Contaminant transport from proposed Jabiluka mine uranium tailings paste repositories – 10 000 year dispersion and dilution analysis

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Abstract. This paper describes the extension of a hybrid numerical/analytical modelling investigation of the possible movement of potential contaminants from tailings repositories towards wetlands adjoining the Jabiluka uranium mining lease in northern Australia. Predictions extending to 10 000 years were requested by a UNESCO scientific committee investigating claims that mining would endanger Kakadu National Park, a World Heritage Area that surrounds the lease. Because of the uncertainty in the model parameters, a Monte Carlo approach was used to generate a large number of possible concentration profiles for radium. An additional regional model was employed to predict the ultimate fate of uranium.

Introduction

It is proposed to mine uranium at the Jabiluka mine site about 230km east of Darwin and 20km north of the existing Ranger Uranium Mine in the Northern Territory of Australia. The proposed mine is situated within a 73km^2 mineral lease near the edge of, but surrounded by, Kakadu National Park which covers an area of approximately 19 800km^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 27ha (0.27km^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 current mining company to proceed. The mining proposal involves milling the ore at Jabiluka. This option would involve storage of mill tailings in deep subsurface repositories to meet current regulatory requirements. The repositories would include the mine void and about 180 specially constructed vertical silos with their tops about 100m below ground level. The current proposal is to dispose of the tailings as a paste after partial dewatering and the addition of cement.

The uranium tailings paste proposal has been discussed by Dudgeon & Waite (1999) whilst two papers by Dudgeon and Kalf (2001) and Kalf and Dudgeon (2001) present a conceptual description and model studies for an investigation of the possible extent of movement of potential contaminants from the repositories.

Topography, Drainage and Climate

The Jabiluka ore body proposed for mining lies in hilly terrain adjacent to the Magela floodplain (Fig. 1 & 2). Ground levels range from several metres above mean sea level over the floodplain to 160m in the hills. (Mine RL's shown in figures are plus 1000m). 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.

Surface water drainage at the mine site is towards the Magela floodplain, which lies about 1.5km to the west of the topographic divide that separates the drainage valley from the Swift Creek catchment. On the eastern side of the divide, surface water flows eastward towards Swift Creek which 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 1500mm. Monthly average rainfall increases steadily from near zero in September to a peak in January/February (approximately 370mm in each month) and decreases rapidly to near zero again in June.

Geology

The orebody is contained within the Cahill Formation which 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 mainly quartz sandstone with a little siltstone. It 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. 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.

