condition of water in White's Open Cut (and its more stratified nature) lead to the decision to only pump-and-treat polluted water from that White's Open Cut and let the Intermediate Open Cut be 'flushed' by surface water inflows from White's Open Cut after some *in situ* treatment with lime (see Allen and Verhoeven, 1986). After treatment, water pumped from White's Open Cut was returned to the Open Cut where it formed a low-density layer atop the untreated water that remained. According to Lawton and Overall (2002b), the layer of treated water extended to 20 m or so beneath the water surface and remained in place for about 10 years after rehabilitation although the treated water was gradually flushed (by 1998).

In April 1998, the White's and Intermediate Open Cut both remained stratified with persistent layers of contaminated water beneath relatively clean water that is actively flushed each year by inflows from the upper East Finniss River. The boundary between clean surface waters and the underlying layer of contaminated water in White's Open Cut was identified at 28 m AHD in 1998 whereas the boundary resided at 25 m AHD in the Intermediate Open Cut (see Figure 4-2). Note that the highly-contaminated waters that lie near the bottoms of the Open Cuts remained similar to water that used to characterize the entire water columns prior to rehabilitation in 1984/1985. Over the last ten years, the depth of the untreated layer in White's Open Cut has decreased by ~7 m and currently resides at 21 m AHD (or within 5 to 6 m of the bottom of White's Open Cut). In the Intermediate Open Cut, highly-contaminated waters were identified at approximately the same elevation as in White's Open Cut (~20 m AHD) but there is more uncertainty regarding the actual depth of the Intermediate Open Cut. These decreases are due to annual 'flushing' of clean waters through the Open Cuts and the consequent removal of contaminants from the top of the untreated layer of water. Note though that untreated water within the layer is not being actively diluted and hence remains highly-impacted by ARD (and hence constitutes a possible source of contaminants to groundwater).

Outflow from the Intermediate Open Cut at gauge GS8150212 represents an integrated expression of water quality in the upper, relatively clean layer of water that moves through the Open Cuts each year. This layer of water essentially represents relatively clean water from the upper East Finniss River that enters via gauge GS8150213 and subsequently mixes with water from the Open Cuts. Mixing is generally restricted to the upper parts of the water columns although some contaminants are entrained from the layer of contaminated water that lies near the bottoms of the pits. Specifically, from 1993 to 1998, annual flow-weighted SO_4 concentrations at gauge GS8150212 were typically twice as high as at gauge GS8150213. Metals concentrations were also much higher at gauge GS8150212 than at gauge GS8150213 (see Table 4-1). The flow-weighted mean 'dissolved' Cu concentration, for example, was 0.22 mg/L at gauge GS8150212 compared to 0.04 mg/L at gauge

GS8150213 from 1993 to 1998. This suggests that a substantial load of contaminants is derived from the Open Cuts each year (which will be discussed in more detailed in Section 4.3).

4.2.4 East Finniss Diversion Channel

Near the end of the 2008/2009 Wet Season, water samples were collected at the head of the EFDC near the weir structure at site 3 (and the former location of gauge GS8150209) (Ryan et al., 2009). At this time of year, the sample collected from the head of the EFDC (at site 3) represents combined flows from Fitch Creek, the upper East Finniss River (after impact from Dyson's area), and seepage from the channel (known as Sweetwater Dam) that collects seepage from the eastern toe of White's Overburden Heap. This sample was slightly acidic (pH 6.4) and characterized by a SO_4 concentration of 512 mg/L. Metals concentrations were usually less than 1000 µg/L or one-to-two orders of magnitude lower than seepage from the nearby White's Overburden Heap (at sites 4 and 5). These characteristics suggest that seepage from White's Overburden Heap affects the condition of surface water in the EFDC but that dilution by surface water from Fitch Creek and the upper East Finniss River maintains relatively low concentrations.

