Application of national water quality guidelines in mine regulation at Ranger mine, Australia

Iles, Michelle

Office of the Supervising Scientist, Supervising Scientist Division, Australian Government Department of the Environment and Heritage.
GPO Box 461, Darwin, NT, Australia 0801
E-mail: michelle.iles@deh.gov.au
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ABSTRACT

The Environmental Requirements (ERs) for the Ranger uranium mine are the Commonwealth of Australia's conditions for environmental protection and rehabilitation attached to the Authority to mine and mill uranium at Ranger – a mine surrounded by World Heritage listed Kakadu National Park in Australia’s Northern Territory. The ERs specific to water quality require that discharged waters must not compromise the environmental objectives. They also direct the Supervising Scientist to determine background water quality for key variables, against which change can be detected, in the main creek traversing the mine.

National water quality guidelines were implemented to determine background values of the key variables and, through an integrated monitoring and assessment program, to identify and assess the ecological significance of changes in water quality. To protect the aquatic ecosystem a hierarchy of management or compliance trigger values for each key variable was set, based on local biological effects and local reference site data. Reporting and investigative responses were prescribed for each trigger level.

BACKGROUND

Energy Resources of Australia’s Ranger Mine is situated in the Alligator Rivers Region (ARR) of the Northern Territory of Australia. The ARR is an area of about 28 000 km^2 located approximately 220 km east of Darwin (see Figure 1.1). It includes the World Heritage listed Kakadu National Park and parts of west Arnhem Land, all Aboriginal-owned lands. The Ranger Project Area lies within, but does not form part of, Kakadu National Park. Several mineral leases and historic uranium mines are also situated in the ARR.

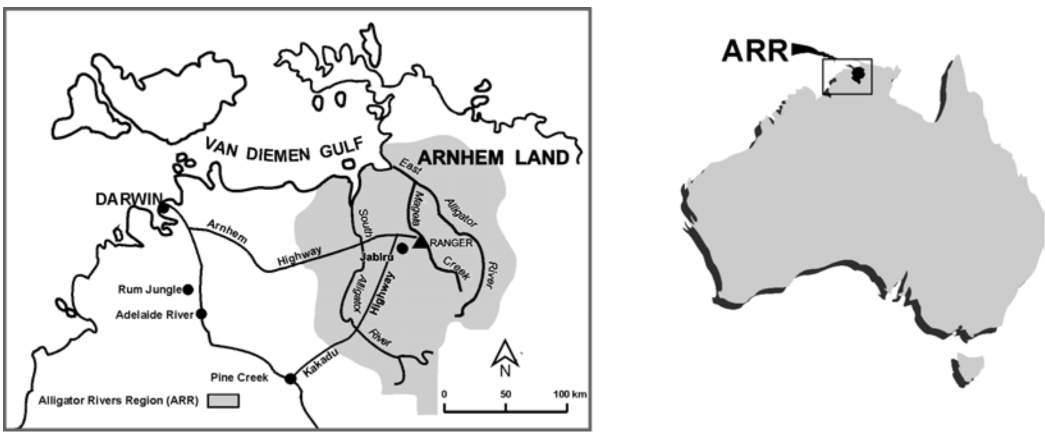

Figure 1: Location of the Alligator Rivers Region (ARR)

Uranium mining regulation in the ARR

The Supervising Scientist Division of the Australian Government Department of the Environment and Heritage undertakes environmental research into, and supervision of, uranium mining in the ARR. The position of Supervising Scientist is established in the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* (the EPARR Act).

The Northern Territory Department of Business, Industry and Resource Development (NTDBIRD) regulates uranium mining activities in the Northern Territory (NT) under its own legislation. However, under the EPARR Act, the Supervising Scientist coordinates and supervises the implementation of laws relevant to environmental aspects of uranium mining in the ARR and develops standards, practices and procedures to protect the environment and people from potential impacts of uranium mining.

