Protection of the environment near the Ranger uranium mine

Supervising Scientist
Environment Australia

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Preface

For almost twenty years, uranium has been mined and milled at the Ranger mine within an area that is surrounded by, but does not form part of, Kakadu National Park. The national and international importance of Kakadu has been recognised by its inclusion on the Register of the National Estate and its inscription on the World Heritage List. The flood plain areas within Kakadu are recognised as one of Australia's Wetlands of International Importance listed under the Convention on Wetlands of International Importance. Much of the land in the region, including the land on which the Ranger deposits were found, has been recognised as part of the traditional estate of the Aboriginal people of the region. For these reasons, operation of the mine has been subject to a rigorous system of regulation and supervision, a system that is unequalled anywhere in Australia and probably anywhere else in the world.

Throughout the operational period of the Ranger mine, the operating company, Energy Resources of Australia, has conducted an environmental monitoring program specified by the Northern Territory Government in consultation with the Supervising Scientist. In addition, the Supervising Scientist has carried out scientific research to enable this monitoring program to be continuously improved. The research program has, for example, enabled the introduction of biological monitoring methods and has enabled a clear distinction to be drawn between natural and mining induced contributions to radon and radon progeny radiation exposure. The research program has also provided data that can be used directly for monitoring purposes.

This report has been prepared to provide a summary of all of the monitoring data obtained in these programs and, on the basis of these data, to provide an assessment of the extent to which the environment of the region, particularly Kakadu National Park, has been protected during the operation of the Ranger mine. We thank Energy Resources of Australia for the provision of its monitoring data and the staff of the Supervising Scientist for providing the results of their research programs. It is our hope that the assessment provided in this report will provide a degree of reassurance to those in the Australian community who are concerned that the conduct of uranium mining at Ranger may cause harm the people or the wetlands of Kakadu National Park.

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1 Introduction

The Alligator Rivers Region, comprising an area of approximately 28 000 km^2, is broadly defined by the catchments of the East, South and West Alligator Rivers (fig 1). It is of outstanding heritage value for its unusual combination of largely uninhabited areas with attractive wild scenery, is highly biodiverse, and has a very large concentration of Aboriginal rock art of world significance. Its national and international importance is recognised by the inclusion of Kakadu National Park on the Register of the National Estate and its inscription on the World Heritage List. The flood plain areas within Kakadu are recognised as one of Australia's Wetlands of International Importance listed under the Convention on Wetlands of International Importance. The Region is rich in natural resources, having a variety of terrestrial and aquatic ecosystems including sandstone heathlands, open woodland, monsoon rainforest, flood plains, large rivers, seasonal water courses and permanent billabongs, as well as large mineral reserves including uranium, gold and platinum group metals. Given the cultural significance and long-practised management regimes of the region, it has all the features associated with being a cultural landscape.

The Region is within an ancient geological basin called the Pine Creek Geosyncline which has a long history of mineral production. Uranium exploration in the Geosyncline was stimulated by the discovery in 1949 of secondary uranium mineralisation near Rum Jungle, south of Darwin. This was followed by a decade of intense exploration activity resulting in the discoveries of economic uranium ore bodies at Rum Jungle and in the upper reaches of the South Alligator River valley.

All the known major uranium deposits of the East Alligator River uranium field have been discovered since 1969. Energy Resources of Australia Ltd (ERA) operates the Ranger Mine, eight kilometres east of the township of Jabiru. The mine lies within the 78 square kilometre Ranger Project Area (RPA) and is near the Magela Creek, a tributary of the East Alligator River. Following successive declaration in stages, the RPA is now surrounded by, but does not presently form part of, Kakadu National Park. Mining and commercial production of uranium concentrate have been underway since 1981. Mining of Orebody No 1 was completed in 1994 while mining of Orebody No 3 commenced in May 1997. (The smaller No 2 orebody is close to Mount Brockman, an Aboriginal sacred site, and will not be mined.)

Other orebodies discovered in the East Alligator uranium field were located at Nabarlek, about 30 kms east of Oenpelli in Arnhem Land, Jabiluka about 20 kms north of Ranger and Koongarra about 25 kms south-west of Ranger. The ore at Nabarlek was mined and stockpiled in 1979 and milling took place between 1980 and 1988. The site has been rehabilitated. The ERA proposal to mine Jabiluka has recently been the subject of environmental assessment under the *Environmental Assessment (Impact of Proposals) Act 1974* and preliminary construction work has begun. There are no immediate plans for mining of the Koongarra orebody.

A key concern for the Australian community throughout the period of mining of uranium at Ranger has been the adequacy of environmental protection measures. This report provides an assessment of the level of protection that has been achieved for the natural environment of the region. The social impact of mining and other developments in the region has been the subject of reports arising from the recently conducted Kakadu Region Social Impact Study.

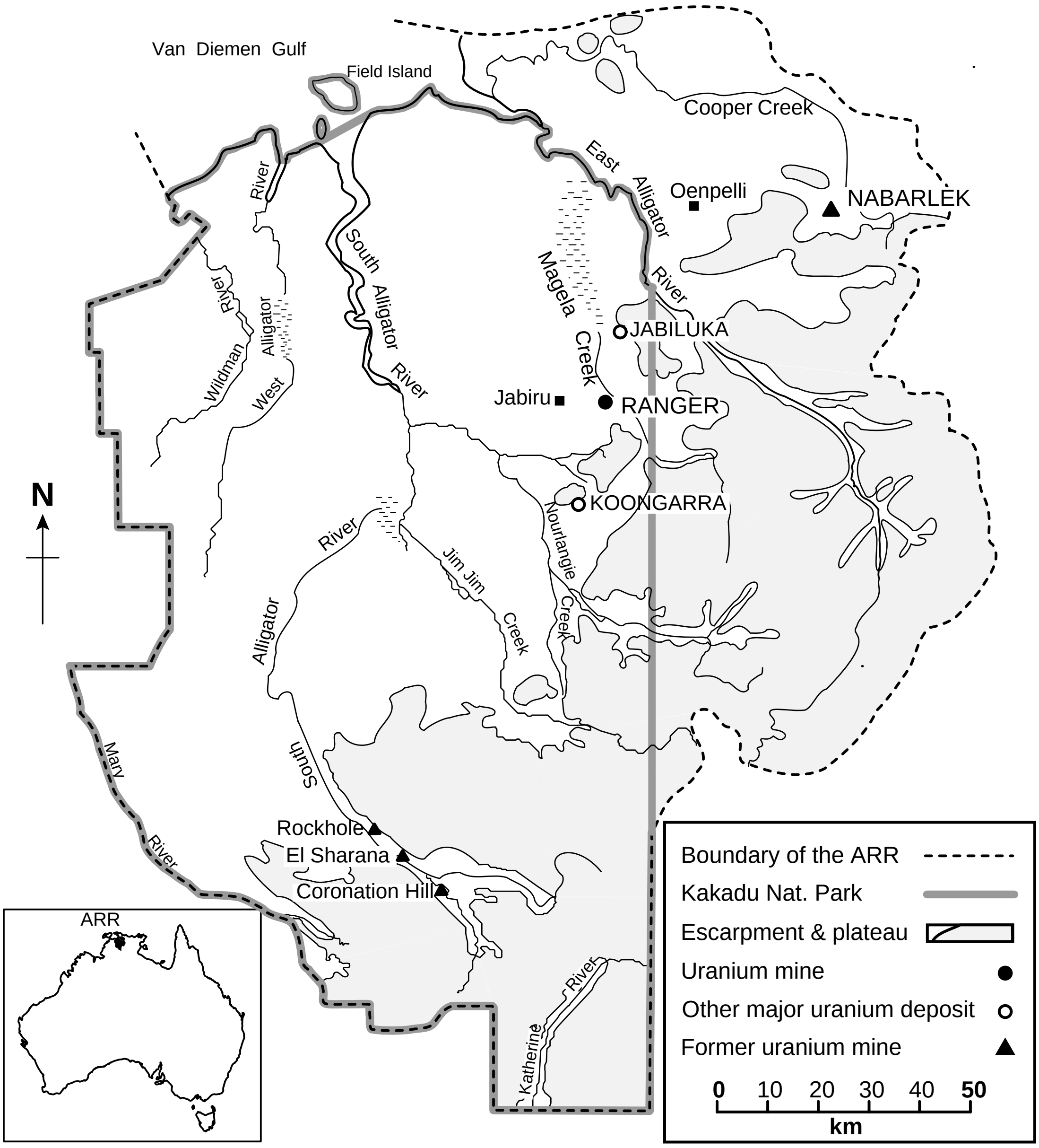


Figure 1 The Alligator Rivers Region in Australia's Northern Territory. The boundary of Kakadu National Park, within the Region, is indicated.

2 Statutory arrangements for environmental protection

2.1 The Ranger Uranium Environmental Inquiry

The first proposal for mining of uranium in the Alligator Rivers Region came jointly from the then Australian Atomic Energy Commission and Ranger Uranium Mines Pty Ltd for the development of the Ranger deposits. An Inquiry into this proposal, the Ranger Uranium Environmental Inquiry (RUEI), was set up by the Commonwealth Government in April 1975 under the *Environment Protection (Impact of Proposals) Act 1974.*

The wide ranging terms of reference given to the Inquiry allowed generic issues of the nuclear fuel cycle, including waste disposal and possible dangers of nuclear weapons proliferation to be considered as well as the site specific environmental aspects of the proposed Ranger development. The First Report of the Inquiry was presented in October 1976 and dealt with generic issues. An essential finding of the first report was that, if properly regulated and controlled, the hazards of mining and milling uranium were not such as to justify a decision not to develop Australian uranium mines.

In May 1977, the Second Report of the RUEI was presented. It contained many detailed recommendations for the conduct of the Ranger Project and proposals for the regulation and supervision of the environmental aspects of uranium mining anywhere in the Alligator Rivers Region. In August 1977, the Government announced its decision to authorise the mining and export of uranium, under the very strict requirements for environmental control recommended by the RUEI.

Essential elements of the plan adopted by the Commonwealth Government to protect the environment and to insulate, to some extent, the Aboriginal people of the Region from the social disruptions inevitably associated with such a major development, were:

- the granting of land to the traditional owners under the *Aboriginal Land Rights (Northern Territory) Act 1976*,
- the establishment of Kakadu National Park, part of which comprised Aboriginal land leased back to the Commonwealth Government for the purposes of the Park, and
- the establishment of a Supervising Scientist to assist in the development of measures for the protection of the environment and oversee their implementation.

2.2 Management of Kakadu National Park

Kakadu National Park is managed by the Director of National Parks and Wildlife through Parks Australia, an agency of the Commonwealth Government, in cooperation with the Aboriginal traditional owners, under the *National Parks and Wildlife Conservation Act 1975* (NPWC Act).

A Board of Management has been established under the NPWC Act and comprises ten Aboriginal people nominated by the traditional owners of the Park, the Director of ANPWS, the Assistant Secretary of Parks Australia North, a person prominent in nature conservation, and a person employed in the tourism industry in the Northern Territory. The Board carries out the following functions under the NPWC Act:

- preparation, in collaboration with the Director, of a Plan of Management for the Park
- decision making on management of the Park in a manner that is consistent with the Plan of Management

- with the Director, monitoring the management of the Park, and
- providing advice, along with the Director, to the Commonwealth Minister for the Environment on the future development of the Park.

Day to day management of the Park in a manner that is consistent with decisions of the Board is the responsibility the staff of Parks Australia working under the Director.

The Director of National Parks and Wildlife does not have any direct responsibility for the environmental supervision of uranium mining at Ranger. Staff of Parks Australia, however, represent the Director in the consultative fora on uranium mining and their views are required, by legislation, to be taken into account.

2.3 Commonwealth supervision of uranium mining

The statutory office of the Supervising Scientist for the Alligator Rivers Region, was established by the *Environment Protection (Alligator Rivers Region) Act 1978* after Government consideration of the recommendations of the Ranger Uranium Environmental Inquiry. The Supervising Scientist is part of Environment Australia, the Commonwealth Department of the Environment. The principal functions of the Supervising Scientist are of a research and supervisory nature; the office does not have a regulatory role. The functions include:

- The conduct of research on the impact of uranium mining on the environment in the Region
- The development of standards, practices and procedures for the protection of the environment in the Region from the effects of uranium mining, and
- The development of measures for the protection and restoration of the environment in the Region from the effects of uranium mining.

The Supervising Scientist carries out both research and audit/supervisory functions.