From site 3, water flows for about 900 m until seepage from the northern toe of the Intermediate Overburden Heap discharges to the EFDC (near the former location of gauge GS8150211). A sample collected downstream of the Intermediate Overburden Heap in April 2009 was more acidic (pH 5.9) and characterized by 20% more SO_4 than at the head of the EFDC. Metals concentrations at this location were 2 to 4 times higher than in the EFDC upstream of the Intermediate Overburden Heap. These data are consistent with historic monitoring data from Henkel (1991ab) that show a similar increase in concentrations (and a gain in flow between the gauges).

There are no point sources of contamination between the head of the EFDC and the Intermediate Overburden Heap but contaminated and/or unimpacted groundwater could discharge from bedrock along this reach of the EFDC. Hence at this time it seems probable that the increase in ARD products in the EFDC downstream of the Intermediate Overburden Heap is related solely to waste rock seepage from the northern toe of that heap either at surface or via the sub-surface (see Section 4.3 for additional discussion of contaminant loads to the EFDC).

Most of the wet season flow in the EFDC is related to water from Fitch Creek and the upper East Finniss River and hence contaminant concentrations in the EFDC are often highly-diluted. Surface water quality in the EFDC during the dry season though reflects only inputs by waste rock seepage and a comparison of wet-and-dry season water quality offers a wealth of information that is relevant to subsequent discussions of contaminants loads to the East Finniss River downstream of the site. For instance, samples collected at HAR Site 1 (GS8150211) from 2008 to 2010 suggest that the EFDC is highly-acidic (pH<4) and 'total' and 'dissolved' metals concentrations are both very high during baseflow periods. The very high concentrations of 'dissolved' metals (and their near equivalence to 'total' concentrations) are due to the enhanced solubility of each metal under highly-acidic conditions in the EFDC at this time of year.

At the beginning of the wet season though when well-buffered water from Fitch Creek and the upper East Finniss River begins to flow into the EFDC, pH conditions in the EFDC increase and metals concentrations decrease by several orders of magnitude. The decrease in metals concentrations (and the disparity between 'total' and 'dissolved' concentrations) is due in part to dilution but also the precipitation of hydrous Al and Fe oxides in the river and the co-precipitation of Cu (amongst other metals). The effect of metals precipitation is particularly apparent in the discrepancy between 'dissolved' and 'total' concentrations of Al as the solubility of this metal is particularly sensitive to pH. Note that 'dissolved' and 'total' concentrations of Co, Mn, Ni, and Zn remain nearly equivalent during the wet season as the solubilities of these metals are less pH-dependent than Al. A disparity between 'total' and 'dissolved' Cu concentrations (and hence large proportion of contaminants in suspended form) has also been identified in the East Finniss River at GS8150097 in previous reports (e.g. Henkel, 1991ab) but that lower 'dissolved' Cu concentrations were broadly attributed in those reports to the precipitation of copper sulphides in part due to the availability of only a small sub-set of metals that did not include Al or Fe. At this time it is therefore important to clarify that the co-precipitation of Cu to Fe and Al oxides is a more likely explanation for lower 'dissolved' Cu concentrations in the EFDC and in the East Finniss River.

4.2.5 East Finniss River Downstream of Mine Site

Surface water quality in the East Finniss River at gauges GS8150200 and GS8150097 are discussed together in this section. Much of these section focuses on flow-weighted samples collected from 1993 to 1998 at both gauges and daily composite samples collected at gauge GS8150097 during the 1990/1991, 1991/1992, 1992/1993, and 1994/1995 wet seasons (data from 1993/1994 is incomplete so not discussed). Data collected more recently by ERISS and HAR Resources is discussed when relevant but continuous flow data for gauges GS8150200 and GS8150097 were not available from 2008 to 2010 so the water quality data collected over this period are less useful than flow-weighted historical data. Note that flow-weighted annual mean SO_4 and metals concentrations provided in Table 4-4 were calculated from flow data provided with the water quality data (see Appendix B) but that the annual flow volumes shown in that table are from Moliere et al. (2007).

