Numerical groundwater flow modelling at the historic Rum Jungle mine site, northern Australia

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Abstract

Rum Jungle was one of Australia's first major uranium mines and produced 3,500 tonnes of uranium oxide and 20,000 tonnes of copper in the 1950s and 1960s. After mine closure, acid rock drainage and the mobilization of metals in mine waste led to significant impacts on groundwater and the East Branch of the Finniss River. A revised rehabilitation plan for the site is being developed by the Northern Territory Department of Resources and a transient groundwater flow model was developed to assist. This paper describes results of the initial phase of groundwater flow modeling.

Key words: groundwater, numerical flow modelling, Rum Jungle, Australia

Introduction

Acid rock drainage (ARD) and heavy metal mobilization at the former Rum Jungle Mine Site have led to significant environmental impacts on local groundwater and the East Branch of the Finniss River (Kraatz, 2004).

Rehabilitation in the 1980s involved treatment of highly-impacted pit water, covering the waste rock dumps (WRDs) to reduce infiltration and oxygen transport, and backfilling one of the open pits with tailings and highly-contaminated soils (Allen & Verhoeven, 1986). Contaminant loads from the mine site were substantially reduced by rehabilitation measures but groundwater and the East Branch of the Finniss River remain impacted by ARD (Ferguson et al., 2012).

- In 2009, the Mining Performance Division of the Department of Resources (DoR) was tasked with developing a revised rehabilitation strategy for the former Rum Jungle Mine Site. Robertson GeoConsultants Inc. ("RGC") developed a transient groundwater flow model for the Rum Jungle mine site to assist with this rehabilitation planning. The overall objective of this modeling work was to understand current groundwater conditions and to evaluate alternative rehabilitation options. The objectives of the initial phase of modeling work were to:
- Develop a conceptual flow model that describes the principal hydrogeologic features of the mine site and all available groundwater monitoring data/hydraulic testing data; and
- Calibrate a transient numerical flow model to groundwater level data collected from August 2010 to November 2011; and

- Verify the numerical flow model using data from a large-scale pit de-watering trial.

This paper summarizes the results of this initial phase of modeling.

Study Area

The former Rum Jungle Mine Site is located 105 km by road south of Darwin in Australia's Northern Territory (NT). The region is characterized by a tropical savannah-like climate and typically receives about 1500 mm of annual rainfall. 90% or more of this rainfall occurs during a distinct wet season that lasts from November to April.

The East Branch of the Finniss River flows through the mine site and was diverted during mining operations to allow access to the Main and Intermediate ore bodies. Flows from the upper East Branch of the Finniss River and Fitch Creek currently flow directly into the East Finniss Diversion Channel (EFDC) and through the Open Pits before flow resumes northward via the natural course of the East Branch of the Finniss River (Figure 1).

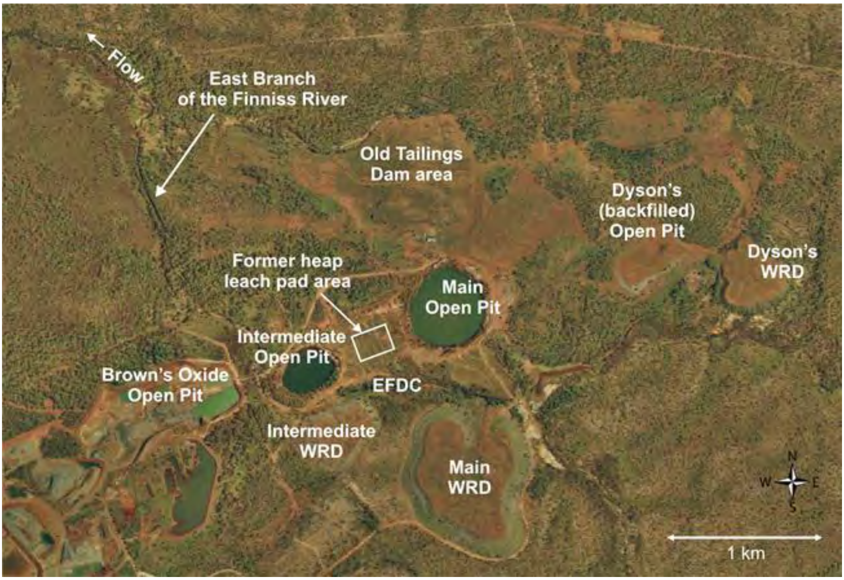

Figure 1 *Open pits, waste rock dumps (WRDs), and other pertinent features of the Rum Jungle Mine Site.*

The mine site features three waste rock dumps (WRDs), the flooded Main and Intermediate Open Pits, Dyson's (backfilled) Open Pit (or 'Landform') and the partially-mined Browns Oxide Open Pit (see Figure 1). Other notable features include the East Finniss Diversion Channel (EFDC), the former Tailings Dam area along Old Tailings Creek, and the former Copper Extraction Pad between the flooded Open Pits (see Ferguson et al., 2012 for additional details).