The audit/supervisory role of the Supervising Scientist involves:

- Review of, and provision of advice on, all applications to the Northern Territory Government for the introduction of new procedures or changes in mining operations
- Review of all environmental data and reports related to environmental protection aspects of uranium mining
- The conduct of Environmental Performance Reviews of mining operations which focus on environmental outcomes and continual improvement
- Participation in technical committees which consider in detail practices and procedures for the protection of the environment, and
- Ensuring a high level of information exchange between stakeholder groups through management of the Alligator Rivers Region Advisory Committee.

The uranium related research of the Supervising Scientist contains programs on:

- The impact of mining on people
- The impact of mining on ecosystems, and
- The development of enhanced mechanisms for environmental protection.

The research program is reviewed by the Alligator Rivers Region Technical Committee.

2.4 Regulation of uranium mining in the ARR

Under an agreement between the Commonwealth and Northern Territory governments, regulation of uranium mining in the Alligator Rivers Region is carried out by the Northern Territory Government. The applicable law under which environmental regulation is achieved is the *Uranium Mining (Environmental Control) Act 1979* and the responsible Minister is the Minister for Resource Development. The Minister exercises his functions under this Act through the NT Department of Mines and Energy (DME).

Commonwealth interests in environmental protection aspects of uranium mining are protected under these arrangements by two principal mechanisms; the specification of the Commonwealth's Environmental Requirements and an agreement on the Working Arrangements.

The Ranger Environmental Requirements are attached to the Authority to mine issued by the Commonwealth under section 41 of the *Atomic Energy Act 1953* and they form part of the Agreement entered into by the Commonwealth and the Northern Land Council (NLC) under section 44 of the *Aboriginal Land Rights (Northern Territory) Act 1976*. Under the UMEC Act, the responsible Minister must give primary regard to the Environmental Requirements when exercising his functions under the Act. The Supervising Scientist has a responsibility to advise the Commonwealth Parliament on the extent to which the licensing and regulatory regime being implemented by the NT supervising authorities gives effect to the Commonwealth's Environmental Requirements.

The Working Arrangements have been agreed by the Commonwealth and the Northern Territory to clarify the monitoring, regulatory and supervisory responsibilities of the two parties and to avoid duplication and overlap. The Working Arrangements ensure that:

- each party can carry out its responsibilities with maximum efficiency and minimum duplication;
- technical aspects of proposed research and monitoring programs are examined and discussed;
- where practical and appropriate, DME and the Supervising Scientist consult before granting approvals or taking any other action in connection with the environmental aspects of uranium mining;
- wherever possible, authorisations are approved in time to avoid delays in mining; and
- the main interested parties, including the NLC, are kept informed via effective consultative and reporting procedures.

The Working Arrangements have been designed to reflect the Supervising Scientist's emphasis on environmental outcomes rather than day-to-day management of minesite environmental controls. The Working Arrangements are currently being reviewed, particularly with respect to clarification of the role of the NLC.

3 Environmental protection measures at Ranger

3.1 General measures for protection of the environment

The primary measures for protection of the environment from the effects of uranium mining at Ranger are the Ranger Environmental Requirements. The ERs specify a range of measures relevant to:

- Control of water
- Atmospheric pollution control
- Technology
- Blasting
- Sulphur stockpiles
- Waste rock dump
- Vegetation protection
- Monitoring, and
- Research.

In particular, the mine operator is required to conduct all its operations in a manner that is consistent with Best Practicable Technology (BPT). BPT is defined to be that technology from time to time relevant to the Ranger Project which produces the minimum environmental pollution and degradation that can reasonably be achieved having regard to a number of factors. These include the level of environmental control achieved in the uranium industry anywhere in the world, cost, evidence of environmental detriment (or the lack of it), the location of the project surrounded by Kakadu, the age and effectiveness of equipment at any time, and local social factors.

The primary regulatory instrument is the General Authorisation, issued under the UMEC Act by the NT Government. The Authorisation specifies in great detail the regulations with which the mining company must comply. Throughout the period during which mining has been conducted at Ranger, particular attention has been focused on the protection of the aquatic environment. For this reason, the control regime adopted at Ranger to ensure protection of downstream ecosystems is outlined in the following sections.

3.2 Ranger water management system

Water at the Ranger Mine is managed within a number of catchments that fall within two principal categories (see fig 2):

- Restricted Release Zone (RRZ) catchments

  The RRZ contains water that may have come in contact with material that has a uranium concentration of greater than 0.02%. This includes water from the mine pit, runoff from the ore stockpiles, runoff from the mill site, process water and tailings water.

  RRZ water is further subdivided into two circuits:

  - Process circuit; contains water used in the mill circuit and tailings water, and
  - Retention Pond 2 (RP2) circuit; contains water from the mine pit, runoff from the ore stockpiles and runoff from the mill site.

- Waste rock catchments

  Waste rock contains uranium at concentrations less than 0.02%. Runoff from this material collects in the sediment settling ponds RP1 and RP4.

Except in Wet seasons of unusually low rainfall, water is discharged from Retention Ponds 1 and 4 to the environment beyond the mine site. Discharge from RP1 occurs by overflow of a spillway through Coonjimba Billabong to Magela Creek. Discharge from RP4 has been both by spillway overflow through Djalkmara Billabong to Magela Creek and also by direct pumping via a pipeline to Magela Creek. Since construction of the new access road around Pit No 3, water from RP4 that collects in Djalkmara Billabong has been pumped to Magela Creek.

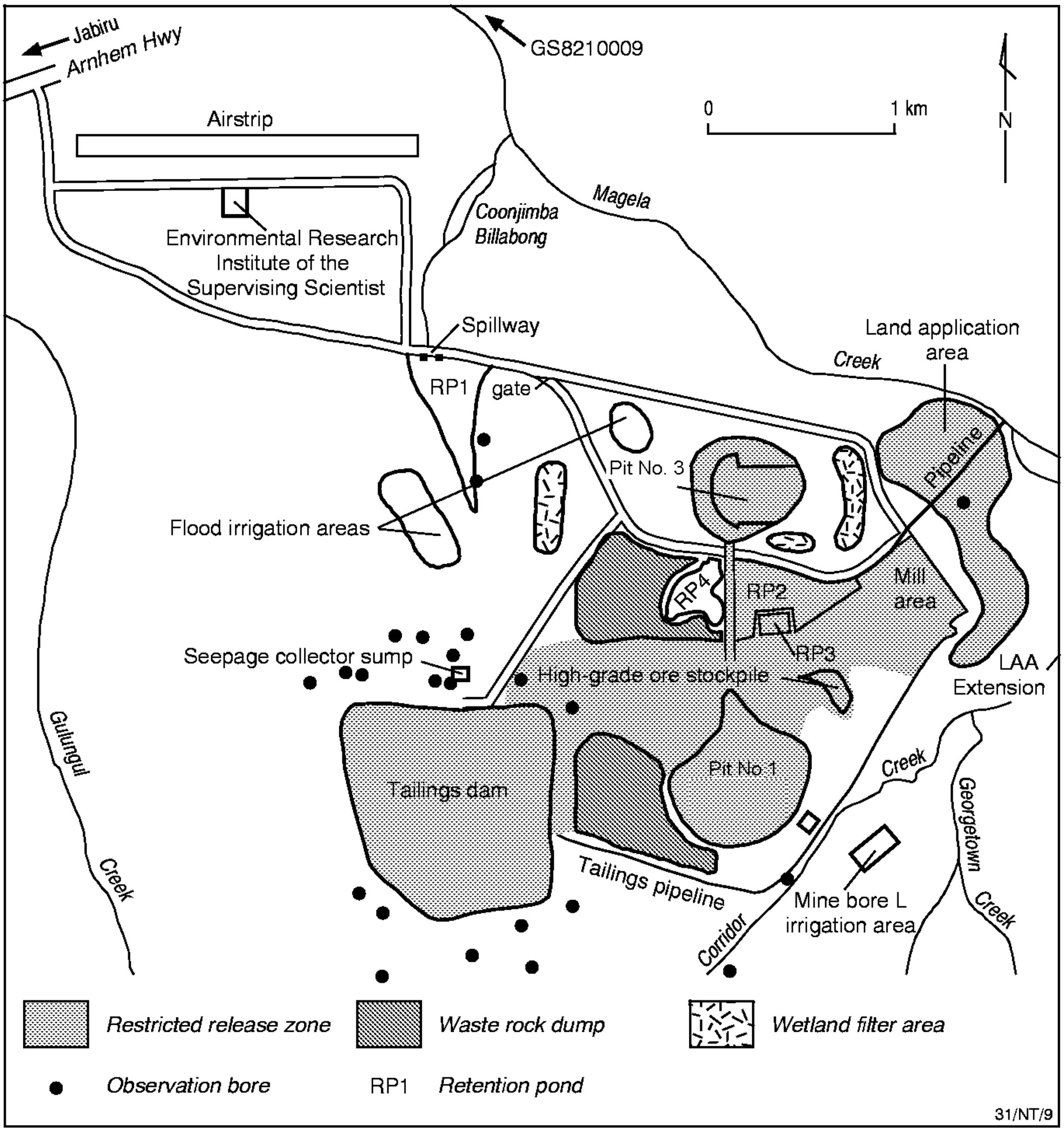


Figure 2 Schematic map of the Ranger mine illustrating the principal features of the water management system

Release of water from the Retention Pond 2 circuit of the RRZ has been assessed within the context of Best Practicable Technology (BPT) for the Water Management System at Ranger. It was concluded that, on the basis of technical considerations only, release of water from RP2 could take place every few years provided that the control regime recommended by the Supervising Scientist (described below) is adhered to. The Commonwealth Government considered the social aspects of BPT in 1987 and 1989 and concluded that releases of water from the RP2 circuit should only be permitted in years of unusually high rainfall; specifically, in those years in which the total rainfall exceeds that expected only once in ten years.

In practice, no releases of water from RP2 directly to the Magela Creek have taken place during the operational life of the Ranger Mine. Release of RRZ water was proposed and approved in 1995 but, following an adverse response by Aboriginal people, ERA decided not to proceed with the release. Instead of discharging water during the Wet season, water has been stored in RP2 and the mine pit and has been disposed by evaporation and by irrigation during the Dry season. ERA has agreed that an application to release water from the RRZ would, in future, only be made under exceptional climatic conditions.

Water in the process circuit at Ranger (ie mill water and tailings water) has never been considered for release to the environment beyond the mine site. These waters are recycled within the mill circuit and are lost by evaporation in the tailings dam and in Pit No 1.

3.3 Control regime for water release at Ranger

A control regime to ensure protection of the environment was proposed by the Supervising Scientist based upon the work of the Environmental Research Institute of the Supervising Scientist (***eriss***). The regime has three components:

- control measures before and during release to ensure protection of aquatic ecosystems,
- control measures before and during release to ensure protection of people, and
- monitoring programs during and after release to assess the adequacy of the control measures.

Issues related to the protection of people will be addressed in section 5.

3.3.1 Control measures

The control measures include the specification of chemical standards that need to be met in the receiving waters of Magela Creek and the conduct of pre-release biological toxicity tests.

The chemical controls consist of a set of standards to regulate the maximum increase in the concentration of a number of constituents in the waters of the creek once the discharged water has mixed fully with natural stream water. There are also limits on the total loads of specified chemical constituents. The choice of constituents specified for control was made after careful assessment of the chemical composition of ore and waste rock, the identification of substances introduced in the milling process and examination of the US EPA list of substances that it recommends for inclusion in the development of water quality standards.

Preliminary standards were derived using a very conservative criterion based on the observed natural fluctuation of constituents in the waters of Magela Creek. For substances that could give rise to concentrations in the creek outside the range of natural concentrations, a detailed toxicological assessment was made on the basis of both international and local toxicology data. Following recommendations on standards by ***eriss*** to the NT Government, DME applied a further factor of safety to the recommended standards for a number of constituents.

In addition to these chemical standards, the flow of water released is controlled so that the dilution by creek water is greater than a minimum value determined by toxicological tests. These tests determine the lowest concentration of the effluent in creek water at which a change is detected for some sensitive measure of the animal's health (the LOEC) and the highest concentration at which no effect is observed (the NOEC). The geometric mean of the lowest NOEC and LOEC values for the three species tested is then divided by a safety factor of 10 to obtain the safe concentration of the effluent in Magela Creek. This value is used to specify the minimum dilution. The choice of species tested was made following an extensive period of research at ***eriss*** during which 19 different species of local aquatic animals and plants were examined to determine the most sensitive species to waters at Ranger and species that could be successfully bred and maintained in the laboratory. The large number of species examined, the use of local native species and the use of a safety factor in specifying the dilution are factors that make the testing program for release of water to the Magela system the most rigorous anywhere in Australia.

The actual minimum dilution required would be the larger of the values determined by the above chemical and biological procedures.

