Australian Journal of Earth Sciences (1994) **41**, 505–508

Likely recharge to permanent groundwater beneath future rehabilitated landforms at Ranger uranium mine, northern Australia

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The magnitude of recharge beneath rehabilitated landforms at former mine sites is one of many variables required for a comprehensive assessment of potential future environmental impacts of those sites. The magnitude of net groundwater recharge that may occur on the rehabilitated Range Uranium Mines landform is estimated to be of the order of 2–5% of the incident rainfall, that is, about 25 to 65 mm/a.

Key words: groundwater recharge, Ranger uranium mine, rehabilitation.

INTRODUCTION

Uranium mining and milling is an important activity in the tropical Alligator River region of northern Australia. The majority of the region has been declared a national park (Kakadu), part of which is entered on the World Heritage List. The only currently operating mine, Ranger (Figure 1), is required under its 'authorisation to operate' to develop strategies to attain a high standard of rehabilitation when the mine closes. The broad rehabilitation goal, established by an exchange of letters between the Northern Territory and Commonwealth Government ministers in 1990, is to 'aim to establish an environment in the [Ranger Project] Area that reflects to the maximum extent that can reasonably be achieved the environment existing in the adjacent areas of Kakadu National Park, such that the rehabilitated Area could be incorporated into Kakadu National Park without detracting from Park values of adjacent areas'. The Ranger Project area is not part of the Park, but is completely surrounded by it. Both the mining company and government authorities have and are undertaking many applied research projects to enable the best planning for rehabilitation of the mine site. One of the important potential problems being investigated is the possibility of the spreading of above-background levels of solutes from the future rehabilitated landform at Ranger. The high rainfall at Ranger (approximately 1300 mm/a, nearly all falling between December and April) means that even a small percentage of recharge could involve a considerable flux of water percolating through elevated landforms with the potential to release weathering products into local streams. Figure 2 illustrates the simplified hydrology of a waste-rock dump, and the two potential pathways for the release of solutes to the environment: surface water and groundwater. Since meaningful on-site measurements are not yet feasible, this paper considers other relevant studies from which an order-of-magnitude estimate could be made of the likely recharge rate beneath the proposed rehabilitated landform. This is one input into an initial consideration of the potential impact of seepage on the surrounding environment.

The load and concentration of weathering products reaching the environment in surface water is likely to decrease from initial levels over a period in the order of years to perhaps decades, as weathering proceeds rapidly on the surface of the landform (Milnes *et al.* 1988). Deep seepage to permanent groundwater (recharge) will pass through a much greater volume of

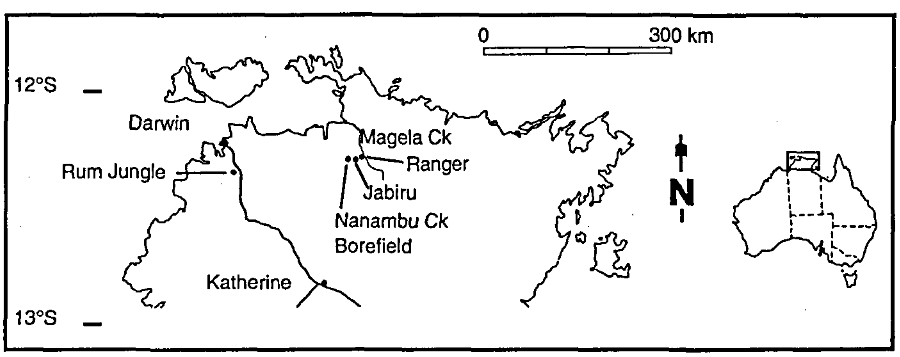

Figure 1 Location map.