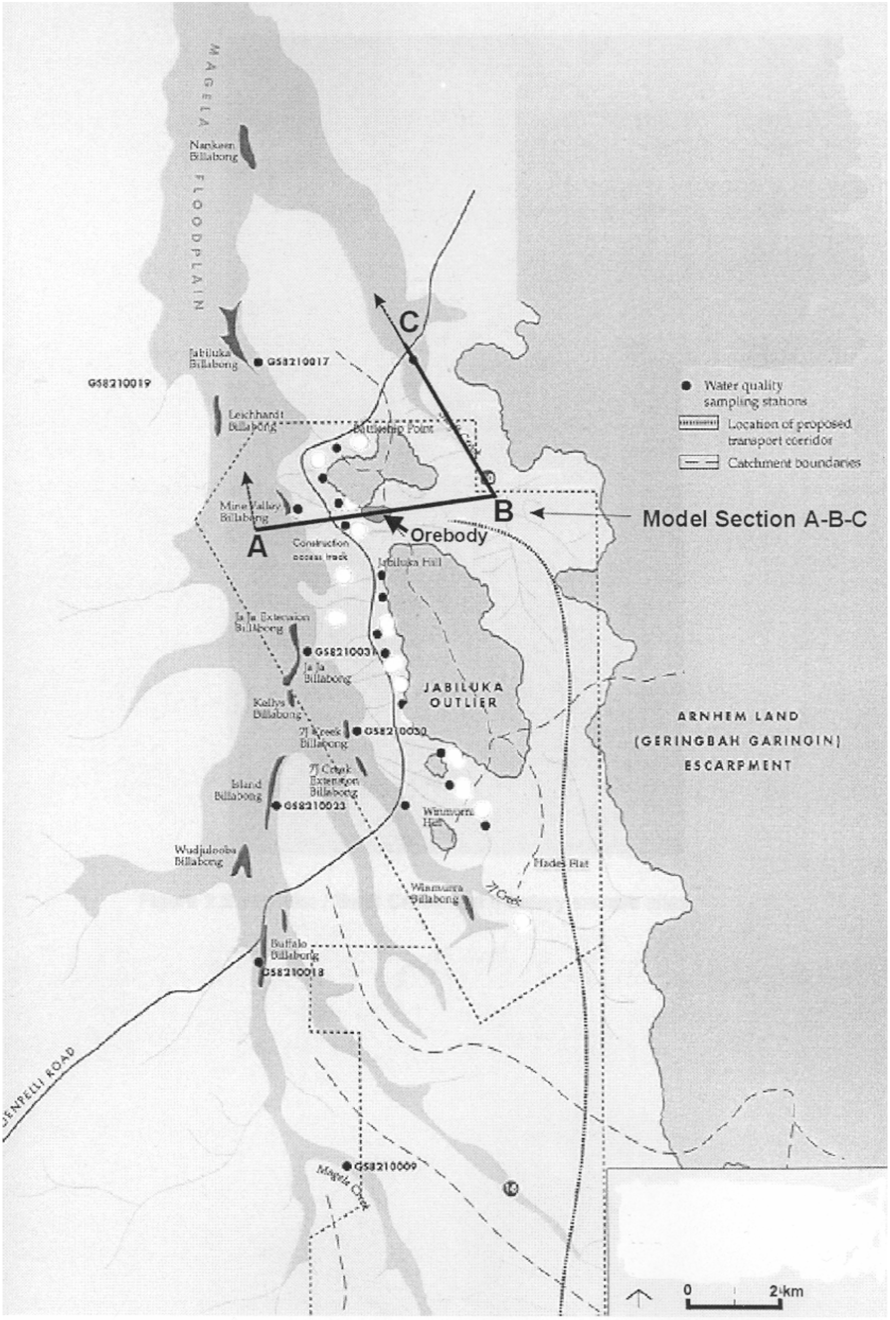

Fig. 1. Plan of Jabiluka site showing key drainage features and sections

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 50m below ground surface.

A conceptual hydrogeological section, A-B-C in Fig. 1, is given in Fig. 2.

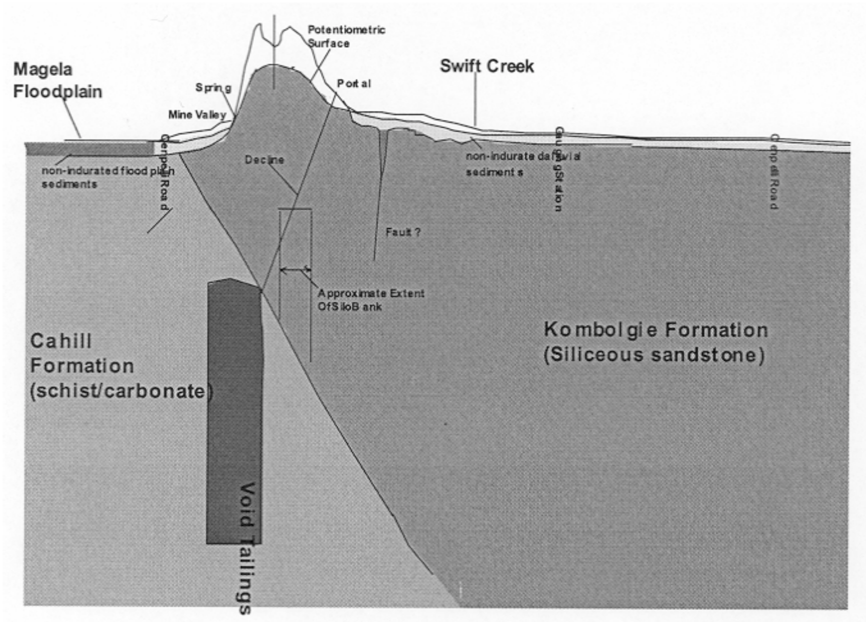

Fig. 2. Hydrogeological conceptual model plane A-B-C

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.