3.3.2 Monitoring

Monitoring is primarily the responsibility of the mining company, with check-monitoring being carried out by the supervising authority, the Department of Mines and Energy. For the releases of RRZ water, for example, the monitoring program includes a full chemical analysis of the effluent water prior to release, daily measurements of the major water quality variables of RP2 water during the first week of a release and once weekly thereafter, and daily measurements on the water quality in Magela Creek both upstream of the release point and at gauging station GS8210009, about 5 km downstream. Monitoring is also required one week after the release is complete.

While chemical monitoring has been accepted as Best Practicable Technology both in Australia and overseas, the Supervising Scientist has advocated the adoption of biological methods that assess the health of animals that are actually exposed to the effluent downstream of the mine site. For this reason, ***eriss*** has developed a number of biological monitoring methods that can be used in the Alligator Rivers Region. In the course of the research programs to develop and refine these methods, ***eriss*** has collected data that can be used to assess the adequacy of environmental protection at Ranger.

There are two types of monitoring programs being developed by ***eriss***; (a) Creekside tests that enable a short-term assessment of the impact of release and (b) Population and community structure tests that assess the long-term impact of the mining operation on aquatic ecosystems.

Creekside tests

In the creekside tests, species of fish (*Melanotaenia nigrans*) and freshwater snails (*Amerianna cumingii*) are exposed to water collected from upstream of the mine site (control) and to water collected from the creek at gauging station GS8210009, some 5 km downstream from the mine. The tests look for any differences in larval survival for the fish species and egg production and juvenile survival for the freshwater snails. Protocols for these tests have been finalised and handed over to ERA for future implementation.

Population and community structure tests

The community structure of macroinvertebrates is studied at the same control and impact sites used in the Creekside tests and any differences are compared with observations in a number of other control streams in the region. In addition, macroinvertebrate communities are being monitored in a number of water bodies on the Ranger lease, in lowland billabongs in the vicinity of the mine and in adjacent control catchments. Fish community structure observations are also made in a number of billabongs in the Magela system, including sites on and off the Ranger lease. These can be compared with observations of community structure in billabongs in the Nourlangie Creek system that is unaffected by mining. Finally, counts of migrating fish that move upstream in Magela Creek past the Ranger site are made each Wet season. The fish migration counts in any one year may be compared with numbers that would be expected on the basis of natural discharge predictors in the creek to determine whether releases of mine wastes have impaired recruitment and subsequent upstream movement of fish. The population and community structure studies are the subject of continuing research but data are available that can be used to assess environmental protection performance.

4 Protection of aquatic ecosystems

4.1 Performance compared to expectation

In assessing environmental performance at Ranger, it is important to note that the Commonwealth approved the mining of uranium at Ranger following an extensive public inquiry into uranium mining, the Ranger Uranium Environmental Inquiry (RUEI) chaired by Justice Fox. The approval was given in the light of certain expectations on the extent of environmental impact that would arise. It is a useful exercise, therefore, to compare the impact that has arisen to that which was expected and considered acceptable at the time by the RUEI commissioners.

The Ranger Uranium Environmental Inquiry made predictions for the loads of a number of metals and radionuclides that were expected by the commission to be discharged from the Ranger mine site, from all sources, by year 10 of the operation into the Magela Creek. These loads and the actual loads released in that year are shown in Figure 3. The latter are 50 to 100 times less than anticipated in the RUEI report. Thus, the level of protection of the environment achieved is, in the case of release of these chemicals, more than an order of magnitude better than was considered acceptable by the RUEI commissioners. The principal reason for this achievement is the lack of release of waters from the Restricted Release Zone at Ranger.

While these data are interesting, it is clearly important to compare performance with current expectations on acceptable levels of environmental protection. This is done below.

4.2 Environmental protection based on chemical assessment

As stated in the previous section, ***eriss*** made recommendations on chemical standards that should apply to the receiving waters of Magela Creek to ensure protection of the aquatic ecosystems downstream from Ranger. One way of assessing the extent to which the environment has been protected during the operational life of the Ranger mine is to compare chemical concentrations observed in the Magela Creek downstream from the mine, before the waters enter Kakadu National Park, with these recommended standards.

The relevant data for the principal constituents of concern, sulphate (SO_4), magnesium (Mg) and uranium (U), are shown in figures 4 and 5. The mean value and the maximum value recorded for each year of operation are shown and the recommended standard is shown as the solid line on each graph.

Sulphate concentrations increased steadily over the first ten years of mining and reached values that were substantially higher than they were prior to mining. Improved on-site catchment management has led to a reversal of this trend. Nevertheless, the observed concentrations have always been at least a factor of ten lower than the standard recommended by ***eriss*** to ensure a high level of environmental protection. The origin of these increased concentrations is runoff from the waste rock piles at Ranger that reaches the Magela Creek primarily through discharges from Retention Ponds 1 and 4. Research is currently underway to establish methods that can be used to limit further increases in sulphate concentrations in the Magela Creek. A similar pattern is observed for concentrations of magnesium in Magela Creek. In this case, the maximum observed concentrations are lower by a factor of five than the standard recommended by ***eriss*** for protection of aquatic ecosystems.

The maximum concentrations of uranium increased slowly until 1991. The origin of the higher values in 1991 is known to be accidental overflow of a bund in the vicinity of the high

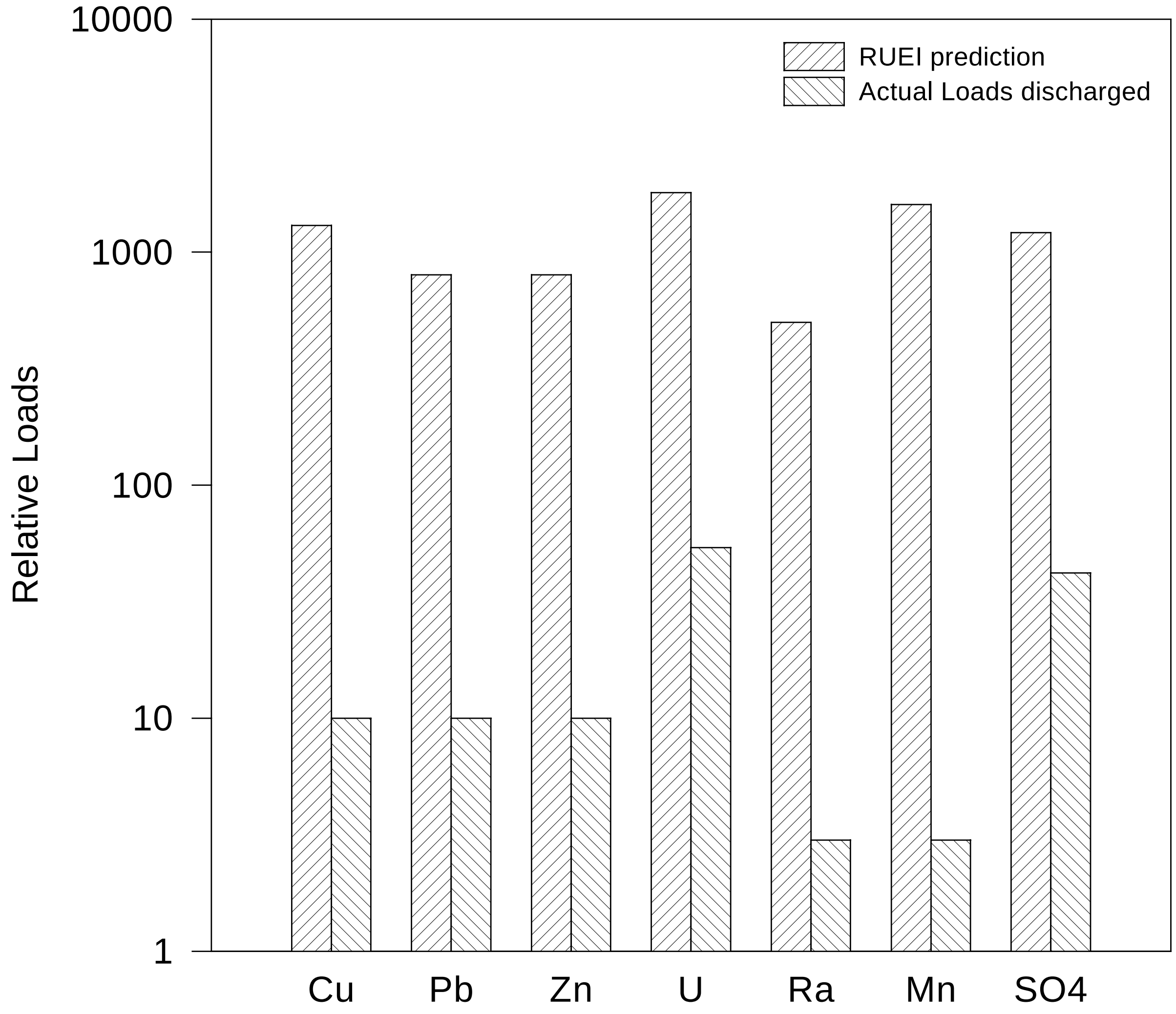


Figure 3 Comparison of actual loads of constituents discharged from the Ranger mine in year 10 of operation with the predictions of the Ranger Uranium Environmental Inquiry. In every case, the actual loads are much lower than the predictions.

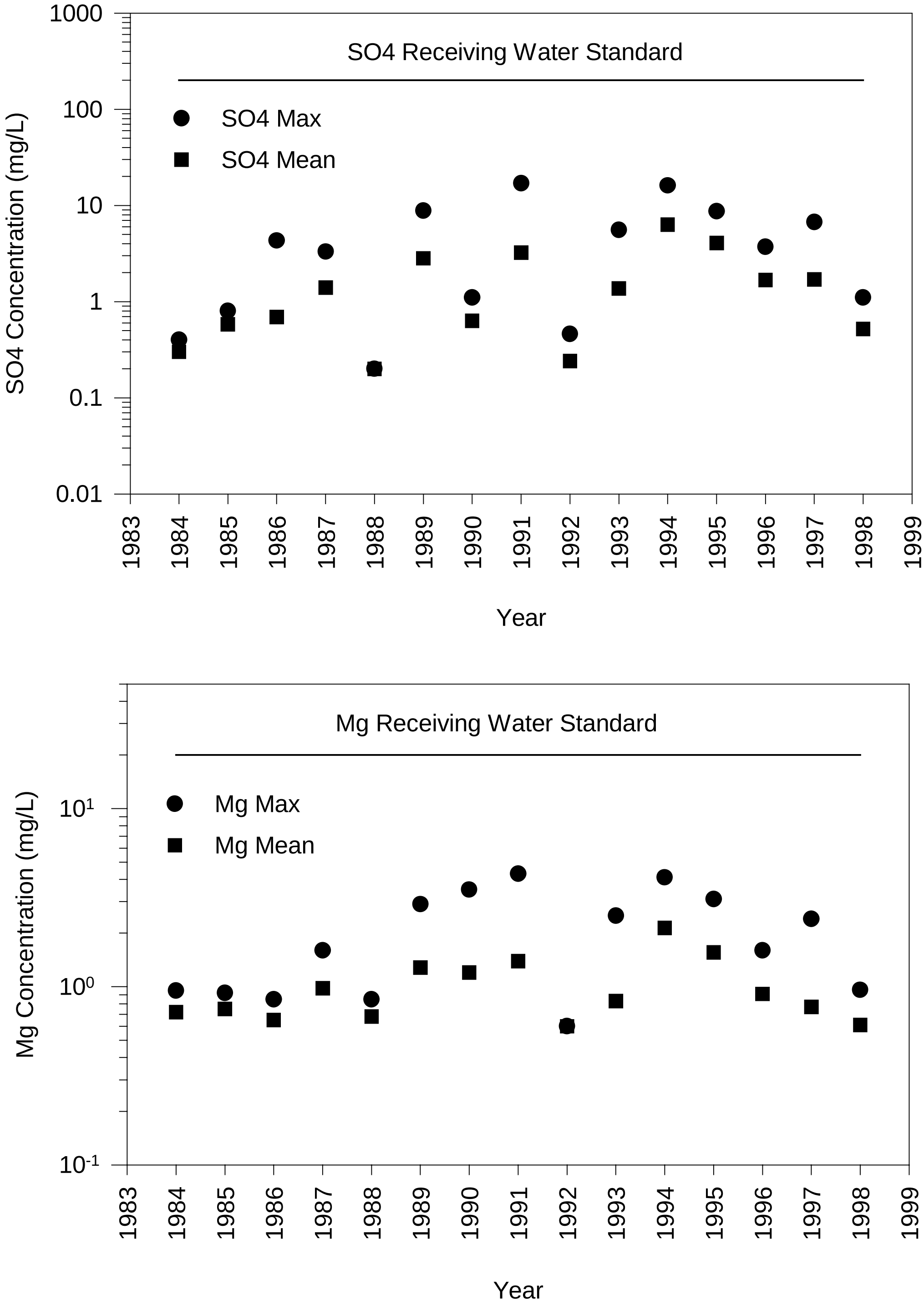


Figure 4 Comparison of sulphate (upper graph) and magnesium (lower graph) concentrations at gauging station GS8210009 downstream from the Ranger mine with the receiving water standard recommended by ***eriss***. Note the logarithmic scale.

