Contaminant transport from proposed Jabiluka mine uranium tailings paste repositories - conceptual description

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Abstract: In 1999 the Australian Government commissioned a number of scientific studies in response to some objections to a proposal to mine uranium and store tailings underground at a mineral lease at Jabiluka in Northern Australia. Kakadu National Park, a listed World Heritage Area, surrounds the lease area. This paper describes the geographic, geologic and hydrological setting for model studies of the movement of potential contaminants from the tailings repositories towards the wetlands adjacent to the mine. Relevant tailings and contaminant properties are also outlined. A second paper describes the model studies in more detail.

1 INTRODUCTION

Energy Resources Australia (ERA) proposes to mine uranium at Jabiluka in Northern Australia. The proposed Jabiluka mine site is about 230 km east of Darwin and 20 km north of the existing Ranger Uranium Mine. It is situated within a 73 km^2 mineral lease near the edge of, but surrounded by, Kakadu National Park which covers an area of approximately 19 800 km^2. The mine will be underground and accessed by a decline from the surface. The area to be occupied by the mine's surface facilities is 27 ha (0.27 km^2). The decline has already been constructed and the first drive into the orebody commenced in 1998. Work has been suspended pending a final decision by the company to proceed.

ERA is currently proposing to mill the ore at Jabiluka. This option will involve storage of mill tailings in deep subsurface repositories to meet regulatory requirements. The repositories will include the mine void and about 180 specially constructed vertical silos with their tops about 100 m below ground level. The current proposal is to dispose of the tailings as a paste after partial dewatering and the addition of between 1 and 4 percent of portland cement.

The uranium tailings paste proposal was discussed in a paper presented at the IMWA Congress in Seville, Spain (Dudgeon & Waite, 1999). This second paper describes the geographic, geologic and hydrologic conditions at the mine site and the conceptual model which forms the basis for a numerical modelling investigation of leaching and movement of contaminants away from the tailings repositories. Tailings paste and contaminant property data required for the modelling are also outlined.

The groundwater investigation forms part of an assessment of the risk of nearby wetlands being adversely affected by potential contaminants from the mine. Since the mineral lease is within the boundaries of Kakadu National Park, a designated UNESCO World Heritage Area, particular care is being taken to ensure that groundwater in the park will not be deleteriously affected by tailings disposal. There is genuine concern over the impact of the mine on ecological and cultural values of the area surrounding the mine. The anti-uranium mining lobby has also taken the opportunity to use the World Heritage area issue to try to prevent the mine proceeding.

The study was commissioned by the Australian Government's Department of Environment and Heritage which is responsible for an ongoing comprehensive investigation of potential effects of the mine on the park. The resulting report (Kalf & Dudgeon, 1999) was included in a submission by the Australian Government to UNESCO's World Heritage Committee in response to moves by opponents of the uranium mine to have Kakadu National Park placed on the endangered list.

The significant potential groundwater contaminants in uranium ore or processing materials are uranium, radium, magnesium sulfate and manganese. The study examines the leaching and movement of these materials from the repositories towards the wetlands over time spans up to 10 000 years in the case of the radioactive materials and 200 years for the others.

A more complete description of factors which will control the sub-surface movement of these substances from the tailings repositories, including a detailed description of the numerical, analytical modelling with a full set of results and a list of references, may be found in Kalf & Dudgeon's 1999 report.

2 TOPOGRAPHY, DRAINAGE AND CLIMATE

The Jabiluka ore body proposed for mining lies in hilly terrain adjacent to the Magela floodplain (Figures 1 & 2). Ground levels range from several metres above mean sea level over the floodplain to 160 m in the hills. (Mine RL's shown in figures are plus 1000 m). The hilly terrain forms a broad north-south ridge which is intersected in an east-west direction by numerous drainage gullies situated on both sides of the topographic divide. The ore-body which ERA proposes to mine, Orebody No 2 in Figure 2, is located below Mine Valley, a broad shallow valley carved from the surrounding quartz sandstone.

Surface water drainage in Mine Valley is towards the Magela floodplain, which lies about 1.5 km to the west of the topographic divide that separates Mine Valley from the Swift Creek catchment. On the eastern side of the divide, surface water flows eastward towards Swift Creek that joins the Magela floodplain several kilometres further north.