Flow-weighted mean concentrations at gauges GS8150200 and GS8150097 both show a clear dilution trend in response to inter-annual variability in rainfall amount (i.e. concentrations were highest when rainfall was lowest and vice versa). This suggests that annual contaminant loads from the site to the East Finniss River vary somewhat from year-to-year but that the impacts of these loads on surface water are muted by the amount of incident rainfall for a particular year. The diluting effect of rainfall (and its role in 'flushing' contaminants to the East Finniss River) is especially apparent from the daily composite data collected from gauge GS8150097 in the early 1990s (see Figures 4-3 to 4-6). Note from Figure 4-3, for example, that SO_4 (and metals) concentrations increased dramatically in early December in response to the first rains of the Wet (i.e. 'first flush') before an extended period of dilution that is often interrupted by brief periods of rain. Other notable features of the daily composite data are highlighted on the figures and trends in metals concentrations are discussed in more detail below.

4.3 CONTAMINANT LOADS

Annual contaminant loads for the East Finniss River at gauges GS8150200 and GS8150097 from 1993 to 1998 were determined as the product of the flow-weighted annual mean contaminant concentrations and annual flow volume estimates from Moliere et al. (2007). Note that only gauge GS8150097 was monitored from 1998 to 2001 and that updated flows for these years were not provided in Moliere et al. (2007). Average annual flows from 1993 to 1998 were considered a reasonable approximation of a typical year at the mine site and hence used to estimate contaminant loads to the East Finniss River from the flooded Open Cuts and the EFDC. Note that additional work is needed to confirm that historic data from the 1990s are representative of current conditions at the mine site (i.e. with data from the 2009/2010 and 2010/2011 wet seasons).

The average SO_4 load to the East Finniss River at gauge GS8150200 is estimated to be 3672 t/yr (Table 4-2b). The annual SO_4 load at gauge GS8150097 is typically about 5% higher than upstream at gauge GS8150200 but this difference is not considered significant. The similar SO_4 loads at these gauges suggests that the majority of SO_4 in the East Finniss River is derived from the mine waste units upstream of gauge GS8150200 and not inflows from contaminated groundwater and/or surface flows from Old Tailings Creek. Metals loads downstream at gauge GS8150097 are typically about 10 to 20% lower than at gauge GS8150200. This decrease is due to the precipitation of 'dissolved' metals between the gauges.

The 'total' Cu load at gauge GS8150200 was estimated to be 14 t/yr (Table 4-2b). 'Total' Cu loads for individual wet seasons from 1993 to 1998 ranged from 6 t/yr in 1995/1996 to 16 t/yr in 1996/1997. These estimates are comparable to previous load estimates of 10 to 12 t/yr from Lawton and Overall (2002a). 'Total' Mn, Ni, and Zn loads were 24, 5, and 10 t/yr, respectively (see Table 4-2). Note that the 'dissolved' Cu load at gauge GS8150200 was only about one-third of 'total' Cu load because of the large difference in 'dissolved' and 'total' Cu concentrations mentioned in the previous section. The 'total' and 'dissolved' Mn, Ni, and Zn loads were much closer to one another by comparison.

The contaminant loads at gauge GS8150200 represent the combined loads from the flooded Open Cuts (at gauge GS8150212) and the EFDC. The loads at gauge GS8150212 can be further partitioned into (a) loads derived from the impacted waters that enter White's Open Cut at gauge GS8150213 (i.e. from the upper East Finniss River) and (b) loads attributed to contaminated waters in the Open Cuts themselves (see Table 4-3a). The loads at gauge GS8150213 are representative of late wet-season loads delivered from Dyson's Area to White's Open Cut via the upper East Finniss River (i.e. excluding the early, more contaminated waters that are diverted to the EFDC prior to flows registering at gauge GS8150213). These loads are informative though as they suggest that only a small proportion of the loads delivered to the EFDC via outflow from the Intermediate Open Cut (at gauge GS8150212) are derived from Dyson's Area. Instead, the vast majority of loads at gauge GS8150212 are comprised of contaminants from deep, highly-contaminated waters in the flooded Open Cuts. Specifically, 520 t/yr of SO_4 and 2.7 t/yr 'total' Cu are attributed to highly-contaminated layers of water in the Open Cuts. This annual net Cu contaminant load from the Open Cuts is consistent with the 3.3 t/yr estimated by Lawton and Overall (2002b) and should reduce over time as the layers of contaminated water are further eroded. Other net contaminant loads from the Open Cuts are provided in Table 4-3a.