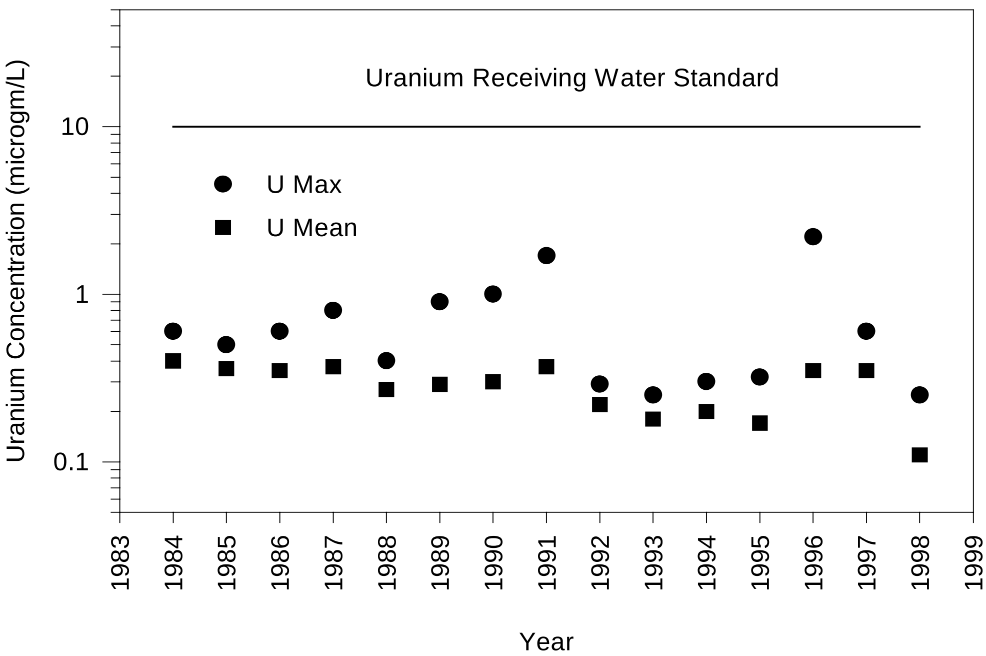


Figure 5 Comparison of uranium concentrations at gauging station GS8210009 downstream from the Ranger mine with the receiving water standard recommended by ***eriss***. Note the logarithmic scale.

grade ore stockpile. The water management system at Ranger was modified in 1992 to ensure that, even under extreme climatic circumstances, such an overflow could not reach the off-site environment but would instead be diverted to the mine pit. Since 1992, the maximum observed concentrations in Magela Creek have generally been low and the mean values are now similar to those in the early years of operation. The maximum value recorded in 1996 was investigated and no cause was established. The records show that this high value was an isolated measurement and may well have been caused by sample contamination. All values are, however, retained on the data base, even if suspect. In all years, the maximum concentrations of uranium have been lower than the standard recommended by ***eriss*** by at least a factor of five.

Similar data could be presented for all the constituents for which standards have been recommended by ***eriss***. In all cases the observed concentrations at GS8210009, where the Magela Creek enters Kakadu National Park downstream from Ranger, have been lower than the recommended standards.

4.3 Environmental protection based upon biological assessment

As stated above, ***eriss*** has been carrying out research since 1987 to develop biological monitoring methods that can be used to assess the environmental impact of uranium mining on aquatic ecosystems downstream from the Ranger mine. Suitable biological methods for assessing impact were not available prior to this program and, in common with the practice adopted elsewhere in Australia and overseas, chemical monitoring was used to assess the environmental impact of uranium mining. Some of the methods developed by ***eriss***, for example creekside monitoring tests, are now at a stage where they are being handed over to the mine operator, ERA, but they are not yet part of the routine regulatory program. However, during the development of the new methods, ***eriss*** has obtained data that can be used to assess environmental impact downstream from Ranger.

4.3.1 Creekside monitoring

In the creekside tests, species of fish (*Melanotaenia nigrans*) and freshwater snails (*Amerianna cumingii*) are exposed to water collected from upstream of the mine site (control site) and to water collected from the creek at gauging station GS8210009, some 5 km downstream from the mine. The tests look for any differences in larval survival for the fish species and egg production and juvenile survival for the freshwater snails.

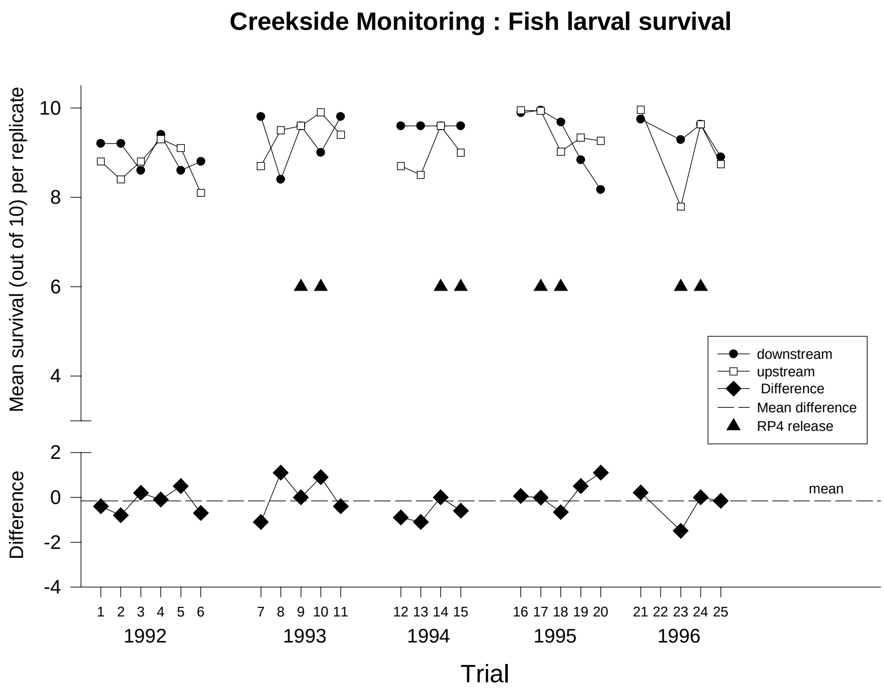
The results of a number of tests carried out in the period 1992–1996 are shown in figure 6. For the fish tests, larval survival at both sites was found to be between 80% and 95% with a relatively low variability. The difference between the upstream and downstream responses is also plotted; the mean value of the difference is approximately zero and in all cases the measured differences from this mean value are not statistically significant. Periods during which water from RP4 at Ranger was being discharged are indicated on the graph. These data show that such releases had no effect on the ability of larval fish to survive in waters downstream of the mine.

The data for snails show that there is quite a significant natural variation in the egg production rate of snails. Nevertheless, the variation at the downstream site is matched very well to that at the upstream site and the difference in response between the two sites is not statistically significant. Again, the discharge of water from RP4 (at the times indicated on the figure) had no detectable effect on the reproductive rate of freshwater snails.

These results come as no surprise since the rate of release of water from RP4 was limited by the requirements imposed by the chemical standards and by the dilution required on the basis of pre-release toxicological tests with the application of a safety factor. The monitoring data, therefore, confirm the adequacy of the controls imposed on the discharge of waters from the mine site.

4.3.2 Population and community structure monitoring

Macroinvertebrate communities have been sampled from a number of sites in Magela Creek at the end of significant Wet season flows, each year from 1988 to the present, with the aim of developing a monitoring technique to detect any impact from mining. The design and methodology of the research project have been gradually refined over this period to meet the needs of cost efficiency and improved ability to confidently attribute any observed changes to mining impact.



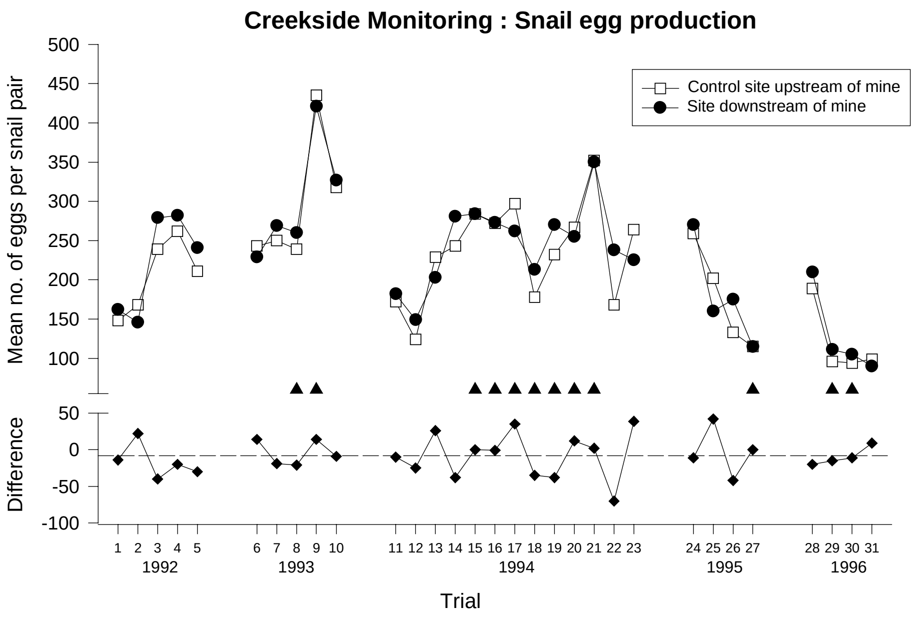


Figure 6 Biological monitoring of the impact of mining at Ranger using fish larval survival (upper graph) and freshwater snail reproduction (lower graph). Data are shown for animals exposed to water from sites upstream and downstream of the Ranger mine. Differences between upstream and downstream responses are also shown. Periods of release of RP4 water are indicated.

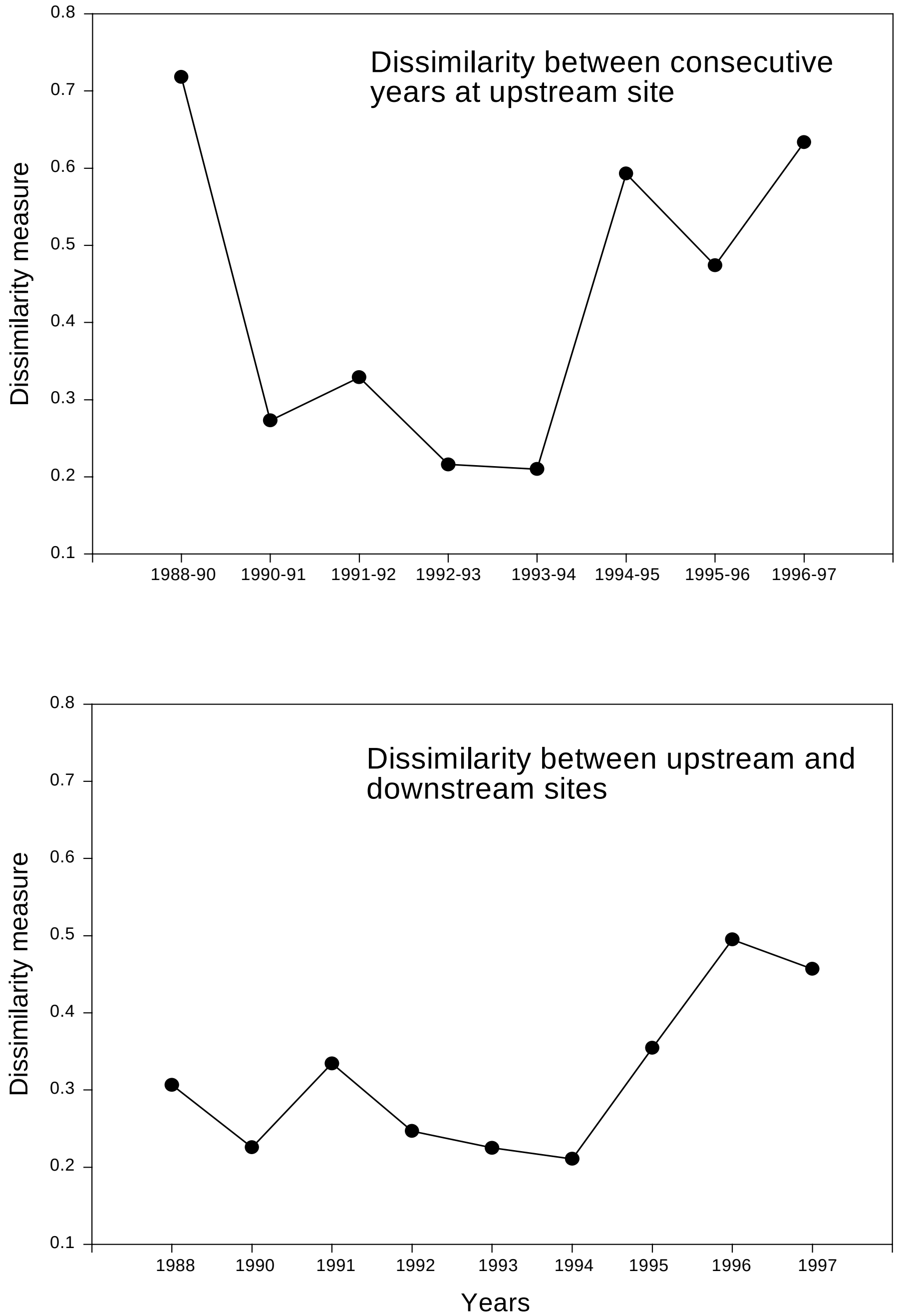


Figure 7 Dissimilarity (using the Bray-Curtis measure) in macroinvertebrate community structure in Magela Creek over time (i) at an upstream control site (upper figure) and (ii) between upstream and downstream sites (lower figure). Family-level data analysed.

