Characterisation of hydrogeological conditions and solute transport pathways in the region of the Ranger uranium mine tailings storage facility, Northern Territory, Australia

Alan Puhalovich[1], Andrew Thomas[2], Nathaniel Toll[3], Philippe Puig[3], Alana O'Neill[3]

[1]*Golder Associates Pty Ltd, Level 1, 48-50 Smith St, Darwin, Northern Territory 0800*
[2] *Golder Associates Pty Ltd, 199 Franklin St, Adelaide, South Australia 5000*
[3] *Energy Resources of Australia Ltd, Level 10, TIO Centre, 24 Mitchell St, Darwin, Northern Territory 0800*

Abstract

Hydrogeological investigations comprising geophysics surveys, long-term pumping test and tracer tests, drilling investigations and monitoring bore installations and groundwater quality sampling and analyses indicate that the groundwater system is highly anisotropic, with solutes migrating slowly and primarily along preferential pathways developed within or adjacent to rocks that have experienced significant faulting. Available data indicate that contaminant plumes primarily exist to the north and west of the TSF and lie primarily within weathered rocks located in the immediate vicinity of the dam wall areas.

Keywords: groundwater, water quality, tailings, solute, seepage

Introduction

The Ranger Uranium Mine is located within the Ranger Project Area, about 250 km east of Darwin, Northern Territory and is owned by Energy Resources of Australia Ltd (ERA). It has been operating for over 30 years. The RPA is entirely surrounded by, but excluded from, the adjacent Kakadu National Park. Processing of ore has resulted in the production of processing wastes ("tailings"), which are deposited in a 1 km^2 area tailings storage facility (TSF). Groundwater monitoring data indicate that seepage from the TSF has influenced local groundwater levels and groundwater quality.

Airborne electromagnetic (AEM) geophysics surveys using the "SkyTEM" system, long-term pumping test and tracer tests, coring and air-drilling investigations and monitoring bore installations and groundwater quality sampling/analyses have been undertaken to better understand seepage pathways in the region of the TSF.

Climate, Geology and Hydrogeology

The climate is characterised by a wet-dry season cycle, with rainfall mostly occurring through the wet season months of November to April. The average annual rainfall is 1,576 mm (BOM, 2012). A significant rainfall-evaporation deficit exists in the months of April to November. The site lies within the Alligator Rivers Uranium Field, which in turn lies in the eastern part of the Pine Creek Geosyncline, a remnant of a deformed and metamorphosed Early Proterozoic sedimentary basin (Needham, 1982; Needham and Ross, 1990). The Early Proterozoic rocks are underlain by the Archaean granitoid basement of the Nanambu Complex and unconformably overlain by flat lying Middle Proterozoic quartzites of the Kombolgie Formation and other unconsolidated sediments. The key units in the region of the TSF are easterly dipping schists, amphibolites and within the Upper, Middle and Lower Cahill Formation and Nanambu Complex granitic gneisses and schists.

Tailings Storage Facility Design

Prior to construction, the TSF floor was cleared of vegetation leaving clay and weathered rock as the foundation. A compacted clay core was, however, constructed on the face of the TSF's walls and is keyed into weathered gneiss and schist bedrock by an excavated cutoff. The TSF's foundations were not grouted around the entire length of the Dam's walls, although some grouting was undertaken along the northern wall in zones identified from air photos as lineaments, inferred to be related to faulting within bedrock materials (Coffey Mining, 2010).

Geophysics Surveys

The objective of AEM geophysics surveys was to identify zones of elevated ground conductivity, which may form pathways for seepage in the region of the TSF. The SkyTem (helicopter) system measures ground conductivity responses at a range of frequencies, which resulted in a series of maps being produced indicating ground conductivities at notional 10 m intervals to a maximum depth of 100 m. An approach utilising mathematical analysis within a geographic information systems (GIS) application was used to delineate gradients/contrasts in ground conductivity and estimate the spatial continuity of zones of elevated conductivity. The results were compared with measured groundwater quality from adjacent bores and provided indications of the likely vertical and lateral extents of fault structures beyond the footprint of the TSF. The only extensive fault system, beyond the immediate wall areas, was identified to exist to the north of the TSF.

