Nabarlek Uranium Mine Design, Construction, Operation Monitoring and Decommissioning of the Water Management System

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ABSTRACT

The Nabarlek Uranium Project located in Arnhem Land in the Northern Territory of Australia was a small high-grade deposit which was the first uranium mine brought into operation following the extensive Commissioner Fox Inquiries into uranium mining during the late 1970s.

The operation is almost complete and decommissioning plans have been prepared.

This paper reviews all phases of the water management and tailings disposal for the project and compares results with design predictions.

Water quality

Waters were to be separated into various ponds depending on the degree of contamination and with the objective that the least contaminated would be suitable for release.

Tailings were to be treated with lime and barium chloride before discharge from the plant and water reclaimed from tailings was to be treated again with barium chloride to remove radium before discharge to evaporation ponds.

The pH of tailings was to be 8-10 and quantities of radium and sulphate entering the pond catchment area per year were estimated as shown in Table 1.

Table 1 Water quality

	Quantity (m^3)	Radium (pCi/L)	SO_4 (mg/L)
Dewatered tailings	195,000	3	3,000
Ore stockpile runoff	91,000	40	10
Waste mine rock runoff	94,000	10	0
Plant area runoff	49,000	60	10
Open pit catchment	63,000	3	0
Open pit seepage	19,000	3	0
Rainfall	551,000	0	0
Total	1,062,000	8.3	543

CIVIL DESIGN ASPECTS

Description

Evaporation ponds and water ponds were designed as 'turkey nest' impoundments with 8 m maximum water depth.

The geotechnical profile was sandy surface soils, gravely clay, clay, extremely weathered dolerite (EWD), highly weathered dolerite (HWD) and fresh dolerite.

Pond floors comprised 1 m of compacted EWD and embankments were zoned mine waste and compacted EWD.

Seepage estimates

Estimates of seepage by P. Hollingsworth Consultants are shown in Table 2. The estimates are calculated for full ponds.

Table 2 Estimated seepage

	Depth (m)	Permeability model (A)	Permeability model (B)
Floor of pond	0-1	3×10^{-8} m/sec	3×10^{-9} m/sec
EWD	1-12	3×10^{-7} m/sec	3×10^{-7} m/sec
HWD	12-18	3×10^{-5} m/sec	3×10^{-5} m/sec
Fresh dolerite	18	3×10^{-9} m/sec	3×10^{-9} m/sec
Seepage estimates		260 m^3/day	220 m^3/day

Construction

Construction of the ponds was carried out using two twelve-hour shifts per day. The work included some 900,000 m^3 of excavation and was completed during the six month dry season in conjunction with the mining.

A requirement of statutory approvals was to prevent drying out of the 35 ha of compacted floors. This was achieved sucessfully by covering the compacted EWD floor with 250 mm of loose EWD. Testwork showed there was no moisture loss at the top of the compacted material and in situ permeabilities obtained were $k = 10^{-9}$ m/sec.

Tailings disposal

To meet regulations for control of dust and radon, tailings were to be deposited subaqueously from a pontoon. Methods of covering the tailings on completion of operations were not addressed during the design phase.

MONITORING PROGRAMME

Description

As part of water management, the monitoring of the groundwater flow system adjacent to the water management structures and in the surrounding areas constitutes the single largest project monitoring effort. It is carried out on a regular basis to determine what effects, if any, seepage will have on the connate groundwater and ultimately surface water systems in the area, both within the operational life of the mine and after mining and rehabilitation have ceased.

Seepage from the ponds area moves vertically down until it intersects an aquifer system associated with weathered Oenpelli dolerite and it then moves laterally down hydraulic gradient towards the east. The dolerite aquifer is flanked to the north by an unconsolidated to weakly consolidated sand aquifer of alluvial/eluvial origin and to the south by a weathered schist aquifer associated with the Myra Falls Metamorphics. To date, seepage from the ponds has not been detected in either of these flanking aquifers. Seepage from the pit enters the weathered schistose aquifer and then moves laterally down gradient towards the south-east.

Monitoring network

The monitoring network consists of a weather recording station and two Class A Evaporation Pans and four daily read rainfall gauges. Forty bores are monitored on a fortnightly basis for water level and are sampled on a variable basis for water quality; ten production bores are monitored for water quality and quantities of water abstracted. All water management ponds are monitored for water level and water quality as well as all water transfers and quantities of any chemicals added. Water quality sampling is undertaken at several surface water locations, including billabongs and along the tributaries of and in Cooper Creek. Water quality analysis is carried out in the Queensland Mines laboratory on site.

Monitoring philosophy

Environmental monitoring at Nabarlek has gone through three phases:

- Phase I - baseline data collection.
- Phase II - a research and development phase during which testing for the most applicable long-term monitoring practices were carried out.
- Phase III - involving the implementation of the most applicable monitoring programme developed in Phase II.