Macroinvertebrate data for the 10-year period 1988-1997 have been analysed for a site in Magela Creek upstream of the Ranger mine (control) and a site 5 km downstream in order to illustrate comparative changes in community structure at the sites. Results are expressed in terms of dissimilarity measures – metrics that quantify the degree to which community structure differs between two samples, sites or sampling occasions. Dissimilarity measures range from 0 (the taxa and relative abundances of two samples are identical) to 1 (the taxa and relative abundances of two samples share nothing in common). Results for family-level data are presented in figure 7 by way of the dissimilarity in community structure (i) between the control and downstream sites over time (lower figure) and (ii) between consecutive years at the upstream site (upper figure). From these data we can conclude that changes from year to year in the dissimilarity index between the upstream and downstream sites are smaller than the natural variation that occurs at the control site. Hence, any change in community structure that has occurred downstream from the mine has not been ecologically significant and may have been due to natural variability.

A marked feature of the fish community of the Magela Creek system is a large migration from the floodplain to the upper reaches of the creek in the latter part of the Wet season, of two fish species, chequered rainbowfish and sailfin perchlet. These species are, numerically, among the most dominant in the region. For the rainbowfish, this migration has been shown to be mostly 'young-of-the-year' and hence it provides an indication of the recruitment for the year. The migration is presumably an adaptation ensuring that some of the fish recruited from the vast floodplain breeding grounds return to permanent waterholes upstream which act as refuges during the long Dry season. This migration has been monitored for 12 years by visually counting fish moving past a point downstream from the mine. The migration of both species is strongly correlated with the early flooding and inundation of the floodplains as indicated by the size of creek flow in December (early Wet season). Early inundation of the floodplain provides abundant resources at the time of peak spawning activity and a longer growing season which apparently results in greater numbers of young fish large enough to migrate when migration stimuli occur later in the Wet season. This relationship for the rainbowfish has high statistical significance and is shown in figure 8.

Also shown in figure 8 is the amount of Ranger mine waste-water released from retention pond RP4 in the same Wet season. It is very clear from the figure that the fish movement was not related to the volume of RP4 water discharged and this was confirmed by statistical analysis. It is concluded from this that there has been no impact of mine waste waters released so far on this ecologically significant fish species in Magela Creek.

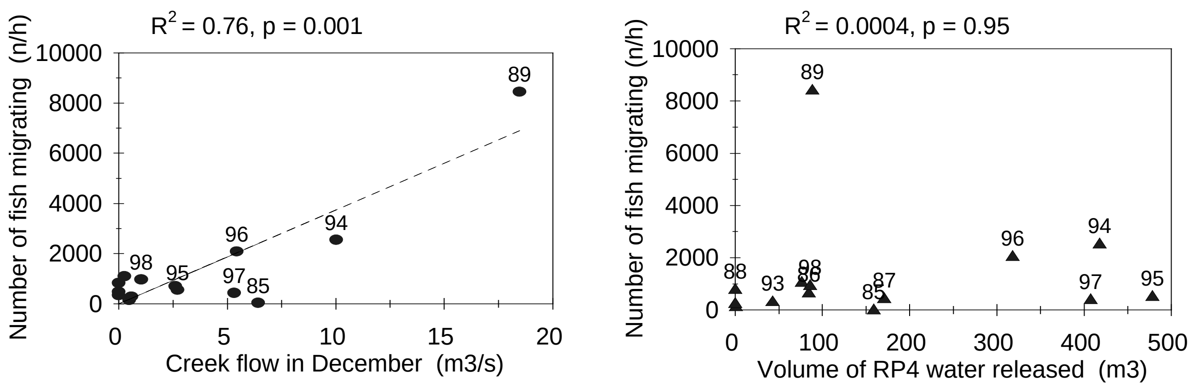


Figure 8 Relationship between the net upstream migration of chequered rainbowfish (mean number per hour at midday) in different years and (a) creek flow in December (mean daily flow) and (b) the amount of Ranger RP4 water discharged in each Wet season. The dashed line is the linear regression line of best fit for these points where a statistically significant relationship was shown. The numbers above the symbols indicate the years in which observations were made.

Studies of fish community structure in billabongs have shown no evidence of mining related effects in recent years. In one study, the fish in two lowland channel billabongs, one on Magela Creek downstream of the Ranger Mine and the other on a separate 'control' catchment, Nourlangie Creek (a tributary of the South Alligator River), have been monitored by a visual counting technique, using a canoe with a transparent bow. Multivariate measures of the dissimilarity between these fish communities, shown in figure 9, indicate that, although there are differences between streams, the difference has remained relatively constant over the study period, 1994 to 1998. Again, these data illustrate that operation of the Ranger mine has not affected the structure of fish communities in the first in-stream billabong of the Magela floodplain downstream from Ranger.

Overall, the biological monitoring program has shown that operation of the mine has had no detectable impact on a range of sensitive indicators of ecological health including the survival of larval fish, the reproduction of freshwater snails, the migration patterns of fish, and the community structure of fish and macroinvertebrates.

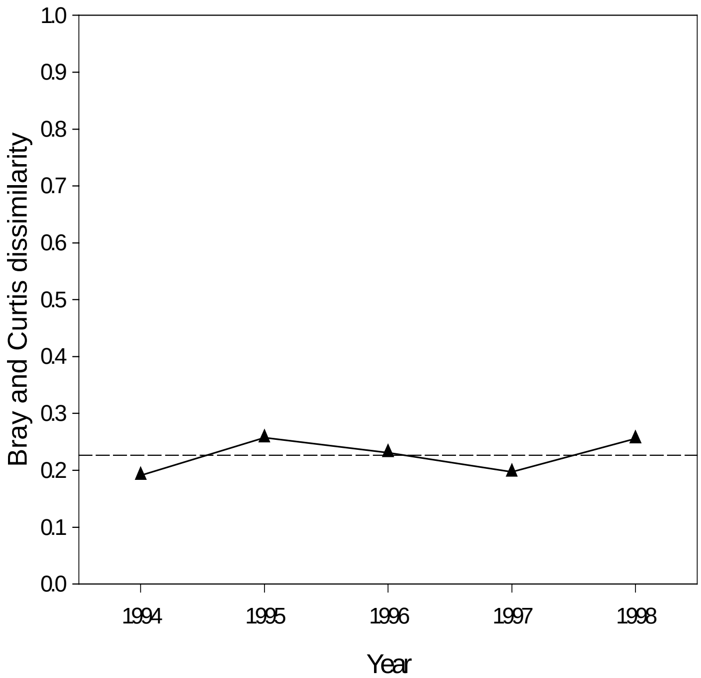


Figure 9 Multivariate measures of the dissimilarity between the fish community structure in Mudginberri Billabong on Magela Creek downstream from Ranger mine and in Sandy Billabong on Nourlangie Creek, the ‘control’ stream

5 Protection of people

The principal pathways by which members of the public can be exposed to radiation from the mining and milling operations at Ranger are:

- surface water transport of the long-lived radionuclides of the uranium series contained in waters discharged from the mine, and
- atmospheric transport of radon and its short-lived radioactive progeny and dust containing the long-lived nuclides of the uranium series.

5.1 The aquatic pathway

Release of radionuclides into the surface waters of the Magela Creek does not give rise to enhanced concentrations in drinking water for the non-Aboriginal population of the region since the local potable supply is derived from groundwater bores that are unaffected by mining. The major effect of such releases is increased concentrations of radionuclides in aquatic flora and fauna through bioaccumulation processes. Hence the group most at risk are those people who derive a significant proportion of their food from a traditional diet based on hunting and fishing in the Magela Creek system downstream from the mine site. The so-called 'Critical Group' has, therefore, been identified as the Aboriginal people living near Mudginberri Billabong.

Radiation exposure of people can only be measured directly by the use of intrusive techniques such as the analysis of urine and faeces samples and whole body monitoring. The estimated doses received by people are so low that they could not be detected by these methods and their use is therefore not justified. For this reason, radiation exposure of members of the public is calculated not measured.

In the case of the aquatic pathway, doses are calculated by modelling the physical transport of radionuclides in the surface water system, estimating the uptake of these radionuclides in aquatic flora and fauna, using the diet of the critical group to estimate the total intake of each radionuclide and converting this ingested intake into radiation exposure. ***eriss*** has carried out extensive research on each of these processes to enable reliable dose estimates to be made. Wherever uncertainties exist, conservative assumptions have been made to ensure that the dose is not underestimated. For example, it is assumed that 70% of all food consumed by the people concerned is derived from traditional hunting and fishing. This is certainly an overestimate.

The results obtained for the radiation exposure of people arising from the discharge of waters from RP1 and RP4 at Ranger are shown in figure 10 for each year since operation of the mine began. Those years for which no estimate is given were years of low rainfall during which no discharges took place from either RP1 or RP4. Also shown in the figure is a line representing the public dose limit recommended by the International Commission on Radiological Protection (ICRP). In all years the estimated radiation dose to members of the public is less than the dose limit by more than a factor of 20.