Those relevant laws include the Ranger Environmental Requirements (ERs) issued under Section 41 of the *Atomic Energy Act 1953*. The ERs set out the Commonwealth's environmental protection conditions with which the company must comply (these are implemented through Northern Territory legislation and instruments). ER 3.3, related to water quality, instructs the Supervising Scientist to determine background values for water quality in Magela Creek and requires action if that water quality changes as a result of mining operations.

ESTABLISHING WATER QUALITY CRITERIA

Magela Creek flows past the Ranger mine into a series of billabongs and floodplains. A compliance point is located several kilometres downstream of the mine, inside the project area. Water quality standards, in the form of a hierarchy of values that trigger increasingly stringent management responses ("trigger values"), had previously been set for key variables in Magela Creek (Klessa 2001) to provide a framework for detecting, interpreting and acting on changes in water quality.

An extensive review of those trigger values was recently undertaken (Iles 2003 & 2004) to align the process with key elements of the National Water Quality Management Strategy. Major stakeholders, representatives of Commonwealth and Territory Governments, the mining company and the Northern Land Council (which represents the Aboriginal Traditional Owners of the area), were involved in the process.

National Water Management Stratetgy

The Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand developed the National Water Quality Management Strategy (ANZECC & ARMCANZ 1994) to provide a consistent framework for the management of water resources across Australia. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality – the "*Guidelines*" –were developed (ANZECC 1992) and revised (ANZECC & ARMCANZ 2000) to provide a strategic approach for implementing the broad national management strategy at a local level.

The five-step management framework recommended in the revised *Guidelines* was used to establish water quality objectives in a manner that was consistent with the National Water Management Strategy, satisfied the Ranger ERs and met stakeholder expectations. Environmental values recognised in the *Guidelines* are: Aquatic Ecosystems; Primary Industries (including aquaculture and human consumption of foods); Recreational & Aesthetics; Drinking Water; Industrial Water; and Cultural and Spiritual Values. The Supervising Scientist Division carries out a range of programs to address a number of these environmental values. However, from this point this paper deals with establishing water quality guidelines and objectives to protect Aquatic Ecosystems. Each step in the process is briefly described.

Step 1: Define the primary management aims

The first step is to define the water body, determine the environmental values to be protected and the level of protection to be assigned, identify the environmental concerns and determine management aims.

The ‘water bodies’ are the channels, billabongs (seasonal and permanent) and extensive floodplains of Magela Creek downstream of the mine (the area to be protected) defined and characterised by many studies carried out over the years. Potential environmental concerns for these water bodies are chemical uptake and bioaccumulation, toxicity and radiation doses to the downstream biota and Aboriginal population, increased turbidity and sedimentation and changes in chemical and physical parameters.

The high conservation/ecological value aquatic ecosystems were identified as the dominant environmental value to be protected. Apart from human health values, stakeholders also recognised ‘Cultural and spiritual values’ as an environmental value to be protected, however, strategies on how to define and protect this value need to be developed. Minimising physical and chemical change as much as practicable in line with Aboriginal wishes, as discussed below, is one strategy.

The *Guidelines* recommend managing a high conservation/ecological value system so that, relative to a reference condition (i) the values of the indicators of biological diversity should not change, and (ii) there is no detectable change in the levels of chemical and physical stressors and toxicants – this latter condition can be relaxed where there is considerable biological assessment data showing that such changes will not affect biological diversity in the system.

Protection of the biodiversity is the primary management aim for Magela Creek. However, although many years of monitoring has shown that changes in some chemical and physical stressors and toxicants have not affected the biological diversity, Aboriginal Traditional Owners of the area do not support relaxing this second condition. Therefore, minimising physical and chemical change as much as practicable, regardless of biological effects, became the secondary aim.

Step 2: Determine appropriate Water Quality Guidelines

Water quality guidelines describe, numerically or literally, the water quality appropriate to support the environmental values of the system.