The region is subject to consistent annual wet and dry seasons. It has an average yearly rainfall of about 1500 mm. Monthly average rainfall increases steadily from near zero in September to a peak in January/February (approximately 370 mm in each month) and decreases rapidly to near zero again in June**.**

3 GEOLOGY

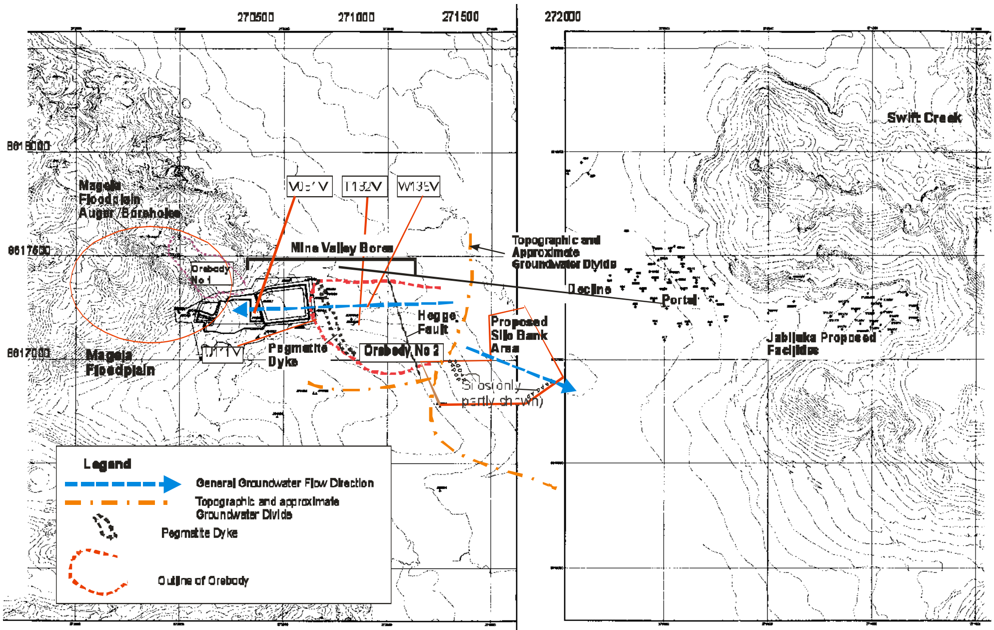
The orebody is contained within the Cahill Formation that is mostly schist but includes some carbonate. To the west, the Cahill formation underlies the Magela floodplain and forms the bedrock that dips east and south beneath the overlying Kombolgie sandstone Formation.

The Kombolgie Formation is comprised mainly of quartz sandstone with a little siltstone and forms the broad north-south topographic ridge and the elevated plateau further east. Most of the sandstone is better described as quartzite because of the deposition of secondary silica, although some relatively friable layers do occur. The intergranular porosity is very low and the groundwater flow at the mine site is restricted mainly to the joint and fracture system. Inspection of the decline constructed through the Kombolgie sandstone to gain access to the orebody showed appreciable inflow only at one fracture zone. Most joints were dry.

Along the Magela floodplain, clays (generally dark organic clay overlying grey clay of marine origin), silts and sandy alluvial sediments overlie the Cahill Formation. The bedrock in contact with the sediments is weathered.

Immediately east and west of the topographic divide the weathered bedrock in the lower drainage valley slopes is overlain by sands and silts. Drilling has revealed that weathered bedrock can occur up to 50 m below ground surface.

Strongly developed lineaments comprising joint/fracture systems in the sandstone are evident from aerial photographs of the Jabiluka outlier and the elevated sandstone outcrop north of orebody No 2. These structures strike at 60 to 80 degrees with another less dominant set at 350 degrees. The structural lineaments are less well defined in Mine Valley. However, it is possible that Mine Valley may have formed along zones of rock weakness created initially in the past by one or a number of these structures that have now been filled in with weathered material.