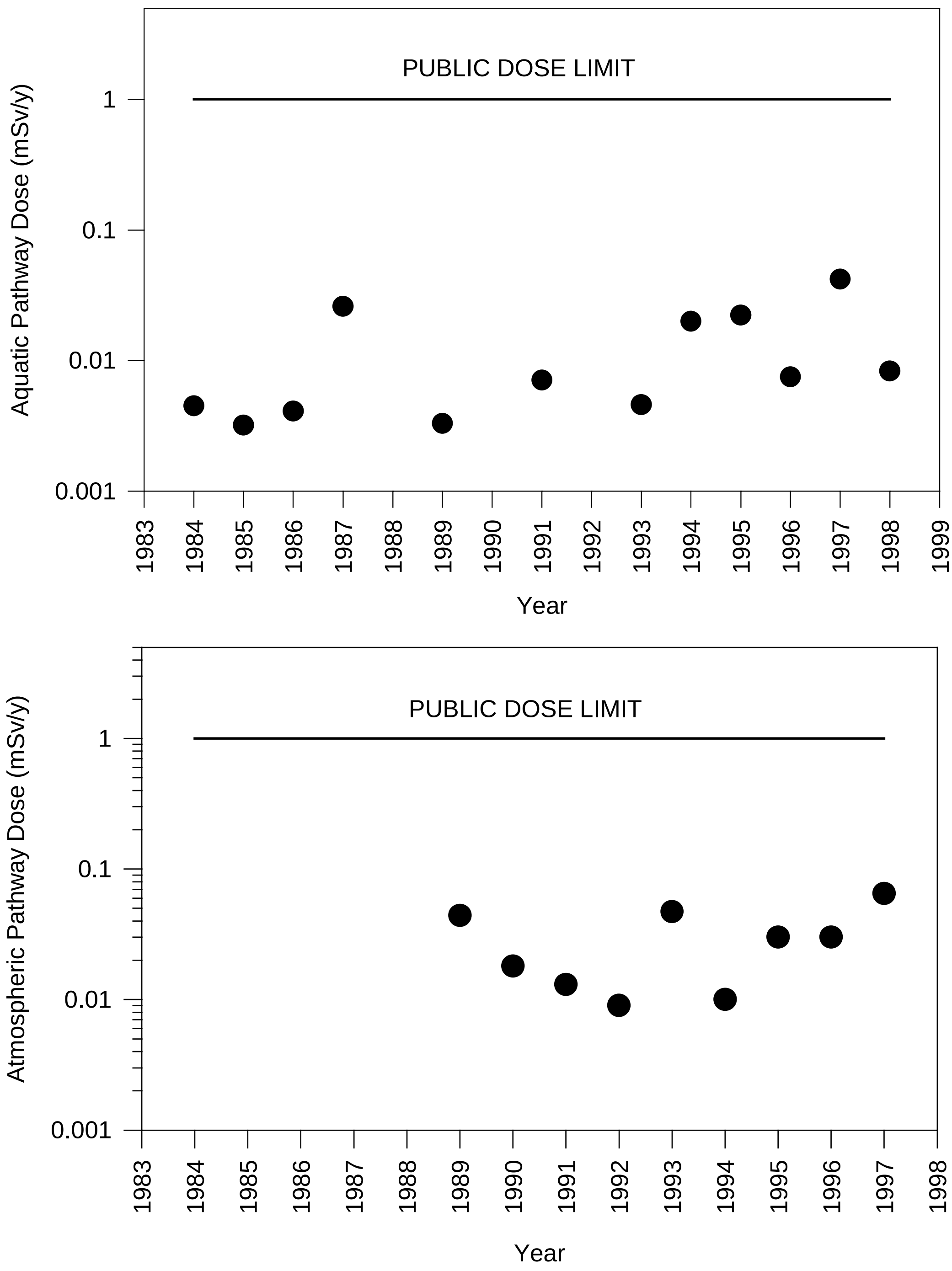


Figure 10 Radiation exposure of members of the public resulting from operation of the Ranger Mine via the aquatic pathway (upper graph) and the atmospheric pathway (lower graph). Note the logarthmic scale.

5.2 The atmospheric pathway

Radon is a short-lived radioactive gas which, together with its radioactive progeny, is always associated with uranium. It occurs naturally in the atmosphere, arising from trace quantities of uranium found in all soils and rocks. Radon is released from a uranium mine at concentrations substantially above normal background rates and can lead to increased radiation exposure of the public. As radon can disperse over large distances from the point of emanation, its atmospheric concentration at a location several kilometres from a mine could be due both to radon sources associated with the mining project and to natural background sources. For regulatory purposes, the contribution from these two sources needs to be distinguished because the regulatory dose limits apply only to the contribution from the mine-related source. The need to make this distinction becomes important when the combined radiation dose due to both mine-related and natural sources exceeds the prescribed limit, as is the case at Ranger.

eriss has developed a method of separately identifying the mine-related and background components by measuring radon and radon progeny concentrations arising from wind sectors containing only the natural background sources, and those from wind sectors containing both background sources and mine-related sources. Following the completion of this research, ERA has used a simplified version of the method, but one that is adequate for routine monitoring at Ranger, to make public dose estimates. The results obtained in this program since 1989 are shown in figure 10 and a comparison is drawn with the public dose limit recommended by the ICRP. These results show that radiation exposure of members of the public living in the vicinity of the Ranger mine due to the dispersion of radon and its progeny from the mine site has always been less than 10% of the recommended dose limit.

Similar methods have been used to determine the dose due to dispersion of radionuclides in dust from the mine. The estimated dose for members of the public is about 5% of the recommended dose limit.

6 Specific incidents at the Ranger Mine

The operator of the Ranger Mine, Energy Resources of Australia, has been required, since 1979, to report to the supervising authorities any infringement of the Environmental Requirements. The reporting arrangements have, however, also recognised that incidents that do not involve infringements may still be perceived to be of significance. The supervising authorities have, therefore, required ERA to report any significant environmental events or incidents that have the potential to:

- Cause adverse impact on the environment surrounding the mine
- Cause harm to people living or working in the area, or
- Cause concern to traditional owners or the broader public.

All such incidents are assessed by the Supervising Scientist and are reported in the Annual Report to the Australian Parliament.

Appendix 1 contains a list of all such incidents and infringements of the Environmental Requirements that have been reported throughout the life of the mine. The Supervising Scientist has investigated every such incident and, with two exceptions, has concluded that there has been no significant environmental impact at the time of the incident nor has there been any lasting environmental detriment.

One of these exceptions was the incident on 5 July 1982 which involved the health and safety of two workers in the packing plant. Following the incident, the Supervising Scientist undertook a specific study of radiation safety standards at Ranger and submitted a special report to the Minister for the Environment on 11 November 1983. The Supervising Scientist concluded that some radiation protection procedures at Ranger could be improved but, despite some reservations about training, assessed that radiation exposures of workers during routine operations were likely to have been below the appropriate regulatory dose limit. Since the time of the incident, substantial improvements have been made by ERA in standards of radiation protection and training.

The second significant incident resulted from a spill of diesel from tanks at the power station at Ranger followed by drainage into Retention Pond 2 on 6 December 1995. This resulted in the death of 40 water birds. The Supervising Scientist concluded that this was the first unacceptable environmental impact that had arisen as a consequence of operations at Ranger. The company has since revised procedures to ensure that the incident should not be repeated. The company also commissioned an independent audit of fuel management, and the management of similar hazards, and implemented the recommendations from the audit report.

It should be noted that, in November 1996, a fatality occurred at Ranger during excavation of foundations for the mill expansion. While this incident was obviously one of great concern, it was considered in the context of non-radiological workplace safety rather than as issue of environmental concern. It is, therefore, not listed as an incident in contravention of the Environmental Requirements.

Apart from the two incidents noted above, all incidents have been assessed by the Supervising Scientist as being of little or no environmental significance. A question that is often asked, however, is “On what basis was this assessment of environmental significance made?” To address this question, the Supervising Scientist has developed a simple matrix to explain, in relatively simple terms, the basis used for assessing ecological significance. The matrix is shown in figure 11.

The significance of an ecological impact may be considered in terms of two issues: how severe the impact is and how long it lasts. Assessment of impact severity is based on the actual damage to the ecosystem or landscape. In the matrix chosen, severity of impact has been classified in one of five categories ranging from 'no detectable change' in the physical, chemical or biological variables that characterise the environment through various categories to one in which change occurs 'at the ecosystem level'. The duration of an impact has been classified, in increasing significance, from less than one month to indefinite impact. The **position** within the matrix in which any particular incident is characterised provides a technical description of the environmental impact arising from that incident. This description is given in general terms by the label on the appropriate cell.

Whilst it is possible to determine the severity and duration of an impact with a high degree of objectivity, the interpretation of the significance of an impact is much more subjective. Depending on factors such as an individual's personal relationship with, use of, or appreciation of the areas concerned, the level of the individual's scientific understanding, or the individual's stance on relevant moral or cultural issues, the perception of the significance of an impact can vary significantly.

The **cell shading** shown in Figure 11 represents the Supervising Scientist's view of how the significance of environmental impacts should be regarded in the ARR. Cells which are heavily shaded are considered to describe impacts that are ecologically significant and require immediate intervention including, where appropriate, cessation of operations until the cause of the impact is eliminated. Those that are lightly shaded represent impacts of moderate environmental significance which do not meet community expectations on mining company performance and require remedial action. Cells without shading represent impacts that are considered to have no significance to ecosystem health or conservation values of the region. Whilst some stakeholders may consider the shading should be applied differently, it should nevertheless be possible for them to discuss and agree on the technical elements of an impact. Debate would then focus on interpreting the significance of the impact through different approaches to cell shading.

The ecological significance of the incidents recorded in Appendix 1 have been assessed by the Supervising Scientist within this framework. The number of incidents that meet the descriptors for each cell in the matrix is shown, in Figure 11, in that cell. Most incidents have given rise to no ecological impact while some, including minor tailings spills, fall into the 'brief non-biological impact' category. One incident (the bird kill on RP2 in December 1995) falls into the category of moderate ecological impact but no incident, in the opinion of the Supervising Scientist, has led to significant ecological impact.

In summary, of the total of 106 incidents that have been reported since mining began at Ranger in 1979, only one incident has been assessed as being of moderate ecological significance and one incident has had significant impact on people working at the mine. While the list of incidents reported appears large, this is a reflection on the rigour of the reporting framework and not a reflection on the standard of environmental management at the Ranger mine.

Duration of impact / Severity of impact	Less than 1 month	Less than 1 year (less than a complete seasonal cycle)	Within project life (estimate No. of years to recovery)	Indefinite
Change at the ecosystem level	Brief serious impact	Short term serious impact	Extended serious impact	Long-term serious impact
Mortality within some species	Brief moderate impact #(1)[1]	Short term moderate impact	Extended moderate impact	Long-term moderate impact
Stress or behavioural change to individuals	Brief mild impact	Short term mild impact	Extended mild impact	Long-term mild impact
Physical or chemical changes only	Brief non-biological impact #(14)	Short term non-biological impact	Extended non-biological impact	Long-term non-biological impact
No change detectable	No impact #(91)	No impact	No impact	No impact

#(Number of environmental incidents) #[1] Bird kill in RP2 in December 1995

Heavy shade = significant impact Light shade = moderate impact Clear = insignificant impact (See text for interpretation)

Figure 11 Assessment of ecological impacts arising from incidents at the Ranger mine from 1979 to August 1998

7 Long term environmental protection issues

The principal thrust of this report has been to provide an assessment, based upon the extensive monitoring and assessment programs that are in place at Ranger, of the extent to which the environment of the Kakadu region has been protected during the years since mining of uranium commenced. Concerns are, however, sometimes publicly expressed about the likelihood of future environmental impact particularly with respect to seepage of contaminants from tailings repositories and the long-term dispersal of the radioactive tailings themselves.

Tailings at Ranger are currently stored in the above-grade tailings dam and in the mined-out No 1 Pit. While the Environmental Requirements allow for the possibility that ERA may apply for approval to rehabilitate the tailings in the dam *in situ*, the company has decided that such an application will not be made and that all tailings will be returned to Pits No 1 and No 3. (To be accepted, any such application would need to be judged by the Supervising Scientist as no less protective of the environment than tailings placement in the mined-out pits.)

Following rehabilitation, therefore, all tailings will be below the surface of the natural landscape in the region, with the highest point of the tailings mass many metres below the surface and no higher than mean sea level. In studies carried out the Supervising Scientist, the erosional stability of landforms of the Ranger Project Area have been assessed using information on landform genesis and chronology. The erosional stability of the top 2 metres of landforms in the vicinity of No 1 and No 3 Pits was found to be of the order of millions of years. Following removal of most of the uranium, the longest radiological half-life of the radionuclides in the tailings is about 77,000 years. The radioactivity of the tailings will, therefore, have decayed away before dispersal of tailings can occur. Hence, from the perspective of tailings dispersal, the rehabilitated Ranger site does not represent a long-term environmental risk.

The dispersal of contaminants via seepage into groundwater is both a short-term and a long-term issue. In the short-term, seepage can arise from the tailings contained in the tailings dam; in the long-term from Pits No 1 and No 3.

Because metals and radionuclides are adsorbed to a very significant extent on the rocks of the aquifer through which seepage water passes, the only short-term hazard arising from seepage is that associated with conservative substances such as sulphate which, because of the introduction of sulphuric acid in the mill circuit at Ranger, is present at high concentrations in tailings water. Monitoring results obtained for sulphate concentrations in observation bores in the vicinity of the tailings dam show that sulphate is moving out from the tailings dam towards Retention Pond 1 (RP1) and that seepage is contributing to the concentration of sulphate in RP1. However, the contribution of seepage is small compared to that arising from rainfall runoff from the walls of the dam which have been constructed using waste rock from the mining operations.

The short-term impact on the environment arising from these processes can be assessed from the data presented previously in figure 4 in which sulphate concentrations at the gauging station (GS8210009) in Magela Creek, downstream from the mine site, are plotted. These data show that although concentrations increased in the early years of operation, mean and maximum concentrations have stabilised in recent years and, in all years, concentrations have been more than a factor of 10 below the standard for environmental protection recommended by the Supervising Scientist. These results have been obtained over the 20 year life of the mine and the tailings dam will only contain tailings for approximately twenty more years. This observation, and the fact that seepage only currently makes a small contribution to the observed concentrations, implies that the likelihood of sulphate from seepage causing any significant environmental impact during the life of the mine is very small.