Long-Term Pumping and Tracer Tests

A long-term pumping / tracer test was undertaken over a period of six months in the region of an inferred pathway of elevated permeability (north of the TSF). The objective of the tests was to determine the sustainability and practicality of recovering seepage affected groundwaters, the anisotropy of aquifer permeabilities and key groundwater and solute transport parameters. A series of tracer injection tests were implemented using a Manta flowthrough cell system. A potassium chloride (KCl) tracer was injected into a single bore, with use of in-line pH, EC and chloride sensors at the pumping bore and key mointoring bores. The results from the tracer test indicate that the hydrogeological system immediately north of the TD is complex, with rocks within the Coonjimba Fault much less permeable than expected. The average hydraulic conductivity of the permeable, weathered rocks in this region was approximately 2×10^{-6} m/s.

Coring and Drilling Investigations

Drilling investigations comprised air hammer and coring investigations (including limited packer testing and EC leachate extracts on core samples) around the perimeter of the TSF, particularly to the north and south-west of the TSF, in areas where historical data indicated sub-surface migration of solutes. The scope and extent of drilling investigations undertaken in the region of the TSF walls was defined by an independent working group established by ERA in 2009.

A total of 78 piezometers were installed around the TSF and single piezometer and nested sites (Figures 1 and 2). The results of the investigations indicated that the presence of permeable rocks was primarily a function of the degree of weathering and structural controls. Rocks with elevated permeabilities were found at selected locations, typically to depths of up to 50 m, within gneissic and schistose rocks. The hydraulic conductivity of rocks away from the Coonjimba Fault are typically difficult to measure and expected to be generally less than 1×10^{-8} m/s.

Groundwater Quality Sampling and Analyses

Groundwater quality sampling and analyses has been undertaken from over 100 piezometers in the immediate region of the TSF, with poorer groundwater quality most significant to the north of the TSF along a major fault pathway, with a magnesium-sulphate plume estimated to extend several hundred metres to the north of the TSF.

Measured concentrations of 'conservative' solutes (e.g. magnesium and sulphate), are significantly lower (typically an order of magnitude lower) than tailings pore water and process water concentrations. This indicates the very slow rate of breakthrough of contaminant plumes, relative to the expected life of the TSF.

Figure 1 *Locations of Drilling Investigations / Monitoring Bores (South and West Wall areas)*

Figure 2 *Locations of Drilling Investigations / Monitoring Bores (North Wall area)*

Interpretations

The results of the investigations indicate the presence of preferred groundwater flow pathways, often aligning well earlier studies of the locations and characteristics faults in the TSF area (e.g. Brown & Lowson, 1990). The studies indicate that structural and weathering controls are very important factors in defining groundwater flow pathways, consistent with the conceptual hydrogeological models developed for the overall Ranger site (Puhalovich, 2010). The results of the study have enabled delineation of key hydrogeological units in the region of the TSF, aligning well with key hydrogeological units defined by Puhalovich (2010) relevant to the rest of the Ranger site. These include Primary Hydrogeological Units found within alluvial units and weathered and fractured rocks beneath creek lines and Secondary Hydrogeological Units which are found within weathered and fractured rocks away from creek lines and are less permeable and less extensive than the Primary Hydrogeological Units.

The groundwater quality data suggest that some inferred faults are tight and act as barriers whereas others are more open and permeable. This is explained by Brown & Lowson (1990), i.e. most faults appear to consist of a thin central zone of fractured pegmatite or sheared bedrock flanked by bedrock that is brecciated and sheared ('damaged'). When the damaged zone is absent, the fault usually has low permeability. On the other hand, faults with flanking zones of brecciation and shearing have higher permeability and act as conduits of groundwater flow.

Conclusions

It is concluded from the study, which combined a number of hydrogeological investigations, indicate that the groundwater system is highly anisotropic, with solutes migrating slowly and primarily along preferential pathways developed within or adjacent to rocks that have experienced significant faulting. Available data indicate that contaminant plumes primarily exist to the north and west of the TSF and lie primarily within weathered rocks located in the immediate vicinity of the dam wall areas.

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