Water quality variables of importance were identified in assessments conducted prior to, or in the early stages of mining (eg Supervising Scientist 2003). Those for which guidelines were needed were identified on the basis of being; (i) indicators of a mining signal (weathering products magnesium, sulphate, EC), (ii) process additives (manganese), (iii) potential toxicants/stressors (uranium, magnesium, turbidity), (iv) parameters able to influence toxicity of potential contaminants (pH, calcium) or (v) potentially detrimental to human health (radium-226)[1] (Klessa 2001).

Details of how site-specific guidelines and objectives were determined for these variables are given below.

Step 3: Define Water Quality Objectives

Water Quality Objectives are based on scientifically derived guidelines and modified by other inputs such as social, cultural, economic or political constraints. They are numerical values or statements that can be incorporated into water quality management plans and can be measured and reported against.

Details of how site-specific objectives were agreed upon by stakeholders are given below.

[1] Annual release loads, set for some other elements and measured at point of exit, were not part of this review.

Step 4: Establish Monitoring and Assessment Program

The mining company, the Northern Territory Department of Business, Industry and Resource Development and the Supervising Scientist Division have been monitoring/researching the area, including Magela Creek, for over twenty years.

Through a technical committee, stakeholders regularly assess and direct the company's monitoring program and environmental performance.

The Supervising Scientist Division surface water monitoring program comprises a mix of chemical and biological early warning components (eg regular water sampling, creek-side toxicity testing and bioaccumulation studies) and biodiversity assessments for long-term change assessments (eg fish and macroinvertebrate community structures). Full details of the program are available from Humphrey *et. al.* (1999) and van Dam *et. al*. (2002).

Step 5: Initiate appropriate management response

Appropriate responses based on meeting water quality objectives have been agreed amongst stakeholders. A three-tier approach of increasingly stringent management actions in response to Magela Creek water quality has been operating for several years. It is described below.

Local water quality management

Deriving local science-based guidelines

ANZECC & ARMCANZ (2000) recommend deriving guideline values for physical and chemical stressors and toxicants using, in order of preference, (1) local biological effects data, (2) local reference site data, or (3) the default values provided (based on regional reference data or global biological effects data).

The derivation of local radium limits (based on human health protection in accordance with International Commission on Radiological Protection recommendations) are described elsewhere (Klessa 2001, Sauerland *et. al.* 2003), and a toxicity-based guideline for magnesium (incorporating the influence of calcium) is still being finalised. Guidelines for the other key variables were derived from biological effects or reference site data.

For uranium, Hogan *et. al* (2003) determined a high-reliability site-specific toxicity value from toxicity data for five local species from four taxonomic groups using a species sensitivity distribution approach (modified from the methodology of Aldenberg & Slob (1993)) recommended and described in the *Guidelines*.

The 'No Observed Effect Concentrations' (NOEC) from direct toxicity tests for each of the five species (table 1) are plotted on a log-logistic[2] probability plot (figure 2). The central line through the toxicity data in figure 2 represents the line-of-best-fit. The dotted line (from y = 1) points to the uranium high-reliability trigger value of 6 μg/L, which is the concentration predicted by the log-logistic model to protect at least 99% of species in Magela Creek. The curved lines around the fitted line represent the 95% confidence limits. The 99% protection level (y = 1) on the lower 95% confidence limit is 0.3 μg/L, on the lower 80% confidence limit (not shown) it is 0.9 μg/L.

[2] The data fitted that distribution better than several others tested.

Table 1 Summary of chronic toxicity of uranium in Magela Creek water to local species (from Hogan *et. al*. 2003)

Species	Test endpoint	NOEC (μg/L)	Reference
Moinodaphnia macleayi	Reproduction (3 brood)	18 [a]	***eriss*** unpubl, Semaan (2001)
Chlorella sp.	Cell division rate (72 h)	117[a]	Hogan et al (2003)
Hydra viridissima	Population growth (96 h)	183[a]	Hyne et al (1992)[b]; ARRRI 1988
Mogurnda mogurnda	Mortality (7 d exposure / 7 d post-exposure)	400	Holdway (1992)
Melanotaenia splendida inornata	Mortality (7 d)	810	Holdway (1992)

[A] Toxicity values represent geometric means from ≥ 2 tests. [b] Publication presented nominal concentration, therefore, measured concentrations from eriss records were used for TV derivation.