Groundwater Flow Directions

Recharge of the groundwater system is by direct infiltration of rainfall into the shallow fractured aquifers and aquitards. 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 and then north along the flood plain. In the east it flows towards Swift Creek.

Leaching and Transport Model

Groundwater flowing through the tailings 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. Dispersion (both lateral and longitudinal) and adsorption onto aquifer/aquitard material will reduce concentrations.

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.

The main potential contaminants of concern included uranium and radium 226. Absolute paste pore water concentration values based on data obtained from the nearby Ranger uranium mine and the literature were: sulfate 20.000mg/L; magnesium 5 000mg/L; manganese 500mg/L; uranium 15Bq/L and radium 226 15Bq/L.

The leaching and transport of contaminants by the groundwater flow, and beneficial or detrimental effects such as those described, were investigated by a predominantly modelling approach. A hybrid model was used to quantify both concentrations and time of travel of potential contaminants emanating from the repositories towards the Magela wetlands.

The models used were:

1. A regional scale two dimensional (2D) section finite element section model to determine head distributions, flow directions and the range of Darcy velocities along Section A-B-C (Fig. 1) parallel to the groundwater flow lines.

2. A local scale three-dimensional (3D) finite difference solute transport model applied to a 1m thick horizontal layer of horizontal flow through and around a repository to determine the concentrations of contaminants leached from the tailings.

3. An analytical contaminant transport model to determine concentrations along the flow paths represented by the finite element flow model. The effects of advection, dispersion in three co-ordinate directions and retardation are accounted for. The model uses as input the flow velocities determined from model 1 above and source concentrations determined from model 2 above. This model was combined with Monte Carlo simulations to determine concentration profiles for a large number of parameter values within selected ranges.

Details of the contaminant and aquifer characteristics, models and model parameters and results are given in Kalf and Dudgeon (2001). In summary 1 000 year simulations conducted for radionuclides uranium and radium 226 indicate that the bulk of these contaminants is restricted in movement to within several hundred metres from the repositories. Provided that adequately low permeability can be achieved in the tailings paste, the concentrations will remain at background levels within the wetlands. This situation would also apply to manganese.

Sulfate was found to be the most mobile contaminant but concentrations emanating from the tailings paste would be low if the tailings paste permeability were 10^{-4}m/day or lower. Sulfate concentrations in the wetlands currently occur at high levels due to naturally occurring processes in the acid sulfate soils of the floodplain. Some sulfate from the tailings will reach the floodplain to the west, but concentrations are predicted to be less than those that occur naturally in this area. It is significant that pre-mining sulfate levels currently in the Magela floodplain are substantially reduced by dilution and flushing during the annual wet seasons.

Ten Thousand Year Dispersion and Dilution Analysis

For radium 226, a Monte Carlo simulation was conducted to determine the concentration profiles based on 255 runs (realizations) with a uniform distribution assumed for all aquifer parameters. The cumulative probability that the 50% normalized concentration will lie within a given distance from the source is shown in Fig. 3. Thus, for example, there would be an 88% probability that the 50% normalized concentration level will lie within 200m from the source.