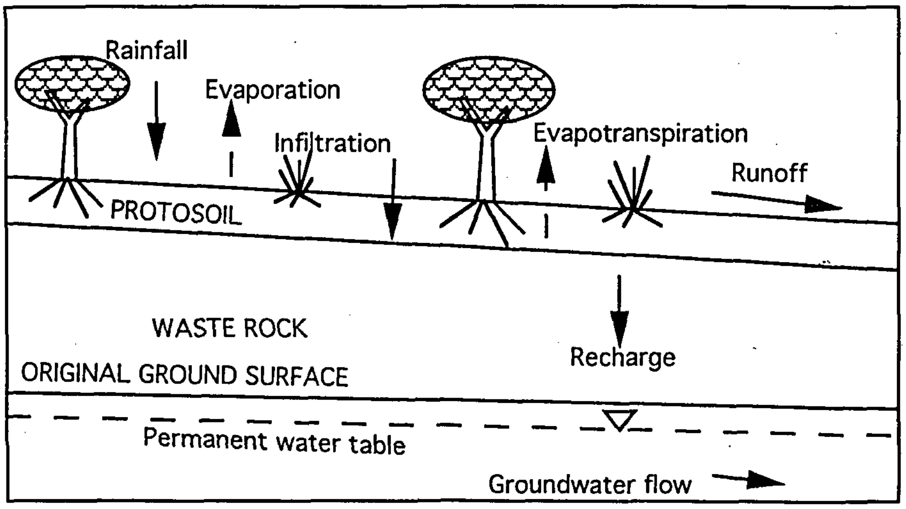

Figure 2 Diagrammatic representation of the simplified hydrology of a rehabilitated waste-rock dump. Water and solute fluxes are shown by plain arrows, water only (vapour) fluxes by dashed arrows. The permanent water table may be above or below the original ground surface, depending on local circumstances.

waste rock (and tailings, if left above ground), and, combined with much slower reaction rates at depth, will remain a potential source of solutes for decades or centuries. The magnitude of water flux and the concentration of solutes contained will determine whether this is a problem or not.

Ranger waste rock quickly weathers into relatively impenetrable protosoils that have low infiltration rates (Milnes *et al.* 1988; Gardiner *et al.* 1990). This rapid soil development means that the waste rock dumps may be expected to become hydrogeologically comparable with fractured-rock groundwater systems, which in the region include a layer of clayey material in the soil profile.

REVIEW OF RELEVANT STUDIES

Jabiru town water supply

The town water supply for Jabiru township is drawn from two bores in the Nanambu Creek borefield some 20 km west of the town. The bores draw water from a dolomite aquifer beneath micaceous schists that are in turn overlain by clayey sub-soils (Pidsley 1990). Both rock types form part of the Cahill Formation which hosts uranium mineralization at Ranger, and indeed a uranium anomaly is present close to the borefield. Pidsley (1990) investigated the performance of the borefield, and the potential for expanded extraction from the aquifer should it be required in the future. He estimates wet-season recharge as comprising 15% of the annual rainfall, but goes on to state that a considerable proportion of this is lost each dry season by evapotranspiration from shallow water tables (< 10 m below ground level) accessible to deep-rooted perennial native vegetation. This compares to an estimate in the adjacent Magela catchment (in which Ranger is located) of wet-season recharge of 10–20% of rainfall (Chapman 1988). Estimates of effective or net annual recharge may be made from information in Pidsley's (1990) report. The average annual extraction from the borefield in recent years is 850 ML/a, of which a 'small' proportion is drawn from a regional aquifer throughflow of 1100 ML/a. The area affected by drawdown from the bores is 6.6 km², and, if a quasi-steady state is assumed, the remaining proportion of production is provided by annual net recharge. If all production came from recharge, the required average rate over the affected area would be 130 mm/a (10% of the average rainfall). On the assumption that half of the production is derived from throughflow, net average recharge would be 65 mm/a (5% of rainfall). These two sets of figures give approximate limits to the likely range of net annual recharge at the site.

Another approach, which has been validated against other methods in tropical climates (Sukhija *et al.* 1988), is to use the chloride balance of the aquifer (Eriksson & Khunakasem 1969; Allison & Hughes 1983). The mass balance is given by:

$$V_R C_R = V_P C_P - V_S C_S \quad (1)$$

where V is the volume of water per unit area, C is the concentration of chloride, and subscripts R, P and S denote recharge, precipitation and streamflow, respectively. There is no loss of chloride in evaporation, and dryfall is incorporated in the rainwater contribution. The fraction of precipitation leaving the catchment as streamflow is estimated from the mean runoff coefficient, r, so that:

$$V_S = r V_P, \quad (2)$$

and the first equation can be rearranged to solve for V_R / V_P.

$$V_R / V_P = (C_P - r C_P) / C_R \quad (3)$$

It is readily acknowledged that r, as defined here, is dependent on many factors such as rainfall intensity, total rainfall, antecedent soil moisture conditions, soil type and topography. A gross average is, however, suitable for these calculations, since the residence time of groundwater is typically in the order of many years. Hart *et al.* (1987) used a mean value of 0.25 for the Magela Creek catchment to the east of the Nanambu Creek borefield, while Vardavas (1988) calculated actual values between 0.31

and 0.49 (mean 0.39) for that catchment over the wet seasons 1978/79, 1979/80, 1982/83 and 1984/85. The regional variation due mainly to the nature of stream catchments may be gauged by the data of Vardavas and Cannon (1988), who give mean runoff coefficients for four creeks in the Alligator Rivers region of 0.17 (lowland terrain), 0.35 (Magela Creek, mixed terrain), 0.44 (mixed terrain) and 0.52 (rugged terrain), using 3 to 7 years' data. Ranger Uranium Mines Pty Ltd (1991) has calibrated runoff coefficients for small, well instrumented catchments in their project area, and suggest a runoff coefficient of 0.10 for undisturbed lowland woodland terrain on an average rainfall year, ranging between 0.05 and 0.30 for 1-in-10 low and high rainfall years, respectively. Considering the relatively subdued topography of the Nanambu Creek catchment, a value of 0.20 is adopted, with estimated bounds of −0.10 and +0.20.