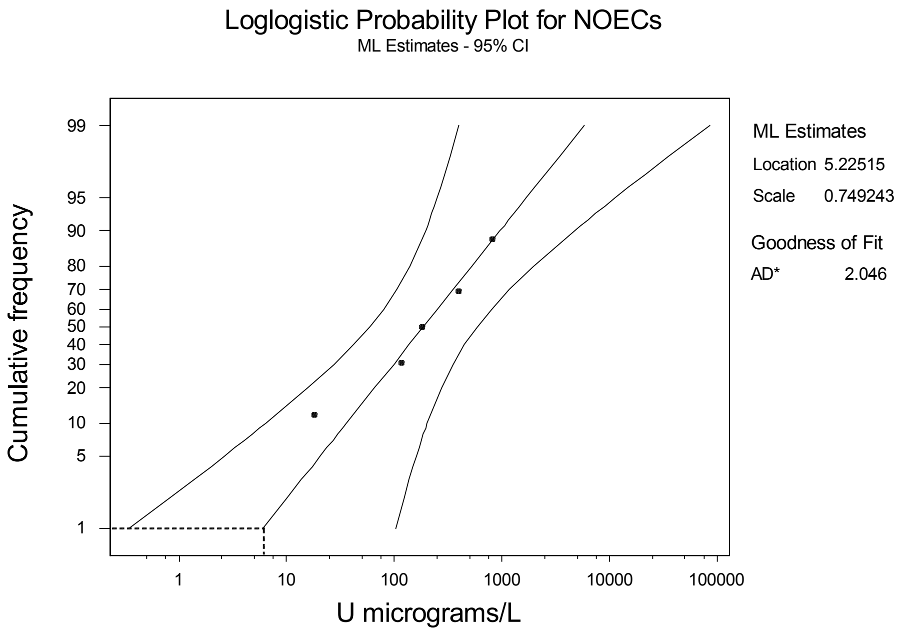

Figure 2: Probability plot of uranium NOECs for Magela Creek species (from Hogan *et al*. 2003)

For pH, EC, turbidity, manganese, magnesium and sulfate 80th, 95th and 99.7th percentiles were calculated from 10 years (1993–2003) of reference site data. For pH, low values are also a concern so 20th, 5th, and 0.3rd percentiles were also calculated. These percentiles are distribution independent near-equivalents of one, two and three standard deviations around a mean respectively and so represent the three smallest steps of change statistically detectable in datasets that are not normally distributed, the status of most of the water quality data.

The percentiles were displayed over ~20 years of downstream data as a control chart (eg Figure 3) to determine how often the downstream data exceeded the reference site percentiles. If the percentiles are exceeded with the frequency statistically expected (20, 5 and 0.7% assuming identical distributions between the two sites), for the three respective percentiles, they provide suitable guidelines for identifying change from background values if it occurs.

Exceedances more frequent than statistically expected indicate that a change from background has already occurred. This is the case for uranium, EC, magnesium and sulphate.