Model Setup & Discretization

Figure 2 shows the boundaries of the model domain for the Rum Jungle Mine Site. The boundaries of the model domain (shown in red) were defined by local topographic highs and low-lying drainage lines (creeks) such that cross-boundary flows into the modeled domain can be assumed to be negligible.

Groundwater flow was simulated with MODFLOW-2000 using the Layer Property Flow (LPF) package and the Preconditioned Conjugate Gradient 2 (PCG2) solver to solve the flow matrix (Harbaugh et al., 2000; Hill, 1990). MODFLOW was run transiently (monthly time steps) to simulate seasonal variations in groundwater levels from August 2010 to November 2011.

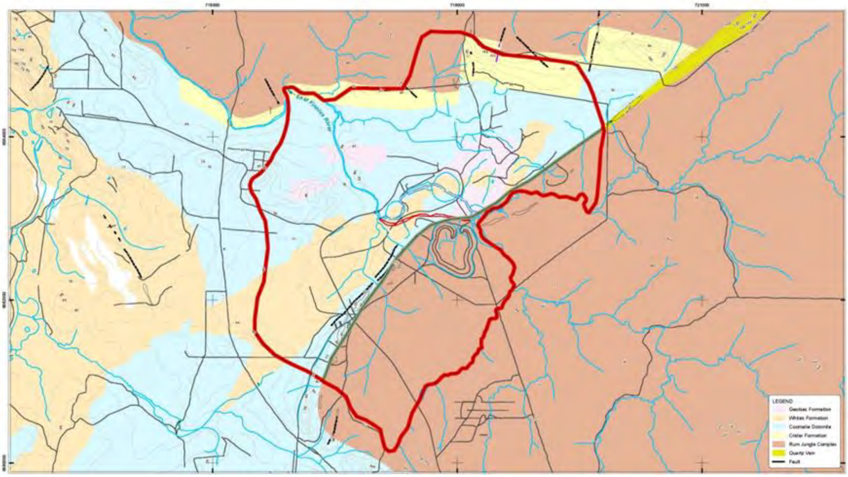

Figure 2 *Numerical model domain, Rum Jungle Mine Site*

The model domain was spatially discretized into a 3-dimensional grid with a uniform grid spacing of 25 m. Initially, 3-layer and 4-layer models were developed and partially-calibrated but the model domain was ultimately discretized as a 6-layer model.

Current topography at the Rum Jungle Mine Site was used to define the top of Layer 1 and the top of Layer 2 outside of the footprints of the WRDs and Dyson's (backfilled) Open Pit. Within the footprints of these mine waste units, the top of Layer 2 was defined by the pre-mining ground elevation in that area (implying that the thickness of Layer 1 is variable). Hydrostratigraphic units used to assign hydraulic properties (and recharge) are shown in Figure 3.