The concentration of chloride in Nanambu Creek is not known, but in common with other Alligator Rivers region creeks, it is expected to be low. The mean value in Magela Creek is about 1.5 mg/L (Hart *et al.* 1987), and this value is used for C_S.

Taking V_P as 1300 mm/a, C_P as 0.46 ± 0.04 mg/L (Noller *et al.* 1990), and C_R as 7 ± 4 mg/L (for a production bore, Pidsley 1990), mean recharge V_R is estimated to be 42 mm/a or 2.3% of rainfall, but the imprecision by which the parameters are known permits values between 0% and 3.2%, without allowing for the uncertainty in C_S.

Rum Jungle waste-dump lysimeters

Groundwater emerging from the waste-rock dumps prior to their rehabilitation at the disused Rum Jungle uranium mine, which lies at a similar latitude in the Northern Territory (Figure 1), was considered to be the main pathway transferring heavy-metal pollutants to the Finniss River, with severe ecological consequences (Davy 1975; Bennett *et al.* 1990). Deep infiltration through the rough, rocky surface of the dumps was estimated to be about 50% of rain (Daniel *et al.* 1982; Harries & Ritchie 1982), that is, about 700 mm per year. One of the main objectives of the rehabilitation carried out in the mid-1980s was to reduce this deep infiltration (Allen & Verhoeven 1986). During this rehabilitation of the Rum Jungle mining site, a layer of about half a metre of lateritic clay and clay-loam soil was emplaced on two of the waste-rock heaps (Allen & Verhoeven 1986), with lysimeters buried beneath the clay to assess the achieved infiltration rates. Although the pre-rehabilitation conditions on the Rum Jungle waste-rock dumps, and the severity of acid production there are not comparable to the situation at Ranger, the infiltration rates on the rehabilitated Rum Jungle dumps may be comparable to those to be expected on the Ranger landform, where weathering rapidly produces a clayey top layer. The latest results from Rum Jungle are given by Bennett (1991) and are summarized in Table 1, which assumes that the net deep infiltration to the lysimeters is representative of the accession to the water table (recharge). Recharge as a percentage of rainfall is given as the average and standard deviation of annual percentages, and does not exactly match the absolute recharge figures. A numerical target for recharge after rehabilitation was apparently not set, but the measured values of 5% or less, representing a decrease of an order of magnitude, are considered to achieve the desired reduction in water ingress (Bennett *et al.* 1992).

Ranger tailings dam lysimeters

Following the Stage IV construction of the Ranger Uranium Mines tailings dam in 1990, various chemical and hydrological monitoring programs have been carried out and reported by the mine (Ranger Uranium Mines Pty Ltd 1991). Five lysimeters (of which four are operational) were installed within the northern wall of the dam beneath a clayey infiltration-limiting cover, providing a comparison with the capped dumps at Rum Jungle and the natural situation with a clayey soil at Nanambu Creek (Pidsley 1990). In the first wet season of operation (1990/91) only two of the lysimeters flowed; the observed infiltration was 21 and 51 mm, that is, 0–4% of rainfall, which was 1351 mm for that wet season. While these are preliminary figures, they are in accord with the other observations.

CONCLUSION

Recharge rates in the order of 2–5% of the incident rainfall, that is, about 25–65 mm/a, occur at sites of similar hydrogeological character to that expected to occur on the rehabilitated Ranger Uranium Mines landform, and under a comparable climate. This range of recharge values is recommended for use in further assessment of the medium-term potential for escape of solutes from the final rehabilitated landform via groundwater, should that be justified. It should be noted, however, that because of the relatively low pyrite content of the waste rock at Ranger, it is anticipated that the groundwater pathway of release of weathering products is not likely to be a major problem.

Table 1 Summary of results of lysimeter studies on rehabilitated waste-rock dumps at Rum Jungle mine site (after Bennett 1991).