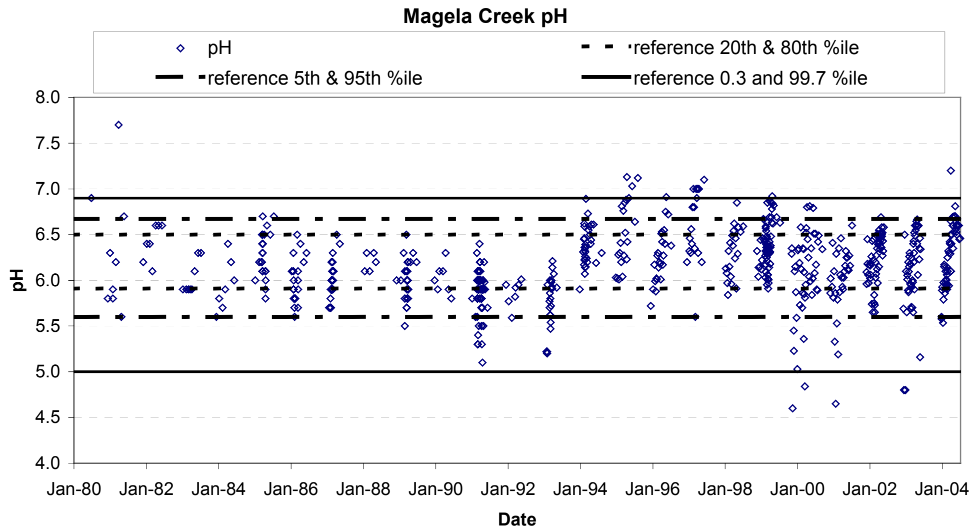

Figure 3: Historic downstream pH overlaid with reference site dataset percentiles. The percentiles, exceeded with the frequency expected, provide a good management guide for change in water quality.

Guidelines to objectives

The scientifically rigorous and defensible local guidelines discussed above were presented to a Technical Committee of stakeholders for discussion. Economic, political and cultural aspects were considered by the committee in modifying the guidelines to become water quality objectives.

- Achieving reference site conditions during the life of the mine is not realistic for some parameters and the numeric triggers based on reference site data need to be relaxed for the approach to be useful for managing water quality. On the other hand, the Aboriginal Traditional Owners of the area do not want to see any change to the natural water quality.

To reconcile the above opposing issues, the system of having numerical values alone as water quality objectives was expanded. Coupled numerical and narrative water quality objectives (table 2) were developed which support both the scientific objectives of data interpretation and ecosystem protection assessment, and, the secondary management aim of minimising water quality changes downstream of the mine.

The numerical objectives form a hierarchy of values that trigger increasingly stringent management responses, they are known as ‘focus’ action’ and ‘guideline’ or ‘limit’ trigger values. Focus, action and guideline triggers are based on local water quality data. Limits apply when the value is based on local biological effects data (from ecotoxicological testing) or dietary modelling (as for uranium and radium respectively). The actions provoked by these ‘trigger values’ are described in a later section.

Uranium trigger values

For uranium the high-reliability site-specific toxicity value was adopted as a ‘limit’, i.e. as a maximum permissible level not to be exceeded as a consequence of mining.

For reactive and precautionary management purposes, values that trigger investigative or corrective action were needed to ensure maintenance of water quality suitable to the primary (biodiversity) management aim. Due to elevated uranium concentrations in Magela Creek downstream of the mine the reference site data percentiles are not meaningful reactive management guidelines – they would be continuously exceeded at concentrations not detrimental to achieving the primary management aim.

Although elevated relative to the reference site, downstream uranium concentrations are still more than a magnitude lower than the ecotoxicity limit. The lower 80th and 95th confidence limits of the ecotoxicity value (figure 2) are equivalent to concentrations that have occasionally been measured downstream but which biological monitoring has shown does not have detrimental effects on ecosystem health. Therefore, lower 80th and 95th confidence limits (at the 99% species protection level) of the ecotoxicity trigger value were adopted as the 'focus' and 'action' trigger values.

Other trigger values

Where reference site data percentiles provide a useful tool for identifying change, numeric objectives, based on the 80th, 95th and 99.7th (and the 20th, 5th and 0.3rd for pH) percentiles were adopted as the 'focus', 'action' and 'guideline' trigger values. This approach was adopted for pH, manganese and turbidity.

Magnesium, sulfate and EC are elevated at the downstream site so reference site percentiles would be continuously exceeded at concentrations shown not to be detrimental to achieving the primary management aim. Trigger values for these variables were based on percentiles of a dataset that included some local sites with elevated concentrations of these variables that biological monitoring had showed did not affect the primary management aim. Narrative statements coupled to the trigger values address the secondary management aim of minimising change. This is interim measure until a toxicity based guideline for magnesium is available.

An example of water quality objectives using each of these approaches is given in table 2.