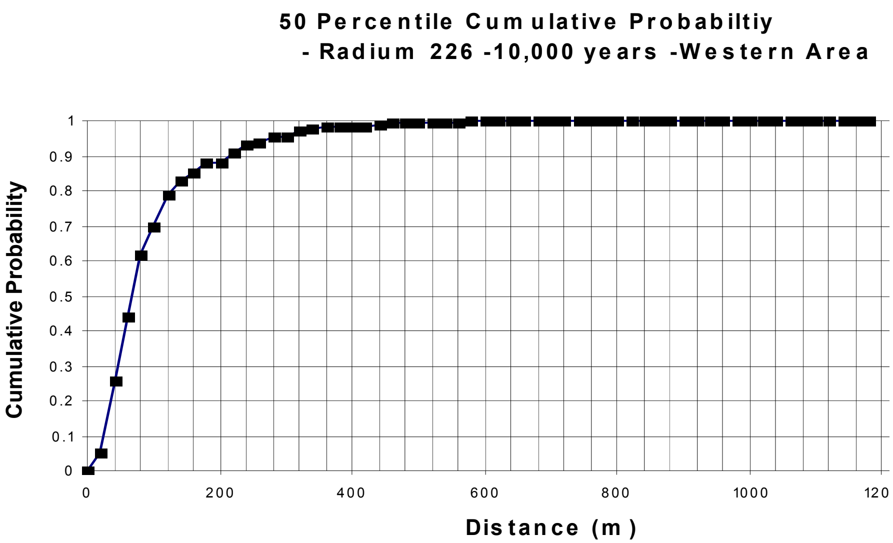

Fig. 3. Cumulative probability of travel distance of 50% concentration

For uranium, the type of analysis applied to radium was not considered suitable because of the greater dispersion in the far field. The leaching model was therefore run over 10 000 years and the mass lost from the silos was determined. The concentration profile through two typical silos with a paste permeability of 10^{-4} m/day is shown in Fig. 4 with groundwater flowing from left to right. Concentrations in Fig. 4 are shown as a percentage of the source concentration versus distance. Because of the high levels of dispersion and dilution over this time, the bulk concentration levels were subsequently determined in the Magela flood plain.

For Fig. 4, the most conservative scenario, about 40% of the 3800 tonnes of uranium is leached during 10 000 years. Assumption of a 10% upward flow flux yields total solute uranium flux of about 15 kg/year. By comparison, data provided by the Supervising Scientist, Environment Australia indicate that there is some 800 kg/year of uranium recycled from leaf litter and grasses. Surface water inflow carries an additional 100 kg/year of uranium. Wasson (1992) has also estimated that 5 000 tonnes per year of sediment with a uranium concentration of 6mg/kg is deposited on the flood plain; i.e. 30kg of uranium per year. The conclusion is that the dispersed uranium mass created by leaching is small compared to that coming from other sources. For the assumed upward groundwater flux of 10% the uranium concentration increase is calculated to be about 0.014 μg/L.

Fig. 4. 10 000 year concentration profile through two typical silos

To determine more precisely the vertical flux of groundwater into the Magela Creek drainage system during dry periods, an additional section model extending north along the Magela floodplain was developed as shown in Fig. 5.

The results indicate that the upward flux component of the groundwater down valley flow would amount to 0.1% if there is no ponded water at the surface. With wet season ponding of water at the surface, the upward flow would be reversed. Hence the uranium flux would be much less than that calculated on the basis of 10% upward flow. In addition high adsorption of uranium could be expected within the clay layers that overlie the thinner sandy layer shown in Fig. 5.

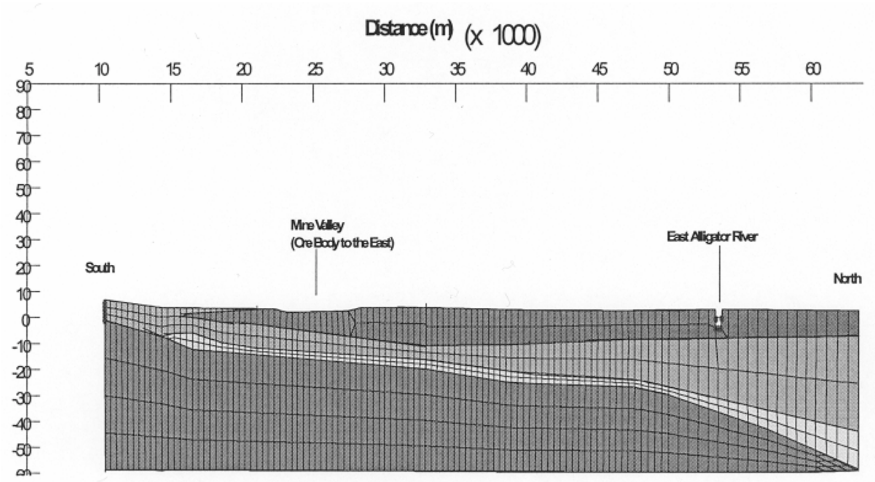

Fig. 5. Finite element model to determine upward flux component.

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