Flow in the EFDC was not routinely monitored from 1993 to 1998 (nor is it currently) so annual flows (and loads) from the EFDC to the East Finniss River were estimated as the difference between gauges GS8150200 and GS8150212. By this calculation, annual flow in the EFDC from 1993 to 1998 was 20×10^9 L or about 60% of flow at gauge GS8150200 (see Table 4-3b). Contaminants in the EFDC originate primarily from the White's and Intermediate Overburden Heaps but also include contaminants 'flushed' from Dyson's Area early in the wet season (prior to flow registering at gauge GS8150213). Contaminants loads in the EFDC are summarized as follows:

- 2544 t/yr SO_4 (or 70% of the SO_4 load at gauge GS8150200)
- 10.7 t/yr (or 75% of the 'total' Cu load at gauge GS8150200); note that 80% of this load is comprised of 'particulate' Cu that is likely sorbed to Al and Fe hydrous oxides within the river
- 8.1 t/yr (or 85% of the 'total' Zn load at gauge GS8150200); in contrast to the Cu load, the 'dissolved' Zn load represents 80% of the 'total' Zn load due to its higher solubility in circum-neutral waters and the lack of co-precipitation to hydrous oxides in the river
- 55.6 t/yr (or 97% of the 'total' Fe load at gauge GS8150200); this suggests that nearly all of the Fe in the East Finniss River has precipitated to some extent within the water column (and hence does not pass through the 0.45 µm filter membrane); no historic data is available for Al but more recent data collected from the EFDC suggests that this metal behaves similarly to

Fe and hence readily precipitates in the East Finniss River as the pH of river water increases downstream.

Note that the inferred contaminant concentrations in the EFDC from 1993 to 1998 needed to account for contaminant load estimates in the EFDC are provided in Table 4-3b. These concentrations were calculated by dividing the annual contaminant load by 20×10^9 L and hence correspond to flow-weighted concentrations from 1993 to 1998. These concentrations compare reasonably to flow-weighted data collected from the EFDC at gauge GS8150209 during the 1990/1991 wet season and data for the early 2009/2010 wet season (i.e. on December 15, 2009). Hence it is reasonable to expect concentrations of this magnitude in the EFDC although the relative contributions by individual mine waste units remains unconstrained at this point.

The combined net annual contaminant loads from the White's and Intermediate Overburden Heaps are provided in Table 4-3c (i.e. heaps). Note that the development of a load balance that further apportions loads according to specific mine waste unit should be a major focus of future project phases but that insufficient data is currently available to do so in this report. Specific data/developments that are required for this type of analysis include detailed water quality (and flow) data for gauges along the East Finniss River (including the proposed mid-station gauge near bores PMB20 and PMB21), routinely collected seepage data (flows and water quality), and an improved conception of current groundwater flow conditions throughout an entire wet season.

5 CONCLUSIONS

This report provides an overview of historic data that is relevant to site hydrogeology and a detailed description of seepage, groundwater, and surface water quality available as of the end of 2010. The focus of the data review provided was to identify areas of the site that were under-represented in the historic bore network at the site and thereby develop a workplan for the 2010 drilling program (see RGC, 2010b). Results from bores installed in 2010 will enable a more detailed conceptualization of current conditions at the site but the following preliminary conclusions were reached based on the data reported here.