Phases I and II were considered complete for monitoring of seepage around the water management ponds after 6 years of operations. During this time, detailed assessments of site hydrogeology, groundwater flow patterns, solute transport velocity and the hydrogeochemical characteristics of advancing seepage fronts had been made. Sufficient data and experience had been gained to allow monitoring to progress to the third or long-term phase for the lifetime of the water management ponds. The Phase I and Phase II water quality monitoring programme consisted of:

- monthly analyses (referred to in later sections as Quality 1 analysis)
- ponds
- groundwater
- surface water:

  electrical conductivity (EC)
  pH
  Ca
  Mg
  Na
  K

SO_4
NH_4
Ra
Cl
U
NO_3
Zn
HCO_3
CO_3
OH
Mn
Cu
Pb

Analysis of Phase I and Phase II data revealed that EC, pH and SO_4 concentration were the appropriate indicator parameters for the passage of seepage fronts. Further, it has been possible to subdivide the existing groundwater monitoring locations into three categories:

- 'Prime sites', which included surface water monitoring sites at exit points from the project area and those groundwater monitoring bores just ahead of and down hydraulic gradient of the seepage front.

- 'Secondary sites', which included bores well ahead of the seepage front.

- 'Tertiary sites', which included bores behind the seepage front.

The level of monitoring required would follow the order listed above. Figure 1 shows the present location of the seepage front and the dominant groundwater flow paths toward exit points from the project site. Figure 1 also shows a prime detection ring which subdivides bores outside the seepage front into primary and secondary status.

The Phase III monitoring programme recommended and implemented includes the monitoring of EC, pH and SO_4 concentration once every 2 months at prime monitoring sites. Should analysis results suggest the arrival of a seepage front, then a full chemical analysis (Quality 1) would be undertaken until such time as it is confirmed that the solute seepage front has passed the particular bore(s). At this time, the bore's status would be downgraded to a Tertiary site.

The Tertiary monitoring sites are not hydrochemically monitored on a short-term regular basis. All bores, however, are analysed to Quality 1 standards twice a year so that an accurate picture of the overall hydrochemistry beneath the project area can be determined. This degree of Quality 1 hydrochemical monitoring is still relatively high when solute transport velocities are taken into account. Assessment of the advance of seepage fronts over the past six years yields maximum velocities of less than 0.5 m/day so that the maximum advance of the seepage front between the 6-monthly full analyses would be less than 100 m.

Results of monitoring programme

Rate of seepage from ponds

The rate of seepage from the water management ponds has been estimated during the operations period by various techniques including water balance and finite difference groundwater modelling techniques. It has been estimated that seepage from the two evaporation ponds and the stockpile runoff pond (SPROP) has ranged from 143-473 m^3/day, which is of a similar order of magnitude to the values originally estimated during the design phase.

Pond water quality

Typical dry season water quality for the evaporation ponds is shown in Table 3. Each pond essentially stores ammonium sulphate rich wastewaters that have high levels of nitrates and significant levels of manganese. Other heavy metals are relatively low as is uranium in all ponds and radium concentrations in EP2 and SPROP. EP2 has shown a gradual increase in total salt levels as a result of evaporative processes over the last few years. The pH in EP2 is lower than in the other ponds and has historically fallen below 5 on a number of occasions. This was due to the dissociation of ammonium ions to nitrate with the subsequent liberation of hydrogen ions. A catalyzing force is necessary for this reaction to take place and it is considered that microbial action was the cause. The pH has been adjusted by the occasional addition of lime.

Table 3 Typical water quality (dry season 1987)

		EP1	EP2	SPROP
pH		6.9	5.8	7.5
EC	µs/cm	10,000	10,000	6,300
Ca	mg/L	430	480	370
Mg	mg/L	370	350	200
Na	mg/L	50	70	30
K	mg/L	50	50	30
NH_4	mg/L	1,400	1,100	660
SO_4	mg/L	6,200	5,500	3,400
Cl	mg/L	50	100	70
NO_3	mg/L	75	30	70
HCO_3	mg/L	20	10	50
Mn	µg/L	1,550	3,500	1,200
Cu	µg/L	100	10	10
Pb	µg/L	30	5	10
Zn	µg/L	40	20	5
U	µg/L	100	40	900
Ra	Bq/L	65	0.3	0.6

Groundwater flow rate
The direction of seepage flow from the ponds has been similar to that initially predicted. The rate of seepage flow from the ponds has been lower than initially predicted. Seepage from the pit only commenced when the water level in the tailings reached a higher elevation than the surrounding groundwater level.

Seepage quality
The quality of seepage from the ponds observed in groundwater bores fits the hydrogeochemical model for seepage from a low level radioactivity process water pond. The buffering capacity of the in situ doleritic soils beneath the process ponds is sufficiently great to rapidly raise the pH of any low pH (<6) seepage water to near neutral and hence effectively reduce the mobility of heavy metals and radioactive species. Through the processes of cation exchange, adsorption, co-precipitation, dilution and volatilization, the concentrations of all seepage components are significantly reduced beneath and adjacent to the ponds. In fact, the dominant ion in solution behind the seepage front is sulphate and this ion is now used as an indicator of seepage front arrival.

OPERATION AND DECOMMISSIONING

Water budgets

Over the period during which records have been maintained, average annual rainfall at Nabarlek has been some 25% greater than the design figure of the long-term average rainfall at nearby Oenpelli. Consequently, a steady build-up of water contained within the RRZ has been experienced, culminating in a total storage of 1,250,000 m^3 of water at the end of the 1984-85 wet season.