Sulphate is not expected to be a significant hazard in the long-term either from the tailings or the rehabilitated landform. The tailings will be placed in the mined-out pits which will be treated (by grouting, the use of filter beds etc) to minimise interaction between the tailings pore water and the fractured rock groundwater aquifer of the Ranger region. The waste rock used in the construction of the rehabilitated landform at Ranger is, unlike that at many other mines, very low in sulphur. No significant impact from sulphate or acidity is expected to occur in the long-term.

A thorough assessment of the probable long-term impact arising from the dispersal of radionuclides in seepage from the mine pits requires detailed hydrogeochemical measurements and modelling. However, a relatively straightforward but conservative estimate can be made by calculating the rate at which any substance leaves the tailings repository (using typical ground water velocities and tailings pore water concentrations) and determining the increase in the concentration in the waters of Magela Creek using typical volumes of water flowing in the creek. This calculation yields a dilution of about 1000:1.

The concentration of radium (the radionuclide in the uranium series that is of greatest radiological significance) in tailings waters is higher than the natural concentrations in Magela Creek by a factor of about 1000. On this basis, the contribution of seepage to the concentration of radium in Magela Creek will be similar to naturally occurring concentrations once it is diluted by the waters of the creek. However, this estimate is highly conservative since it takes no account of the adsorption of radium on the rocks of the aquifer which, as noted above, is very significant and the fact that the permeability of the tailings is much lower than that of the aquifer. It also assumes that all solutes in groundwater from the tailings repository reach the surface in the creek near Ranger rather than much further downstream or even in the sea.

It can be concluded, therefore, that the short and the long-term impact of seepage from tailings repositories at Ranger and the long-term impact arising from dispersal of tailings are not likely to be of radiological or ecological significance.

8 Summary and conclusion

For almost twenty years, uranium has been mined and milled at the Ranger mine within an area that is surrounded by, but does not form part of, Kakadu National Park. The national and international importance of Kakadu has been recognised by its inclusion on the Register of the National Estate and its inscription on the World Heritage List. The flood plain areas within Kakadu are recognised as one of Australia's Wetlands of International Importance listed under the Convention on Wetlands of International Importance. Much of the land in the region, including the land on which the Ranger deposits were found, has been recognised as part of the traditional estate of the Aboriginal people of the region. For these reasons, operation of the mine has been subject to a rigorous system of regulation and supervision, a system that is unequalled anywhere in Australia and probably anywhere else in the world

Environmental management of the region is achieved through the work of federal and state agencies. The Park is managed through a Commonwealth agency, Parks Australia, by a Board of Management on which the traditional Aboriginal owners of the land in the Park form a clear majority. The Ranger mine is regulated by an agency of the Northern Territory Government, the Department of Mines and Energy. The Commonwealth Government, however, has stipulated a number of Environmental Requirements which govern the activities of the Northern Territory in its day-to-day regulation of the mine. The Supervising Scientist, a statutory officer of the Commonwealth, is responsible for assessing the adequacy with which regulation of the mine complies with the Environmental Requirements and, through research on the effects of uranium mining, for developing standards, practices and procedures that will ensure the continuing protection of the environment.

The adequacy with which this regime has protected the people and landscapes of Kakadu National Park has been assessed by extensive chemical, biological and radiological monitoring programs which have been continually upgraded to take into account the results of new scientific research. The chemical monitoring program has shown that, in the receiving waters of Kakadu National Park, the concentrations of all chemical constituents have, throughout the entire period of mining, remained below the standards recommended by the Supervising Scientist and have been significantly below the concentrations predicted by the Ranger Uranium Environmental Inquiry. The biological monitoring program has shown that operation of the mine has had no detectable impact on a range of sensitive indicators of ecological health including the survival of larval fish, the reproduction of freshwater snails, the migration patterns of fish, and the community structure of fish and macroinvertebrates. The radiological monitoring program has shown that the radiation exposure of people living in the vicinity of the mine, either through consumption of foods collected from downstream waters or through radon dispersed from the mine site, has always been significantly lower than the internationally recommended limit on radiation exposure of members of the public.

The operation of a mine cannot be conducted without there being limited spatial and temporal impact on the environment. The environment on the mine lease itself is certainly disturbed but the objective of any environmental protection regime is that there be minimal impact off-site and that this impact is within standards that are set to ensure a high level of environmental protection. A number of specific incidents have occurred at the Ranger mine. The environmental protection regime at Ranger requires the operator to report all such incidents to the supervising authorities and the Supervising Scientist must report on, and assess the significance of, these incidents in his Annual Report to the Australian Parliament. Over the life of the Ranger mine, only two such incidents were considered by the Supervising Scientist to be of significance and neither of these had any lasting impact on the people, biodiversity or landscapes of Kakadu National Park.

The overwhelming conclusion that can be drawn from the extensive chemical, biological and radiological monitoring programs in place at Ranger is that mining and milling operations have been conducted in a manner that has enabled a very high standard of environmental protection to be achieved for the cultural landscape of Kakadu National Park. With respect to the likelihood of future environmental impact, it has been concluded that the short and the long-term impact of seepage from tailings repositories at Ranger and the long-term impact arising from dispersal of tailings are not likely to be of radiological or ecological significance.

Appendix 1 Table of incidents at the Ranger Mine

DATE	DESCRIPTION OF INCIDENT
28 February 1979	Spillage of diesel into Coonjimba Billabong, no significant environmental impact.
9 November 1979	Contractor's plant encroached on fenced off vegetation; area was re-fenced and vegetation restored.
22 November 1979	About 20L diesel spilled into a drain in Jabiru; spill was contained and did not enter natural waterways.
7 December 1979	Small amount of oil-tar spilled a sediment control pond at the Jabiru Police station; no environmental impact.
23 February 1980	One tree knocked over by a contractor; no significant environmental impact.
29 March 1980	ERA pumped water from Borrow areas A & B to ponds 2 and 3 before the ponds were declared officially to be RRZ. No environmental impact.
6 June 1980	Release of 1000 m^3 of silty water from Borrow D to Georgetown Creek; no significant environmental impact.
w/e 27 June 1980	Dry drilling in Borrow Pit A; no environmental significance but wet drilling was to be used under OH&S requirements.
11 August 1980	One sea eagle found shot near junction of Magela and Georgetown creeks.
9 November 1980	One antilopine kangaroo found shot at Gulungul creek borefield; ERA limited access to the area.
1980-81 Wet Season	Sewer at old mess site became surcharged at times and sewage entered Coonjimba Billabong; ERA undertook remedial works; no lasting environmental impact.
9 April 1981	Small volume of water and silt flowed from the Ranger organic dump tank to Georgetown Creek; no significant environmental impact and flow failed to reach main channel.
29 July 1981	Recycle water tank overflowed spilling process water from #3 pond into the neutral thickener area. Some of the water and a minor amount of tailings solids were pumped into the stormwater collection pond which discharges to #2 pond during the wet season. The estimated volume pumped was 40 $m^{3;}$ no lasting environmental impact.
31 July 1981	Fugitive slaked lime dust from a lime transfer operation blew onto the surface of Djalkmara Billabong and was noted through a pH reading of 9.3 during routine monitoring. Impact was small and problem overcome by introducing water spray on lime before and during loading.
5 August 1981	Clarified pregnant liquor tank and associated clarifier tank overflowed into an adjacent bund due to operator error. Liquor was pumped back; further overflow stopped by adjustment of process flow rate; some slight increase in radioactivity in bund during incident but considered minor.

August 1981	During commissioning of the mill, waste rock was used. The ground waste accumulated at one point in the tailings dam and some was exposed to air. Situation was modified once true tailings were produced and procedure introduced to move deposition pile. No environmental impact.
13 August 1981	Sewage manhole at Coonjimba Camp discharged at 3–4 litres/min and effluent was flowing on the track to the billabong; leak was due to a faulty automatic pump control which prevented pump starting; repairs effected; no environmental impact.
3-23 November 1981	Two islands of tailings appeared in the tailings dam, area about 20 sq. metres. Mine closed for 4 days while authorisation and requirement for 2 m water cover were reviewed. Authorisation amended to show water cover rather than specific depth. No environmental impact.
23 November 1981	Spillage of concentrate from a drum outside the store during unloading; the spilt material was cleaned up; no environmental impact.
25 November 1981	Two observed emissions of concentrate dust from the scrubber stack, estimated at 2–4 kg uranium. This exceeded the daily discharge limit of 1.5 kg uranium. Repairs to control system effected to prevent recurrence; no environmental impact.
26 November 1981	Operator found in bare feet whilst working in the tailings dam; estimated radiation exposure was trivial; operator and supervisor advised on importance of following safety procedures.
11 December 1981	Small amount of tailings leaked from a pipeline to the tailings dam floor above the water level; covered with soil; no environmental impact.
14 December 1981	Small tailings spill from breather valve in tailings pipeline on inside perimeter on tailings dam embankment. Breather valves declared redundant and removed; tailings cleared up into dam; no environmental impact.
22 December 1981	#3 sewage retention pond overflowed. Contractor staff failed to be on site as required; ERA took over running plant; environmental impact, following rainfall dilution was very minor.
28 December 1981	Operator accidentally sprayed with ammonium diuranate. No residual contamination after showering; test showed no contamination.
2 January 1982	Break in tailings line inside tailings dam wall; some erosion, wall repaired with waste rock, no environmental impact.
5 January 1982	Small quantity of yellowcake spilt from two drums in transport outside packing area; cleaned up by safety officer; no environmental impact; new procedures introduced to prevent recurrence.
22-23 January 1982	About 40 dead fish were found in Coonjimba Billabong. Water quality checks showed nothing abnormal; natural fish kills occur in the area from time to time.
22 January - 2 February 1982	Acid plant stack emissions measured to be in excess of allowable limit of 2 kg/tonne of acid produced; problem due to incorrect fitting in plant since commissioning; part replaced and level fell to about 1.3 kg/tonne; No lasting environmental impact; new checking procedure introduced.

18 February 1982	Small leak from tailings pipeline detected; line shut down and repair effected within 1 hour including clean up, all tailings stayed in the RRZ. No significant environmental impact.
25 February 1982	Acid mist eliminators in acid plant flooded due to blocked drain and mist level exceeded permitted limits; plant shut down and fault rectified; no environmental impact.
4 March 1982	One m^2 island of tailings appeared above water in tailings dam overnight when pipe was not shifted on time; corrected during the next shift; no environmental impact.
16 March 1982	SO_2 analyser on acid plant damaged by acid; alternative tests showed emissions below limit; no environmental impact.
25 march 1982	Bleeder valve on tailings pipeline leaked a small amount of tailings onto inside top of embankment. Tailings were hosed into dam, no environmental impact.
20 April 1982	30 m^3 pregnant organic liquor solution overflowed from an overflow sump into stormwater system thence to #2 pond. Operation was stopped; sump modified to prevent recurrence; no environmental impact.
16 June 1982	Emissions on packing area scrubber exceed allowable rate; system modified to prevent blockage in water filter; no environmental impacts.
June/July 1982	SO_2 emissions from acid plant stack exceeded allowable limits. Plant modified to prevent further problems; no environmental impact.
22 June 1982	Filter cake from sulfur meter self ignited and was not fully extinguished before dumping in tailings dam; subsequently re-ignited and had to be dowsed with earth; no environmental impact or health risk from fumes.
5 July 1982	Significant incident following a major spill of product. About 1 tonne of yellowcake, onto two personnel. Subsequently radiation safety measures were investigated. No environmental impact.
1 February 1983	< 1 tonne of low grade ore washed outside RRZ with 150 m^3 of RRZ water following drain blockage in heavy rainfall. No significant environmental impact.
9 February 1983	About 200L of diesel spilt at a borefield 800m south of pit #1. No significant environmental impact outside spill site.
23 February 1983	Seven personnel exposed to above permitted levels of radioactive contamination during modifications to yellowcake scrubbers; exposures were short term and less than 5% of the annual limit for designated workers; no environmental or health impacts.
9 March 1983	Labourer exposed to radioactive dust concentration above derived limits. Testing and whole body counting showed that uranium in the body was less than the detection limit of the equipment; no environmental or health impact.
March 1983	Small volume of sewage escaped from Jabiru East following entry of stormwater into system; leading to pump failure; no significant environmental damage.
22 April 1983	Less than 50 litres diesel escaped to Gulungul Creek from a spill at a borehole site 74/1; no environmental impact.