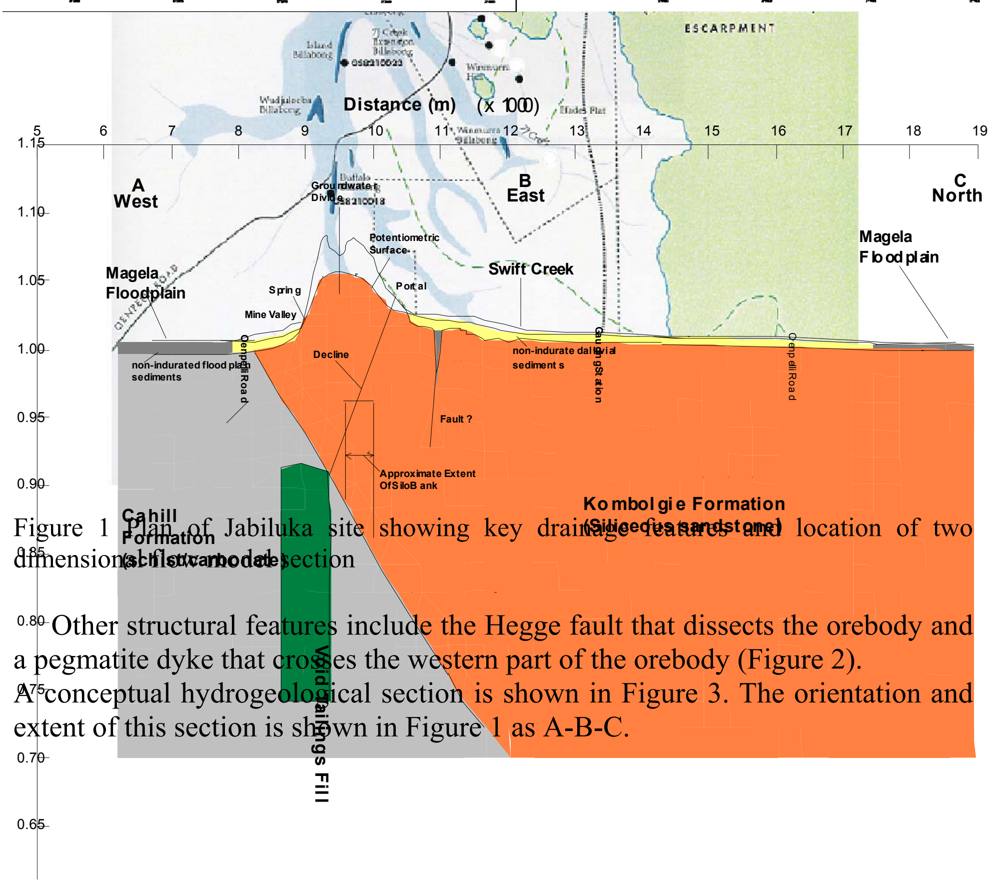


Figure 1 Plan of Jabiluka site showing key drainage features and location of two dimensional flow model section

Other structural features include the Hegge fault that dissects the orebody and a pegmatite dyke that crosses the western part of the orebody (Figure 2). A conceptual hydrogeological section is shown in Figure 3. The orientation and extent of this section is shown in Figure 1 as A-B-C.

Figure 2 Plan of Jabiluka site showing topography and features described in text.

Figure 3 Hydrogeological units along model plane A-B-C

4 GROUNDWATER SYSTEM

Sub-Surface Water-Bearing Zones

There are four main sub-surface water-bearing zones with essentially different hydraulic characteristics:

1. Shallow sandy aquifers overlying weathered bedrock.
2. A weathered bedrock aquifer.
3. A deeper fractured rock aquifer.
4. Floodplain sediments.

The shallow aquifers are contained within topographic valley catchments carved into the surrounding Kombolgie sandstone to the west (i.e. Mine Valley) and to the east (Swift Creek and its tributaries). According to ERA this aquifer is comprised of sands and silts up to about 13 m in thickness.

Beneath this aquifer lies the weathered bedrock which extends down tens of metres below the upper aquifer within the drainage valleys.

The deeper aquifer is comprised of fractured Kombolgie sandstone over most of the area and schists and carbonates of the Cahill Formation further west.

The Magela floodplain sediments consist largely of organic clays and silts with prior stream channels of sand and silt.

Permeability (Hydraulic Conductivity)

Pumping tests to determine aquifer permeabilities in the vicinity of the Jabiluka mine site are described in detail by Kalf & Dudgeon (1999). A summary of salient points follows.