5.1 SEEPAGE WATER QUALITY

Seepages from the four major mine waste units at the site provide the bulk of contaminant loads to the East Finniss River (via the EFDC or the flooded Open Cuts) and are geochemically distinct from one another. Aside from being highly-acidic (pH<4) and characterized by high concentrations of SO_4, other characteristic features of seepage are summarized as follows:

- Seepage from Dyson's Overburden Heap tends to be characterized by higher concentrations of dissolved U and lower concentrations of Cu, Co, Ni, and Zn than seepage from Dyson's (backfilled) Open Cut; this is consistent with Dyson's ore body being mined solely for uranium whereas high metals concentrations in the backfilled pit are related to tailings and contaminated soils stored therein;
- Seepage from White's Overburden Heap is characterized by high concentrations of nearly every dissolved metal as the ore body was mined for uranium and a suite of other metals; seepage from this heap contributes the most volumetrically to the EFDC and hence East Finniss River downstream;
- Seepage from the Intermediate Overburden Heap is the most concentrated source of contaminants at the mine site as metals concentrations can be orders of magnitude higher than in seepage from the White's Overburden Heap or seepages in Dyson's Area; of particular interest is the very high Cu concentrations (which reflect the geochemistry of the Intermediate ore body);

5.2 GROUNDWATER FLOW

A preliminary assessment of groundwater flow at the mine site was prepared to identify major areas of groundwater discharge and recharge. Major features are summarized as follows:

- Groundwater tends to flow from the high-elevation area northwest of Dyson's area towards the flooded Open Cuts (and ultimately the East Finniss River);

- The major mine waste units represent sources of localized recharge (of highly impacted seepage) to local aquifers; seepage from Dyson's and White's Overburden Heaps appears to be primarily limited to shallow seepage in weathered bedrock and/or sediments of drainage channels; seepage from the Intermediate Overburden Heap discharges directly into EFDC but may also enter the more permeable bedrock underlying this waste unit;
- Groundwater flow at the Rum Jungle mine site occurs primarily in the more permeable bedrock units of the Coomalie Dolomite and White's Formation; groundwater flow in the bedrock aquifer appears to be significantly influenced by structures; the Giants Reef Fault is inferred to represent a major barrier to groundwater flow while the NE-SW trending main fault (connecting the White's and Intermediate Open Cuts) is inferred to be transmissive and may represent a major conduit of groundwater flow;
- Both flooded Open Cuts are believed to be well-connected hydraulically to the surrounding bedrock aquifer. In the former heap leach area, groundwater flows from the White's Open Cut towards the Intermediate Open Cut and from there towards the East Finniss River. Initial water level interpretations (January 2011) suggest that moderately-contaminated groundwater present in the Coomalie dolomite immediately to the north of the Open Cuts flows towards the White's Open Cut and potentially also towards the Intermediate Open Cut. However, some moderately impacted groundwater present in the permeable Coomalie dolomite to the north of the heap leach area also flows in a westerly direction towards the East Finniss River;
- The reach of the East Finniss River between the Intermediate Open Cut and the Old Tailings Creek represents the main discharge zone for impacted groundwater from the Rum Jungle mine site. However, more information is required to determine the potential influence of mining activity on the east side of the EFR (at the Browns Oxide mine site) on groundwater flow at the Rum Jungle mine site.

5.3 GROUNDWATER QUALITY

Historic groundwater quality data collected in the 1980s and more recently from 2008 to 2010 has enabled a preliminary conception of groundwater quality conditions at the mine site. Additional refinements will be enabled by data from bores installed in 2010 but the current conception is summarized as follows:

- Groundwater close to the major mine waste units is acidic (pH<5) and highly-impacted by ARD; specifically, SO_4 and dissolved metals concentrations are often very high in groundwater located immediately downgradient of a source of waste rock seepage (or other source of mine waste seepage) as impacts by ARD are particularly apparent near White's

Overburden Heap, the Intermediate Overburden Heap, and between the flooded Open Cuts (i.e. in the former heap leach area);