July 1983	Following a temporary and unauthorised change to connections for the mill process and potable water systems, a small amount of radioactive material was deposited in the potable water supply pipe. Investigations showed no significant exposure through ingestion, to workers; all mill potable water pipes replaced.
13 July 1983	A contractor, without authorisation, pumped a small amount of RP2 water outside the RRZ to use in tailings dam construction. Action was stopped by ERA staff; tests showed no measurable contamination on dam walls; no environmental impact.
20 September 1983	About 40 tonnes of low grade ore dumped outside the RRZ. Clean up was carried out by ERA staff within the day, material returned to RRZ; no environmental impact.
15 August 1983	Minor tailings leak; contained with RRZ; no environmental impact.
16 November 1983	About 100L diesel fuel spilled from split fuel line at borehole 77/2 over an area of 25 m^2. Area cleaned up and reseeded; no lasting environmental impact.
25 January 1984	About 100 m^3 RP2 water escaped from a pipeline within the RRZ; all water contained, no environmental impact.
9 April 1984	Estimated 200 litres diesel spilled from a tank at bore 77/13 when it was tipped over. Area cleaned up and sanded to assist revegetation; no significant environmental impact.
11 July 1984	About 200 m^3 liquid from RRZ leaked outside the RRZ from a joint in a pipe carrying tailings dam seepage back to the dam No environmental impact.
30 October 1984	About 600 litres of water leaked outside the RRZ from the tailings dam seepage collector line; no environmental impact.
20 March 1985	Small quantity of tailings dam water sprayed and ran off the tailings dam wall; water mostly returned through the seepage collector system; no environmental impact.
28 February 1985	Monthly sampling at product packing stack showed uranium levels close to the allowable limit; remedial work undertaken by ERA to repair scrubber system; no environmental impact.
14–16 February 1985	Fish kill in RP2 was reported after water was pumped from RP4. No environmental significance as natural fish kills are reasonably common and also fish may have been physically damaged by the pump. No significant environmental impact.
28 June 1985	ERA detected a level of acid mist above the authorised limit; remedial work alleviated the problem and prevented recurrence; no significant environmental impact.
31 July 1985	A tailings pipeline failure led to about 2 kg of tailings being sprayed outside the RRZ; no significant environmental impact.
1 August 1985	A tailings pipeline failure led to about 2 kg of tailings being sprayed outside the RRZ; no significant environmental impact.
19 August 1985	A tailings pipeline failure led to about 2 kg of tailings being sprayed outside the RRZ; no significant environmental impact.
September 1985	Scaffolding stained with ammonium diuranate was shipped off site to Darwin for re-use; no significant environmental impact.

2 September 1985	About 50 cu m of RRZ water was released accidentally onto an area outside the RRZ adjacent to the irrigation area; no significant environmental impact.
3 September 1985	A small island of tailings appeared above water in the tailings dam; no significant environmental impact.
17 September 1985	Approximately 25 m^3 of water sprayed outside the RRZ. No significant environmental impact after clean up had been completed.
18 September 1985	Approximately 25 m^3 of water sprayed outside the RRZ. No significant environmental impact after clean up had been completed.
24 September 1985	A tailings pipeline failure resulted in About 25 m^3 of tailings being deposited over an are of 1250 m^2 to a depth of 2 cm, outside the RRZ. No significant environmental impact after clean up.
3–7 October 1985	Estimated 500 cu m of process water accidentally sprayed onto land application plots in the RRZ. No environmental impact.
26 November 1985	200 litres of water leaked from a pipeline between the central seepage collector sump and the north wall of the tailings dam. No environmental impact.
4 March 1986	Comparatively high levels of sulfur dioxide emitted during acid plant start up; no environmental impact.
6–7 March 1986	Small tailings island developed in the tailings dam overnight; no significant environmental impact.
3 June 1986	About 5 m^3 of tailings dam water was spilled outside the RRZ from the return pipeline; no environmental impact.
5 December 1986	ERA reported the unlawful removal from site of an empty but radiologically contaminated truck mounted water tank. After negotiating with the owner the tank was returned to site and ERA control; no significant environmental impact.
March 1987	DME determined that ERA were 6 months overdue in submitting a report on revegetation of waste rock as required by ER 26. Also water from RP3 (RRZ) had been used for dust suppression outside the RRZ on a waste rock dump haul road. No significant environmental impact.
March 1987	About 500 cu m of RP4 water was inadvertently released via the pipeline to Magela Creek following a valve malfunction and when the creek flow was below the minimum approved rate; no significant environmental impact.
1–2 February 1988	An overflow occurred of mill process froth from a tailings neutralisation pachuca. Approximately 13 m^3 of liquid ran into RP2 but no liquid left the RRZ; no significant environmental impact.
31 August 1988	Minor RRZ infringement when a contractor inadvertently used a small quantity of RRZ water for dust suppression outside the RRZ. No significant environmental impact.
November 1988	Following a malfunction of discriminators very low grade material was being dumped incorrectly on the waste rock dump, up to 500 000 tonnes of material may have been involved. The area of the waste rock dump was redesignated as RRZ. No significant environmental impact.

20 March 1989	RP2 water level was allowed by ERA to reach a level almost 1 m above the agreed wet season limit. This was to prevent overtopping as a result of a 1-in-100 year storm event. No environmental impact.
9 April 1989	The daily approved application rate of water to the land application area occurred. A small amount of runoff was reported from the land application area. No environmental impact was detected as a consequence of this incident.
13–14 August 1989	About 315 cu m of RRZ water were used for fire fighting when a bush fire threatened both the Ranger and ARRRI laboratories. No significant environmental impact.
25 April 1990	A small quantity of tailings sprayed from a pump when the casing failed. No material left the RRZ. No environmental impact.
22 June 1990	Approximately 2.5 to 3 m^3 of tailings leaked from a split pipe; all material was contained within the RRZ, no environmental impact.
26 February 1991	Uranium enriched water draining from the Ranger high grade ore stockpile was accidentally released to Georgetown Creek and subsequently Magela Creek. The event was not classified as an infringement by DME. The Supervising Scientist estimated that about 25 kg of uranium was discharged to Magela Creek during this event and, based upon the flow conditions at the time, assessed that the concentration of uranium could have been comparable to the receiving water limit for a short period. He concluded that there would have been no environmental impact in Magela Creek.
27 March 1991	Approximately 320 m^3 of additional water were applied to the land application area following equipment malfunction. The water fully infiltrated and there was no runoff. No environmental impact.
27 September 1992	Approximately 430 cubic metres of water from RP2 was transported by mine trucks to locations outside the RRZ for use by the Ranger emergency fire crew in containing and controlling a bushfire burning in and near the Ranger Land Application Area. The fire threatened infrastructure. There were no alternative sources of water in sufficient quantity available to fight the fire. The Supervising Scientist assessed the transfer of water from the RRZ as constituting an infringement of the Ranger Authorisation and a breach of the Environmental Requirements (ER7). No significant environmental impact.
25 January 1993	During heavy rainfall a blocked drain caused a small volume (less than 100 cubic metres) of water to escape from the RRZ. The Supervising Scientist assessed this event as being an infringement of the Ranger Authorisation and a breach of the Environmental Requirements (ER27). No significant environmental impact.
21 October 1993	Failure of a component in the tailings dam sprinkler system, used to minimise dust generation resulted in wind blown spray drifting over the dab embankment outside the restricted release zone (RRZ) boundary. The resulted from coincidental high winds from the NNW at the time of the failure. The quantity of water was small and the area was cleaned up within two days. An evaluation of the likely radiological effect suggested there was no radiological impact beyond natural background. The sprinkler system was repaired and has functioned correctly since the incident.

13 April 1994	About 60 cubic metres of combined rainfall-runoff and seepage from the high-grade ore stockpile discharged outside the RRZ following a pipe joint failure. The pipe ran alongside the drain downstream of the RRZ boundary at the bund in the high-grade ore stockpile drain. Samples taken along the flow path showed an increase in uranium concentration in Georgetown Creek but no change in uranium concentration could be detected in Georgetown Billabong. The pipe has since been relocated wholly inside the RRZ. No significant environmental impact.
10 May 1994	About 50 cubic metres of RP2 water was accidentally discharged outside the RRZ during the installation of a new section of pipe at the RP2 pumping station. The pipe was part of the network that serves the irrigation area. No significant environmental impact.
20 July 1995	About 10 m^3 of RP2 water was used in pre-production drilling at ore body #3 outside the RRZ. No significant environmental impact.
1 August 1995	Approximately 120 m^3 of RP2 water was accidentally discharged outside the RRZ due to a failure in a pipeline carrying water to the constructed wet land filter adjacent to RP1. No significant environmental impact.
6 December 1995	About 12 cu m of diesel spilled from tanks at the power station and ran into RP2. Although cleared up, the spill was responsible for the death of 40 water birds. The Supervising Scientist regarded this incident as the first example of an unacceptable environmental impact at Ranger since operations began.
13 December 1996	An administrative error resulted in a repeat of the incident of 6 December when the residual diesel/water mixture was spilled back to RP2. There were no further bird deaths associated with this incident.
23 January 1996	2–3 m^3 of tailings spilled from the tailings line and flowed outside the RRZ. The incident was the result of a valve failure. The area affected extended over about 60–80 m^2. This soil and grass in this area were removed and the site mulched and reseeded. The valve and the associated support structure were replaced. There was no environmental impact from this incident.
18 February 1996	About 2 m^3 of tailings sprayed from a leak in the pipeline running along the top of the tailings dam embankment. Approximately 0.25 m^3 fell outside the RRZ on the outer wall of the dam. This area was scraped up and returned to the tailings dam. There was no environmental impact.
21 September 1996	A bush fire on the mine site placed significant demand on accessible non-RRZ water for fire fighting. To speed up the turnaround times for water tankers, a decision was made to use RRZ water to create a wet perimeter and to dampen facilities under threat. Approximately 585,000 m^3 was applied to areas outside the RRZ. Failure to extinguish the fire would possibly have led to substantial environmental harm, and so the use of RRZ water in this emergency situation was prudent. No significant environmental impact.
27 September 1996	Preliminary works on the mill expansion commenced before ministerial approval was granted. No environmental impact.

19 November 1996 A segment of the perimeter drain around new extensions to the VLG/LG stockpile washed out during a heavy storm. About 100 m^3 of RRZ water and some sediment was released into RP1 catchment. No significant environmental impact.

10 December 1996 ERA reported another minor failure of the stockpile drainage bund resulting in a small quantity of RRZ runoff entering the RP1 catchment during a severe rainfall event. Further, a drain blocked by sediment at a VLG dump also caused RRZ rainfall runoff to enter a non-RRZ drain discharging to RP1 at that time. The company acknowledged that the primary cause was slumping and erosion of laterite material recovered from surface stripping of Orebody 3. No significant environmental impact.

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24 February 1997 50 $m^3$of VLG/LG ore spilled outside the RRZ zone into the RP1 catchment. The spill was again a consequence of heavy rainfall causing a washout of stockpiled material leading to a breach of the drainage system. Repairs were made and material collected and returned to the stockpile. No significant environmental impact.

29 June 1997 A monitor installed in the power station stack to continuously record the level of SO_2 and CO_2 emissions failed on 29 June 1997. A replacement is expected to be commissioned by 12 September 1997. No adverse environmental impact was observed. No significant environmental impact.

30 June 1997 During the EPR held in June 1997, two other infringements were identified.

– Although monitored continuously, powerhouse stack emissions had not been reported since 1981. This is in contravention of the Authorisation that requires data summary reports to be submitted quarterly. This oversight will be rectified in subsequent reports. Monitoring has confirmed that emission levels have been within prescribed limits during this period

– Gross alpha activity in freshwater mussels has not been monitored and reported since 1990. However, radium and uranium monitoring (the major alpha contributing species) has continued during this period and results have been within prescribed limits. The requirement to monitor and report gross alpha activity is a regulatory issue which has been referred to the Minesite Technical Committee for consideration.

19 December 1997 About 2 cubic metres of tailings slurry escaped from the RRZ due to a leak in the tailings pipeline. The leak was repaired and the spill was returned to the tailings pit. No significant environmental impact.

16 March 1998	To remove rainwater which had collected on the haul road, an ERA employee broke a bund which resulted in approximately 100m^3 of water escaping from the Restricted Release Zone (RRZ). SSG considered that there was no measurable environmental impact associated with this event. ERA made personnel aware of their environmental responsibilities, the bund was repaired, and the area recontoured to avoid water collecting on the road again. No significant environmental impact.
Mid–June 1998	Difficulties experienced in analysing water samples for Pb-210, Po-210 and Th-230 meant that they were not reported in the non- RRZ Water Release Report for 1997/98. ERA committed to report these results once received. No environmental implications were expected as all other chemical indicators were consistent with previous years and well within prescribed limits. No significant environmental impact.