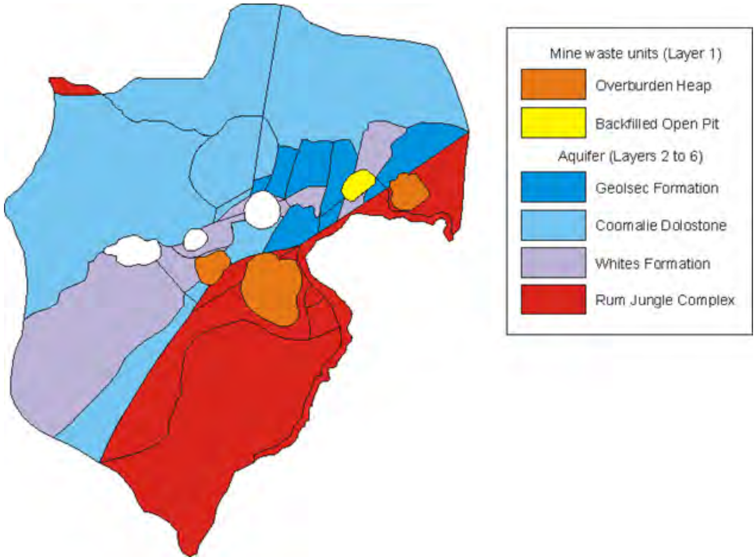

Figure 3 *Hydrostratigraphic units, Rum Jungle Mine Site*

Model Calibration

The model domain was initially discretized solely on the basis of lithology and estimates of recharge, horizontal and vertical hydraulic conductivity (K_H and K_V, respectively), specific storage (Ss), and specific yield (Sy) from the conceptual model were assigned. The model was then calibrated by manually adjusting recharge and the aquifer properties within an acceptable range in order to fit simulated water levels to observed water levels.

The quality of the fit between simulated and observed water levels was visually evaluated based on the geodetic elevation of the simulated water level and the early wet season response of the simulated water level to recharge (RGC, 2012). Groundwater levels in close to sixty wells across the model domain were simulated during the calibration process (see example in Figure 4).

Numerical Modeling Results

Simulated Groundwater Flow Fields

The simulated groundwater flow field for April 2011 (the height of the wet season) is shown in Figure 5. Groundwater generally flows from topographic highs towards the central mine reach and the East Branch of the Finniss River.

Groundwater levels near the Main WRD were simulated to ‘mound’ due to the low K of the Rum Jungle Complex and flow occurs radially outward as a result. Mounding was not simulated near the Intermediate WRD due to the presence of the more permeable Coomalie Dolostone and Whites Formation in this area.

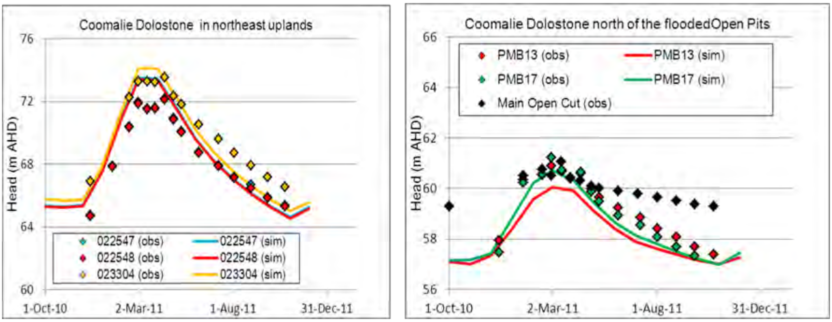

Figure 4 *Simulated and observed groundwater levels at a selection of wells screened in the Coomalie Dolostone*

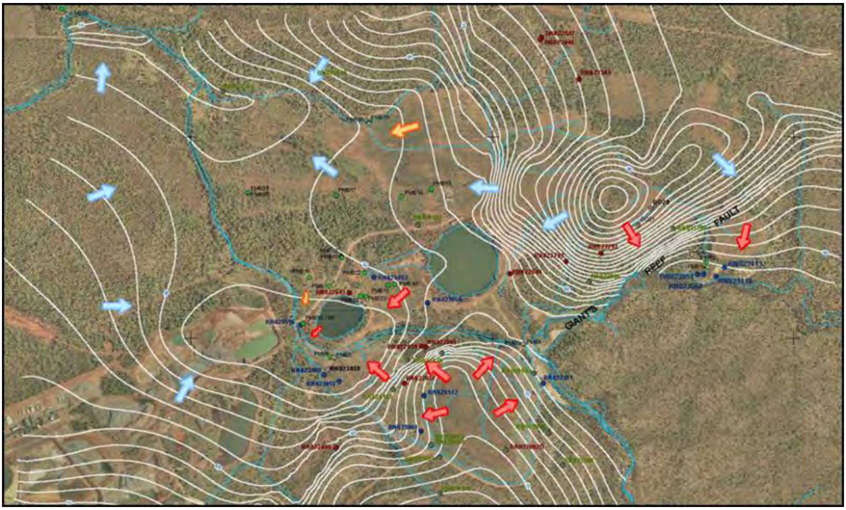

Figure 5 *Simulated groundwater flow field for April 2011 (the height of the 2010/2011 wet season).*

Simulated Groundwater Budget

Key aspects of the simulated groundwater budget are summarized as follows:

- The Main and Intermediate Open Pits represent a net source of water to the groundwater system; specifically, net annual flows to groundwater from the Main and Intermediate Open Pits are 4 L/s and 7 L/s, respectively; higher flows from the Intermediate Open Pit are related to its strong hydraulic connection to highly-permeable zones of the Coomalie Dolostone;
- The Browns Oxide Open Pit receives a net annual inflow of 22 L/s and hence is a major discharge zone for groundwater due to active de-watering; groundwater discharge to the pit is highest in the wet season

when groundwater levels in the vicinity of the pit rise (and pumping rates are highest);

- Annual groundwater discharge to the East Branch of the Finniss River downstream of gauge GS8150200 (at mine site) was simulated to be 44 L/s; groundwater discharge to the various creeks and tributaries of the East Branch of the Finniss River represents an additional 73 L/s;
- Shallow drains near the major mine waste units capture 12 L/s of toe seepage and shallow groundwater discharge; flows from the Main WRD and Dyson's WRD account for half of this annualized flow (4 L/s and 2 L/s, respectively); flows from the Intermediate WRD and Dyson's (backfilled) Open Pit both represent less than 1 L/s.

Note that simulated seepage flows are generally consistent with preliminary contaminant load estimates from RGC (2012) but re-calibration of the model with observed toe seepage during the 2011/2012 wet season is planned to confirm this.

Model Verification

In late 2008, water from the Intermediate Open Pit was pumped to the nearby Browns Oxide mine (for processing) resulting in a drawdown of the pit water level by about 11 m over three months. During this pit dewatering, the groundwater levels at three wells in the central mine reach (wells RN022107, RN022108, and RN022081) were monitored.

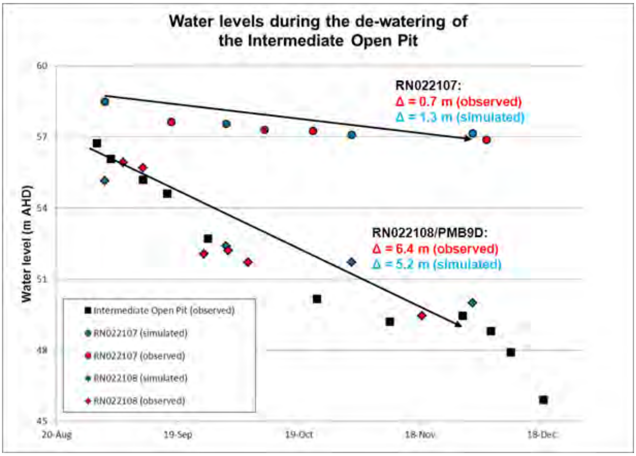

__Figure 6__ Simulated groundwater levels during the pit de-watering trial used for model verification.

The response of the groundwater system to drawdown of the Intermediate pit (in essence a large-scale pumping test) was simulated to verify the numerical model calibration.

The model generally reproduced the observed drawdown in groundwater levels in the surrounding bedrock aquifer in response to pumping of the Intermediate Pit very well (see Figure 3). The calibrated model confirmed that the cone of depression due to pumping of the Intermediate Pit affects groundwater levels in the Coomalie Dolostone and Whites Formation near the pit but not groundwater levels in the Rum Jungle Complex (see Figure 6). Results indicate that the major hydraulic connections between the Coomalie Dolostone and the flooded Open Pits are well-represented in the numerical flow model.

Future Work

The next phase of work at the Rum Jungle Mine Site will involve the evaluation of alternative rehabilitation options with the numerical flow model. Planned work to be completed prior to predictive groundwater flow modeling includes the following:

- Update the numerical flow model with groundwater and pit water level data for the 2011/2012 wet season (which showed a distinctly different rainfall pattern);
- Re-calibrate the numerical flow model with seepage flow measurements collected by the DoR during the 2011/2012 wet season;
- Refine the preliminary contaminant load estimates with additional seepage flow data and observed loads in the East Branch of the Finniss River for the 2010/2011 and 2011/2012 wet seasons;

These updates to the model will reduce the uncertainty that characterizes the current model calibration and will ensure that two very different water years are included in the final calibration (the 2011/2012 wet season was much drier than the 2010/2011 wet season). Additional drilling is also planned in the former Copper Extraction Pad area to better delineate the extent of highly-impacted groundwater in this area (see Ferguson et al, 2012) and to assess its potential to move towards the EFDC and the Browns Oxide Open Pit after rehabilitation.

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

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