Despite this excess rainfall, the water management system has worked extremely well with dry season evaporations often exceeding wet season rainfall, maintaining the contained water within the RRZ well within the available capacity of storage.

By mid-1985, planning for decommissioning was well advanced and the major problem of disposal of up to a million cubic metres of contained water within the RRZ became evident.

The problem of water disposal was one which required a long-term solution. By using only the evaporation ponds available and by reducing the RRZ to the greatest extent as soon as possible, it was estimated that it could take 16 to 20 years to evaporate all the water contained within the RRZ. Alternatives were therefore sought.

Disposal of excess water

By September 1985, thirteen alternative methods for reducing the water budget had been identified and investigated to a greater or lesser degree of detail. These included roofing existing ponds to reduce the amount of water retained within the RRZ, sea disposal by pipeline or truck, release to Cooper Creek, mechanical evaporation plant, extension of existing ponds to provide greater evaporative area and spray irrigation.

When these alternatives were reviewed to compare the environmental effects against cost, it became evident that the release of water to Cooper Creek was the optimal strategy. However this was not acceptable to the Northern Land Council on sociological grounds and Queensland Mines therefore adopted the second best alternative - surface irrigation.

The original concept of spray irrigation of saline water from the ponds was tested in 1984 on disturbed land adjacent to the airstrip. The results of these trials indicated that more extensive trials should continue. An area of 8 ha was provided with spray irrigation equipment and upon receipt of authority to proceed trials were carried out in the 1985 dry season. In the 1986 dry season an even larger area was brought into spray irrigation including some 10 ha of forest land which had not been previously disturbed. (All previous trials had been carried out on land which had previously been disturbed for construction purposes adjacent to the airport and which had been seeded by mixture of imported grasses.)

In the forest area, saline water from EP2 was sprayed into the natural ecosystem of the forest. Initial results showed that the salt water caused salt stress on the leaves of trees. Therefore irrigation by night to ensure wash water which followed each application of saline water washed the salts off the leaves before evaporation was adopted. In addition, aluminium sheets nailed across the tree trunks prevented damage to bark from water jets.

Some 460,000 m^3 of water were disposed of by this method in the 1986 dry season and a mound of slightly saline groundwater was formed within the forest area. The bulk of this mound was washed out during the 1986-87 wet season; however, the irrigation of that area created circumstances which allowed waterlogging of the area in early 1987. Some 200 trees (from a total of some 12,000 trees) died as a result of waterlogging and salt stress.

As the 1987 season progressed it was evident that salt levels in the groundwater had not reduced to the amount anticipated and Queensland Mines was therefore required by the supervising authorities to alleviate the stress on the trees by spraying fresh water into the area which had been irrigated with salt water during the previous year. At the time of writing (March 1988, well into the wet season) it appears that this strategy has been successful. It is, however, too early to say whether or not irrigation of the area with fresh water in the coming year will be required.

During the 1987 dry season the irrigation areas adjacent to the airstrip were used and at the end of November 1988 a total of just over 100,000 m^3 of water remained within the RRZ. This is in fact the absolute minimum to operate the plant and it is evident that in the 1988 dry season all the water remaining in the RRZ can be disposed.

Decommissioning

When production ceases, Queensland Mines will be in a position to place drainage material on the surface and drainage wicks down into the tailings in the pit and to place a superimposed load upon the tailings and to decommission EP1 and the SROP. This will involve pumping them dry via the pit water clarifier to EP2, and scraping the bottom of the pond. (It is expected that up to 100 mm of clay will be taken from the bottom of the ponds in addition to sediments entered during the years of operation.) This material, which is likely to be contaminated, will be placed in the pit. Thereafter the ponds will be back-filled using material from the pond walls and completed with a layer of clay from the clay stockpile and topsoiled in preparation for seeding.

The remainder of the stockpile mound will be removed into the pit as part of the superimposed load, and the plant itself will be decommissioned, cleaned, dismantled and sold at auction. Cleaning will be by sandblasting to remove any contamination materials. After the plant has been removed, foundations will be taken to the pit and the area regraded, ripped, topsoiled and revegetated.

Queensland Mines expects to wait for 2 years for the settlement in the pit to be completed. At that time the mound built over the surface of the pit will be levelled and a layered capping of clay and rock will be placed to ensure the long-term stability and safety of the tailings. The evaporation pond will be emptied, bottom cleaned and the residue buried in a pit excavated in the clay in the bottom of the pond, followed by pushing in the walls and replacing the original contours using the remainder of the clay stockpile. This will be followed by topsoiling of the pit area and pond area and revegetation of those areas.

The revegetated areas will have to be protected for a number of years. This will include burning back to prevent forest fires and protecting them from grazing horses and cattle.

When Queensland Mines has fulfilled its obligations under the terms of agreement with the Northern Land Council and the various statutory obligations, the land will be returned to the original owners.

The bulk of the planning for this work was done by Ken James who was the decommissioning engineer for Queensland Mines from 1984 to 1986.