- The impact of ARD on groundwater appears to diminish considerably with distance from seepage sources as groundwater across much of the site tends to be well-buffered and hence characterized by low concentrations of dissolved metals; much of the impact on groundwater is therefore limited to increased TDS (primarily Ca, Mg and SO_4) and groundwater tends to be neutral to slightly alkaline; the presence of the Coomalie Dolomite (and its high buffering capacity) is of particular importance as this unit has received a substantial contaminant load from upgradient but continues to buffer receiving groundwater;
- Groundwater contamination tends to be limited to shallow aquifer zones as deep groundwater often appears unimpacted or only modestly impacted by conservatively-transported ARD species; this trend is particularly evident in Dyson's area, which is characterized by highly-impacted seepage and very shallow groundwater but impacts to deeper groundwater in Dyson's area appear to be minimal;
- A TDS plume extends to the north and northwest of the flooded Open Cuts and former heap leach area into the vicinity of the East Finniss River; the presence of impacted groundwater downgradient of the site explains historic trends in the East Finniss River, as an additional source of contaminants to the river was inferred from synoptic data collected in the 1990s;

5.4 SURFACE WATER QUALITY & CONTAMINANT LOADS

The majority of contaminant loads to the East Finniss River are delivered via surface water (as opposed to groundwater) as seepage from the various mine waste units tends to occur at surface or in the very shallow sub-surface near a seepage face. The EFDC receives contaminant loads from the White's and Intermediate Overburden Heaps and therefore contributes the majority of SO_4 and metals loads to the East Finniss River at gauge GS8150200 (i.e. 70% of the SO_4 load and 75% of the Cu load). The remainder of contaminant loads to the East Finniss River is derived from the White's and Intermediate Open Cuts (which both contain highly-contaminated waters at depth).

Preliminary water quality data from 2010 bores suggests very high levels of contamination near the Intermediate Open Cut and hence it is not yet clear whether contaminants in this Open Cut are residual or reflect ongoing interaction with local aquifers. Also, in-river processes of metals precipitation (and co-precipitation) appear to be important processes influencing contaminant loads in the EFDC and downstream of the mine site. Additional flow and surface water quality data are needed to further clarify the influence of these processes.

6 CLOSURE

Robertson GeoConsultants Inc. (RGC) is pleased to submit this report entitled Phase 2 Report - Detailed Water Quality Review & Preliminary Contaminant Load Balance, Rum Jungle mine site, NT.

This report was prepared by Robertson GeoConsultants Inc. for the use of NT Department of Resources.

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.

Paul Ferguson, Ph.D.

Senior Geochemist

Christoph Wels, Ph.D., M.Sc., P.Geo.

Principal Hydrogeologist

7 REFERENCES

Ahmad, M., Lally, J.H., and A.J. McCready (2006), Geology and Mineral Deposits of the Rum Jungle Mineral Field, Report 19, Northern Territory Geological Survey.

Allen, C.G. and T.J. Verhoeven (Eds.) (1986), Rum Jungle Rehabilitation Project: Final Project Report, Technical Report No. 7245 10133, NT Department of Mines & Energy (Darwin). June 1986.

Andersen, E.J., Herwig, L.G. and B.R. Moffitt (1966), Heap leaching at Rum Jungle, Australian Mining, 58, 35-39.

Australian Bureau of Meteorology (2010), Online Climate Data, www.bom.gov.au

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

Barrie, DR (1982), "The Heart of Rum Jungle", The Dominion Press, Hedges and Bell.

Coffey Geosciences Pty Ltd. (2005), Browns Oxide Project - Groundwater Assessment, Batchelor, NT.

Davy, D.R. (1975), Rum Jungle Environmental Studies, Australian Atomic Energy Commission report. September 1975.

Fawcett Mine Rehabilitation Services Pty Limited (2007), Estimate of Reclamation & Management Costs for the Rum Jungle Uranium Mining & Processing Site, August 2007.

