

Water Quality, Water Management and the Ranger Uranium Project: Guidelines, Trends and Issues

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Abstract This paper explores the regulation of water quality protection downstream from the Ranger Uranium Project in the Alligator Rivers Region, an area of high conservation value which is both World Heritage- and Ramsar-listed. Available historical monitoring data for surface water quality in Magela Creek downstream of Ranger have been compiled and analysed with respect to hydrologic data and the Australian and New Zealand Environment and Conservation Council–Agricultural and Resource Management Council of Australia and New Zealand (ANZECC–ARMCANZ) regulatory guidelines, introduced in late 2000. The paper focuses on the underlying scientific basis for the current approach and examines the complex inter-relationships of minesite water management, hydrology, climate, monitoring design, implementation and interpretation which are used to differentiate between natural variability and potential mine-derived solutes. The research found that the application of the ANZECC–ARMCANZ guidelines has clearly improved the

regulation of water quality protection downstream from the Ranger Uranium Project. The scientific basis is more coherent than the previous regulatory regime; however, for U (a key parameter of indigenous Mirarr-Gundjehmi and public concern), higher downstream concentrations are permitted than those observed through natural variability, leaving open the potential for an influence of mine-derived U loads while still being within regulatory limits. Another improvement that could be made to the current regulatory regime, to provide enhanced protection of the water quality in Magela Creek downstream of Ranger, would be to explicitly link the water quality monitoring regime with hydrologic flow conditions. The paper makes a valuable case study for the application of water quality guidelines, especially for controversial projects such as uranium mining surrounded by a World Heritage- and Ramsar-listed region on indigenous land—a context of clear relevance for many places around the world.

Keywords Water quality · Regulation · Uranium mining · Water management · Water pollution

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1 Introduction

The potential and actual impacts on surface water quality from the Ranger Uranium Project in the Alligator Rivers Region (ARR) of the Northern

Territory (NT), northern Australia (shown in Fig. 1), have long been a contentious issue. The ARR comprises living culture with various indigenous groups still maintaining close connections to the land and its resources and includes large regions of wetlands listed under the Ramsar Convention as being of international importance, as well as the World Heritage Kakadu National Park—a rare site in that it is listed for both cultural and natural heritage. The region is characterised by a tropical wet–dry monsoonal climate. The engineering, scientific and social complexity for managing accumulated waters at a U mine within these constraints is therefore very high (see GAC 2002; Mudd 2005; Kabir et al. 2008).

The Ranger U Project has, to date, operated under a ‘zero release’ water management system. During the summer wet season, all runoff waters contacting uranium-mineralised materials (defined as $>0.02\%$

U_3O_8) are directed to engineered water retention structures, with accumulated water then treated by either land application (spray irrigation) or constructed wetlands during the winter dry season. All process water used in milling is contained, and the only effective option is storage and evaporation.

The regulatory regime for water management at Ranger has changed over the years, especially as scientific research has expanded the knowledge of ecotoxicity of contaminants in local ecosystems. For the first 21 years of Ranger’s operations from 1979 until 2000, water quality in Magela Creek was regulated by a set of prescriptive requirements. That is, specific load limits and water quality criteria were specified in detail. Following the introduction of the significantly revised ‘Australian Water Quality Guidelines’ (ANZECC and ARMCANZ 2000) in October 2000, combined with regulatory amendments for the