Dump	Years of record	Average annual rainfall (mm)	Average annual recharge (mm)	Average annual recharge (%)
White's	5	1226	28 ± 10	$2.2 \pm 0.5\%$
Intermediate	4	1254	59 ± 25	$4.5 \pm 1.0\%$

ACKNOWLEDGEMENTS

This work is published with the permission of the Director, Environment Division of the Northern Territory Department of Mines and Energy (NTDME), and Ranger Uranium Mines. I thank David Dundas and Tony McGill of the NTDME, and the two AJES reviewers for helpful criticism of the text.

REFERENCES

ALLEN C. G. & VERHOEVEN T. J. 1986. The Rum Jungle rehabilitation project final project report. *Northern Territory Department of Mines and Energy*, Darwin, June 1986.

ALLISON G. B. & HUGHES M. W. 1983. The use of natural tracers as indicators of soil-water movement in a temperate semi-arid region. *Journal of Hydrology* **60**, 157–173.

BENNETT J. W. 1991. Chemical activity and water balance of the overburden heaps at Rum Jungle. Annual Report 1989–1990 to the Conservation Commission of the Northern Territory. *Australian Nuclear Science and Technology Organisation* **ANSTO/C171.**

BENNETT J. W., HARRIES J. R., & RITCHIE A. I. M. 1990. Chemical activity and water balance of the overburden heaps at Rum Jungle. Report to the Northern Territory Power and Water Authority. *Australian Nuclear Science and Technology Organisation* **ANSTO/C84.**

BENNETT J. W., HARRIES J. R. & RITCHIE A. I. M. 1992. Chemical activity and water balance of the overburden heaps. *In* Kraatz M. and Applegate R.J. eds. Rum Jungle Rehabilitation Project Monitoring Report 1986-88. *Conservation Commission of the Northern Territory Technical Report* **51**, 103–119.

CHAPMAN T. G. 1988. Groundwater recharge and discharge in the Magela Creek catchment. Northern Territory Department of Mines and Energy progress report (unpubl.).

DANIEL J. A., HARRIES J. R. & RITCHIE A. I. M. 1982. Runoff and seepage from waste rock dumps containing pyritic material. *Hydrology and Water Resources Symposium, Melbourne*, 11–13 May 1982.

DAVEY D. R. ed. 1975. Rum Jungle environmental studies. *Australian Atomic Energy Commission Report* **AAEC/E365.**

ERIKSSON E. & KHUNAKASEM V. 1969. Chloride concentration in groundwater, recharge rate and rate of deposition of chloride in the Israel coastal plain. *Journal of Hydrology* **7**, 178–197.

GARDINER D., RILEY S. J. & WILLIAMS D. 1990. Infiltration characteristics of the surface of the waste rock dump, Ranger Uranium Mines Northern Territory, under natural rainfall. *Australian Hydrographers Conference*, Darwin, September 1990.

HARRIES J. R. & RITCHIE A. I. M. 1982. Runoff fraction and pollution levels in runoff from a waste rock dump undergoing pyritic oxidation. *Water, Soil and Air Pollution* **19**, 155–170.

HART B. T., OTTAWAY E. M. & NOLLER B. N. 1987. Magela Creek system, Northern Australia. II. Material budget for the floodplain. *Australian Journal of Freshwater Research* **38**, 861–876.

MILNES A. R., EMERSON W. W., RICHARDS B. G., FITZPATRICK R. W. & ARMSTRONG A. B. 1988. The long-term stability of waste-rock dumps in the Ranger Project area, Northern Territory, Australia. *Australian Mining Industry Council Environmental Workshop*, 1988, Darwin, September 1988. Proceedings **2**, 79–94.

NOLLER B. N., CURREY N. A., AYERS G. P. & GILLET R. W. 1990. Chemical composition and acidity of rainfall in the Alligator Rivers Region, Northern Territory, Australia. *The Science of the Total Environment* **91**, 23–48.

PIDSLEY D. 1990. Jabiru groundwater supply assessment. *Northern Territory Power and Water Authority Report* **32/1990.**

RANGER URANIUM MINES PTY LTD 1991. Unpubl. data.

SUKHIJA B. S., REDDY D. V., NAGABHUSHANAM P. & CHAND R. 1988. Validity of the environmental chloride method for recharge evaluation of coastal aquifers, India. *Journal of Hydrology* **99**, 349–366.

VARDAVAS U. N. 1988. A simple water balance daily rainfall-runoff model with application to the tropical Magela Creek catchment. *Ecological Modelling* **42**, 245–264.

VARDAVAS U. N. & CANNON L. M. 1988. One-parameter monthly rainfall-runoff model for catchments in the tropical Alligator Rivers Region. *Alligator Rivers Region Research Institute*, Jabiru, Northern Territory (unpubl.).

(Received 24 September 1993; accepted 16 February 1994)