Parameter	**Objective**	**Trigger values**
pH	To retain the natural distribution of pH in Magela Creek and report and act on any trigger value exceedances.	Focus: 5.9 & 6.5 Action : 5.6 & 6.7 Guideline: 5.0 & 6.9
EC	To (i) report and act on any exceedances of the focus, action and guideline trigger values, and (ii) to sustain the improved water quality seen in the last two wet seasons when practical.	Focus: 21 μS/cm Action 30 μS/cm Guideline: 43 μS/cm
Uranium	To (i) report and act on any trigger value exceedances, and (ii) to sustain the lower uranium concentrations measured in the last two wet seasons when practicable.	Focus: 0.3 μg/L Action 0.9 μg/L **Limit**: 6. μg/L

Table 2: The Water Quality Objectives for Magela Creek

Management responses

The responses invoked by an exceedance of a trigger value are described below. Exceedances will occur occasionally due to natural variation in the water quality so interpretation of notifiable high values should take account of the composition of samples taken upstream. Reports are to the Supervising Scientist, NT Department of Business, Industry and Resource Development and the Northern Land Council.

Exceedance of a focus trigger

Values that are higher than the focus level but lower than the action level will result in a watching brief. A watching brief involves keeping an eye on the data in the coming weeks, or further sampling, to verify whether an upward trend is occurring. An exceedance of a focus trigger does not have to be reported immediately but shall be reported in the Weekly Water Quality Report.

Exceedance of an action trigger

Values that are higher than the *action* level but lower than the *guideline/limit* must be reported immediately and will result in an *investigation* of the cause and *correction* of the cause if mining related. An explanation of the cause (and any corrective action taken) will follow in the Weekly Water Quality Report

Exceedance of a guideline

The company shall treat values in excess of the *guideline* the same as a *limit* exceedance except when there is a corresponding increase at the upstream site. Then, a *guideline* exceedance will be treated as for an *action* exceedance.

Exceedance of a limit

Values in excess of the *limit* must be reported immediately both verbally and in writing. The company will also provide a detailed written report as soon as practical detailing; all relevant data, the circumstances surrounding the exceedance, the corrective actions taken to date; and options for further corrective action.

If in the opinion of the Supervising Scientist the exceedance of a limit is due to operations at Ranger the Supervising Scientist will advise the (Commonwealth) Minister of the circumstances surrounding the exceedance and whether there has been a breach of the Ranger ERs.

FURTHER WORK

The approach to deriving water quality objectives and management trigger values adopted for water quality management and interpretation during the operating life of Ranger mine could be further developed for application during the rehabilitation of the site and ultimately as closure criteria. One approach could be to establish a spatial and a temporal transect of numeric and literal objectives that become stricter along the transect.

Cultural and spiritual values of the area should be identified with the Traditional Owners and water quality objectives developed based on indigenous knowledge and wishes. Methods to identify and monitor these objectives will be needed. The New Zealand 'Cultural Health Index' approach (Tilba & Tierney 2003) is one that can be considered.

CONCLUSIONS

Commonwealth regulations concerning uranium mining at the Ranger mine require background water quality values to be determined and necessitate a framework to identify water quality changes downstream of the mine.

Water quality guidelines based on the distribution of the upstream reference site or ecotoxicity data were derived for Magela Creek in line with the Australian and New Zealand Water Quality Guidelines (ANZECC & ARMCANZ 2000). Socio-political aspects were considered and the scientifically rigorous guidelines were modified to numerical and literal objectives that reflect the management aims agreed to by a committee of representatives of the Northern Territory and Commonwealth Governments, the mining company and the representatives of the Aboriginal Traditional Owners of the area.

The approach adopted satisfies the Commonwealth requirements of the Supervising Scientist, is in line with the National Water Management Strategy and satisfied stakeholder expectations. A similar approach should be suitable for deriving water quality objectives for the rehabilitation and closure stages of mining. Work is needed on approaches to protect the cultural and spiritual values of the area.

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