Henkel, C.H. and J.F. Alcock (1988), East Finniss River and Finniss River Pollution Study 1986/1987, Water Resources Division (Darwin), March, 1988

Henkel, C.H. (1991a), Rum Jungle Rehabilitation Project - Surface Water Monitoring Report 1989/1990, Water Resources Division (Darwin), January 1991

Henkel, C.H. (1991b), Rum Jungle Rehabilitation Project - Surface Water Monitoring Report 1990/1991, Water Resources Division (Darwin), December 1991

Jones, D.R. and K. Turner (2010), Surface Water Quality Monitoring at the Rum Jungle Mine Site, 2008/2009 Wet Season, Registry File SG2008/246. June 2010.

Kraatz, M (Ed.) (1998), Rum Jungle Rehabilitation Project Monitoring Report 1988-1993, Technical Report Number R97/2, NT Department of Lands, Planning & Environment (Darwin). March 1998.

Kraatz, M. (2004), Rum Jungle Rehabilitation Site Scoping Study, Environmental Issues and Considerations for Future Management, Report to the Department of Industry, Tourism and Resources, M4K Environmental Consulting, February 2004.

Lawton, M.D. and R. Overall (2002a), Surface water monitoring, *in* Rum Jungle Rehabilitation Monitoring Report 1993 to 1998, Pidsley, S.M. (ed.), July 2002.

Lawton, M.D. and R. Overall (2002b), Water Quality in White's and Intermediate Open Cuts, *in* Rum Jungle Rehabilitation Monitoring Report 1993 to 1998, Pidsley, S.M. (ed.), July 2002.

Lowry, J. and G. Staben (2007), Development of a GIS database and metadatabase for groundwater modeling and analysis of the Rum Jungle mine site report by Supervising Scientist Division to NT Department of Natural Resources, Environment, the Arts and Sport, May 2007.

McCready, A.J., Stumpfl, E.F., Lally, J.H., and R.D. Gee (2004), Polymetallic mineralization at the Browns Deposit, Rum Jungle Mineral Field, Northern Territory, Australia, Economic Geology, 99(2), 257-277.

Moliere, D., J. Brazier, and D. Jones (2007), Discrepancies between pollutant loads from on-site sources and pollutants loads downstream of Rum Jungle, ERISS Report, December 2007.

Pidsley, S.M. (Ed.) (2002), Rum Jungle Rehabilitation Project Monitoring Report 1993-1998, Technical Report No. 01/2002, July 2002.

Ritchie, A.I.M. and J.W. Bennett (2003), The Rum Jungle Mine – A Case Study, in Environmental Aspects of Mine Wastes, Jambor, J.L., Blowes, D.W., and A.I.M Ritchie (eds.), Mineralogical Association of Canada, Short Course Series 31.

RGC (2010a), Phase 1 Report – Initial Review & Data Gap Analysis, June 2010.

RGC (2010b), Technical specifications for 2010 Rum Jungle drilling program, September 2010.

Ryan, B., Bradley, F. & Bollhöfer, A. (2009), Final Report into the characterization of groundwater at the Rum Jungle mine site, ERISS report, September 2009.

Spratt, R.N. (1965), *Uranium Ore Deposits of Rum Jungle*. In: Geology of Australian Ore Deposits - 8th Commonwealth Mining and Metallurgical Congress, Vol. 1, Australia and New Zealand, 1965. Ed. J. McAndrew, Australasian Institute of Mining and Metallurgy (AusIMM), pp 201-206.

Taylor, G, Spain, A, Nefiodovas, A, Timms, G, Kuznetsov, V and J. Bennett (2003), Determination of the Reasons for Deterioration of the Rum Jungle Waste Rock Cover, Australian Centre for Mining Environmental Research (Brisbane).

Tropical Water Solutions (2008), Water Quality Profile & Bathymetric of White's and Intermediate Open Cuts. Rum Jungle, November 2008.

Water Studies Pty Ltd. (2002), Browns Polymetallic Project – Review of Potential Groundwater Impacts, Report prepared for Compass Resources NL. Report WSDJ00283/1-A.

Watson, G.M. (1979), Rum Jungle Environmental Studies – Summary Report, Uranium Advisory Council.