From the results of airlift tests on seven holes drilled in Mine Valley (Figure 2), ERA has estimated the permeability for the sandstone/schist in this area to be in the range 0.017 to 0.1 m/day. The main water bearing zones found were at the contact between the Cahill Formation schists and Kombolgie sandstone and in the lower sections of the sandstone.

Drilling further west in Mine Valley indicated transmissive zones in the shallow carbonates in the Cahill Formation between the Jabiluka No 1 and No 2 orebodies (Figure 2). One borehole (V081V) indicated a transmissivity of 8 m^2/day and another (U111V) gave a transmissivity of 5 m^2/day. The permeability of the carbonate/schist in this area was estimated to be in the range 0.08 to 0.2 m/day.

ERA has reported that pumping tests east of the divide, between the mine portal and Swift Creek, yielded permeabilities in the range 10^{-3} to 1.2 m/day for the weathered shallow aquifer and 3 x 10^{-2} to 3 x 10^{-4} m/day for the lower sections of the Kombolgie sandstone.

A 30 m wide pegmatite dyke crosses the western part of the orebody. Although no specific hydraulic testing has been conducted to determine its permeability, testing in bore U111V demonstrated partial boundary effects in observation bores on the opposite side of the dyke. It could act as a barrier to groundwater flow from the orebody towards the west and thus impede the movement of contaminants in this direction.

Porosity

Diamond drill cores show that there is little weathering and few open fractures at depth. There is no doubt that the large scale jointing evident on the land surface and in the decline will persist at depth. There will also be smaller scale fractures. However the evidence points to the fractures being tightly closed at depth. For the most part, the sandstone is highly silicified, with virtually no intergranular porosity and a low bulk porosity. For the modelling, bulk effective porosities are conservatively estimated to be in the range 0.5% to 5% for fractured rock at depth, and up to 10% for weathered rock.

5 GROUNDWATER QUALITY

Naturally occurring water quality is a very important factor to be considered when the effects of solutes transported to the floodplain from tailings repositories are assessed. A brief summary of quality studies that have been carried out in the Jabiluka area follows.

In 1976 &1978, seventeen exploration boreholes drilled in the vicinity of the two Jabiluka orebodies were logged for conductivity, pH and Eh at depths from 5 m to 195m. This also included forty seven shallow water samples collected from just below the water table in exploration boreholes, shallow augered holes on the Magela floodplain and two billabongs (ponds). The locations of groups of boreholes in which water levels and/or water quality have been measured are shown in Figure 2. It will be observed that they are in three groups, one west of the mine site in the Magela floodplain, another at the orebody, and the third east of the orebody near the site of the mine's surface facilities in the Swift Creek catchment.

Below a depth of 5m in the 17 exploration holes, conductivity was in the range 620 to 680 μS/cm, pH was between 7.1 and 7.6 and Eh was between +60 and +150 mV. There was virtually no variation between values of each of these parameters in the Kombolgie sandstone and the underlying Cahill Formation schists.

Of the 47 shallow water samples, those taken above the Jabiluka ore bodies 1 and 2 had very low concentrations of chloride, sulfate and silica. Some samples had relatively high bicarbonate content. Chloride content was in the range 6 to 20 mg/L, sulfate less than 14 mg/L, silica in the range 5 to 12 mg/L and bicarbonate 50 mg/L to 223 mg/L.

On the floodplain, a large proportion of samples from augured holes contained high concentrations of sulfate. High sulfate concentrations (1500 to 6850 mg/L) were usually accompanied by low pH (3 to 4) and a high concentration of Fe^{2+} (200 to 700 mg/L). All samples with high sulfate contained higher concentrations of the ions calcium, magnesium, sodium and potassium. No sample had high ion content without a high sulfate content.

Water samples were also analysed for concentrations of the trace elements uranium, copper, lead, zinc and cadmium. Exploration holes near and above the ore bodies had low concentrations of these elements with the highest uranium concentration found to be 0.003 mg/L. On the floodplain, concentrations of uranium were also low with only two samples exceeding 0.01 mg/L.

Subsequent measurements confirm the picture given by the 1976/1978 investigation. Additional information obtained in the period 1992-1996 includes manganese concentrations in the range 0.03 to 3.5 mg/L with an average around 0.3 to 0.4 mg/L. In summary, measured values of groundwater quality at Jabiluka can be separated into two distinct groups. The first group includes groundwater within the fractured bedrock and overlying weathered zone beneath and immediately adjacent to the ridge and extending to Swift Creek in the east. This group is characterised by low total ionic content. It has low chloride, sulfate and silica and neutral to slightly alkaline pH, with no major change in the chemical characteristics noted between the underlying Kombolgie and Cahill formation groundwater. The second group includes groundwater beneath the Magela floodplain. It is characterised by having much higher total ionic content, high sulfate and iron and low pH. In both groups, concentrations of naturally occurring radionuclides are low.

It is considered that chemical characteristics of the good quality water of the first group can be largely attributed to flushing of the aquifers by high levels of wet season recharge through the relatively inert sandstone along the topographic ridge.

The poor quality of the water in the second group is attributed to decay of organic matter and oxidation of pyrite. Seasonal flooding of the floodplain creates alternating reducing and oxidising conditions and acid sulfate soils occur extensively in the floodplain.

The occurrence of low concentrations of radionuclides in groundwater at this site compared to those found around uranium deposits elsewhere in Australia and in the USA is probably also due to wet season groundwater dilution and flushing. The impact of the wet season would be much higher than in the arid climates at these other sites.

6 GROUNDWATER FLOW DIRECTIONS AND DYNAMICS

Recharge of the groundwater system is through direct infiltration of rainfall into the shallow fractured aquifers and aquitards. Because of the lower permeability of the underlying weathered zone and fractured bedrock, vertical flow is somewhat impeded, with flow predominantly in a horizontal direction along the more permeable shallow aquifers. Nevertheless, the low salinity groundwater found in the fractured bedrock indicates continual downward flow to the deeper aquifers and flushing with fresh water recharged during annual wet seasons.

Water table levels in boreholes show that groundwater flows to the east and west away from the Mine Valley topographic ridge. On the western side of the ridge water flows towards the Magela floodplain. In the east it flows towards Swift Creek. Potentiometric heads in the deeper aquifer in the vicinity of the divide are reported by ERA to be less than those in the shallow aquifer, indicating a downward flow component created by the hydraulic gradient.

7 TAILINGS REPOSITORIES AND CHARACTERISTICS

The configurations of the orebody and tailings silos shown in Figure 3 are only approximate. The orebody height varies greatly on either side of Section A-B-C. Under the existing mine plan, ore will be extracted down to RL 650 m. The current proposal for the silos is for their tops to be at about the top of the RL 955m mine level so they are shown at approximately RL 960 m.

Both the mine voids and silos are to be filled with a tailings paste prepared from partially dewatered tailings and cement. The proposed repositories are shown outlined in Figures 2 and 3. About 180 vertical silos, 20 m in diameter are to be spaced at 30 m centres and extend from the RL 955 m mine level down to about RL 820 m. Cover will exceed 100 m.

Although tailings have not yet been produced at Jabiluka, it is expected that they will be similar to those produced at the nearby Ranger mine. The host rock for the uranium in both cases is the Cahill formation schist that can be expected to mill in a similar manner at the two processing plants.

The Ranger tailings were not deposited as a paste. However, measured permeabilities can be taken as a guide to those likely to apply to Jabiluka tailings. Tailings deposited as a slurry normally have a permeability in the range 10^{-2} m/day to 10^{-3} m/day (about 10^{-7} m/s to 10^{-8} m/s). The permeability of a paste without added cement could be expected to be somewhat lower. Adding cement to the paste could be expected to decrease the permeability to 10^{-10} m/s (about 10^{-5} m/day). Since the permeability of the sandstone is generally in the range 10^{-2} to 10^{-4} m/day, the permeability of the paste could be two orders of magnitude lower than the average permeability of the rock surrounding the silos.

Although ERA is investigating tailings paste properties, there is currently no quantitative data available on leaching characteristics of uranium tailings pastes. In particular, the mass flux rates and adsorption behaviour of contaminants from the paste in contact with flowing groundwater are unknown. Conservative estimates have been used in the modelling.

8 POTENTIAL CONTAMINANTS

Magnesium Sulfate

Sulfate is introduced in the uranium extraction process. Up to 50,000 mg/L of sulfate has been measured in the process water at the Ranger Mine. A typical concentration of sulfate in tailings water is 20 000 mg/L. It would be expected that both sulfate and magnesium would have low adsorption characteristics in the rocks comprising the Jabiluka aquifers.

Manganese

Manganese is also introduced in the uranium extraction process. The Ranger tailings pore water generally contains less than 1 000 mg/L of manganese. The concentration in Jabiluka tailings pore water is unlikely to exceed 500 mg/L after neutralisation and paste preparation. Adsorption of manganese is known to occur but is complicated by redox reactions and the formation of manganese compounds of different oxidation states. It would be expected that manganese would have moderately high adsorption characteristics in the aquifer.

Uranium

ERA has quoted 1 mg/L or 10 Bq/L for uranium in the Ranger tailings pore water. For the richer Jabiluka ore, the concentrations could be expected to be about 50% higher.

Radium 226

Radium 226 is a long half-life (1 600 years) decay product of uranium 238. The decay of radium 226 in turn results in Radon Rn 222, a gas that has a short half-life of 3.82 days and can be carried by groundwater. Its mobility has been extensively studied near the Jabiluka project area at the Ranger uranium tailings storage. The results suggest that the mobility of radium 226 is complicated by ion exchange and other chemical reactions in the aquifer.

9 CONCEPTUAL LEACHING AND TRANSPORT MODEL

Groundwater flowing through the tailings repositories will leach contaminants from the paste. The contaminants will then be carried in the direction of the hydraulic gradient imposed on the aquifer by water table differences caused by the annual recharge to the Kombolgie sandstone aquifer. As water flows down gradient, dispersion (both lateral and longitudinal) and adsorption onto aquifer/aquitard material will cause concentrations to become lower than concentrations in groundwater exiting the repositories. Concentrations of various contaminants leaving the repositories will depend on the adsorption/desorption characteristics of the contaminants in the paste, geometry of the repositories, the local hydraulic gradient and the permeabilities of the aquifer and the paste. Groundwater flow velocities, dispersion characteristics of the aquifer, adsorption characteristics of the contaminants in the aquifer and dilution will control concentrations in the groundwater further downstream.

With tailings paste permeability lower than that of the rock surrounding the repositories, groundwater will preferentially flow around them. The lower the permeability that can be achieved for the set paste mass, the lower will be the rate of flow through and leaching from it.

Placement of tailings in silos of regular geometry is likely to be more controlled than placement in the irregular mine void. Each cylinder of paste will block off fractures that act as preferential groundwater flow paths. The effect will be to increase the amount of groundwater diverted around the silos and reduce the leaching of contaminants. Difficulties in completely filling mine voids could cause groundwater to circulate more freely through the paste mass in this situation. A permeable paste mass should be avoided. However, the presence of a high permeability zone surrounding or above the mass could be beneficial in reducing flow through the paste by causing a local reduction in hydraulic gradient.

The leaching and transport of contaminants by the groundwater flow, and beneficial or detrimental effects such as those described, can be investigated by appropriate modelling. A hybrid modelling approach was used to quantify both concentrations and time of travel of potential contaminants emanating from the repositories towards the Magela wetlands. A description of the models used and results are described in a companion paper by Kalf and Dudgeon.

10 ACKNOWLEDGEMENTS

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Transport zanieczyszczeń z proponowanego składowiska odpadów kopalni uranu Jabiluka – opis projektu

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Streszczenie: W 1999 roku rząd Australii zlecił wykonanie badań naukowych w odpowiedzi na obiekcje dotyczące proponowanego wydobywania uranu i podziemnego składowania odpadów w ramach złoża Jabiluka w północnej Australii. Złoże otacza Park Narodowy Kakadu, znajdujący się na światowej liście obszarów chronionych. Artykuł opisuje warunki geograficzne, geologiczne i hydrologiczne obszaru przeznaczonego do badań modelowych. Celem tych badań była prognoza migracji potencjalnych zanieczyszczeń ze składowiska odpadów w kierunku przyległego do kopalni terenów podmokłych. Przedstawione są także istotne właściwości odpadów i substancji zanieczyszczających. Drugi artykuł opisuje badania modelowe bardziej szczegółowo.