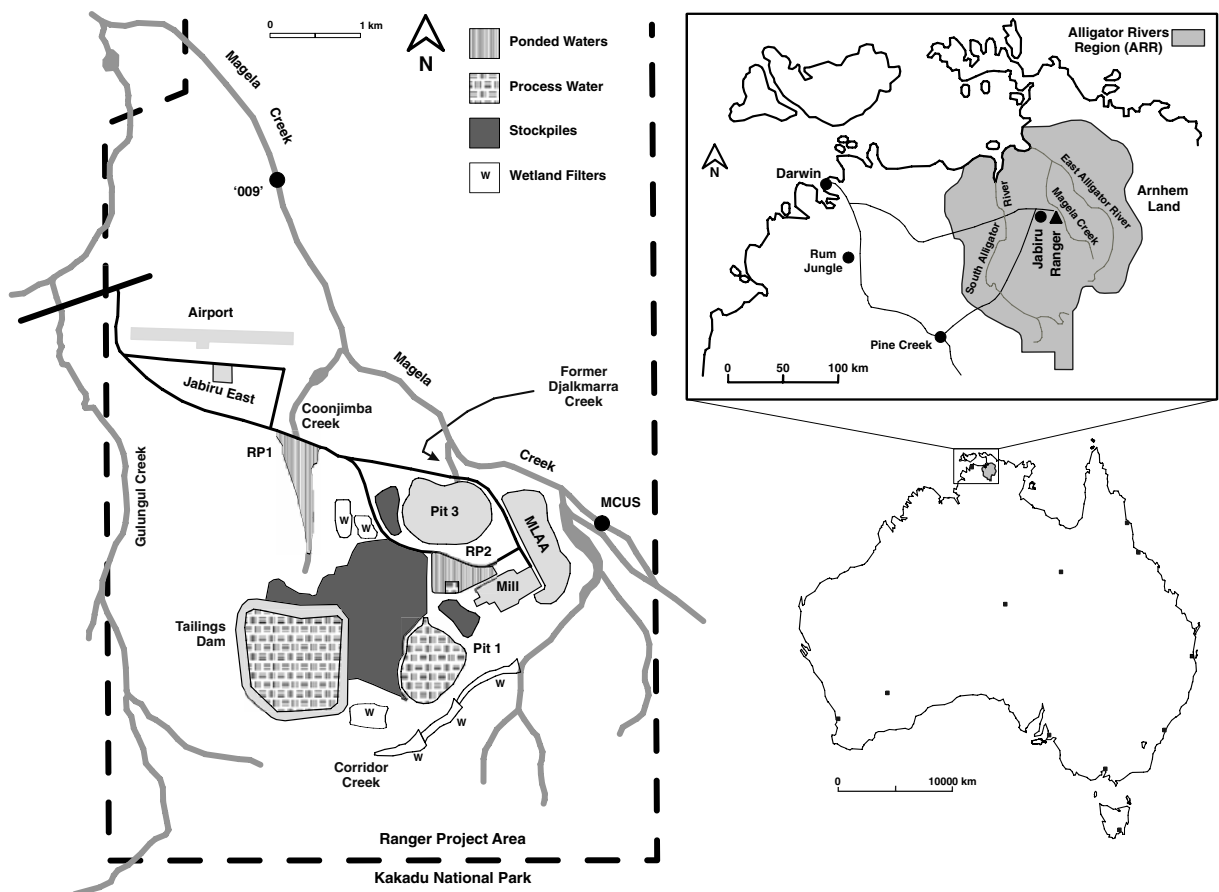


Fig. 1 Location and catchment outline and major water features of the Ranger Uranium Project (adapted from OSS 2002 and Iles et al. 2004)

Ranger project (namely the re-development of the statutory ‘Environmental Requirements’), a new regime for assessing and managing water quality downstream of the Ranger project was introduced based on the Australian and New Zealand Environment and Conservation Council–Agricultural and Resource Management Council of Australia and New Zealand (ANZECC–ARMCANZ) guidelines.

The new regime involves the establishment of a three-tier trigger system for water quality, based on natural variability and/or ecotoxicologically derived concentrations intended to provide a high degree of protection for biodiversity. The fundamental issue in the assessment of water quality downstream of Ranger is the ability to distinguish between natural variability and potential mine-derived solutes. In theory, the new regime provides this ability but the application of the triggers remains contested, due principally to different interpretations of ‘environmentally significant’ concentrations of solutes such as Mg, SO₄ and U. The issue of source differentiation is critical when assessing the ‘first flush’ of a wet season when solutes are often present in elevated concentrations due to low flows and localised areas of acid sulphate soils (especially some billabongs or wetlands).

This paper compiles the available historical monitoring data for surface water quality in Magela Creek downstream of Ranger and analyses these data with respect to hydrologic data and the revised regulatory regime introduced in late 2000. The paper is not a comprehensive account of the entire history of mine site water management, water quality monitoring, assessment and regulation—as this would be an extremely broad and substantive endeavour. Further, the paper does not seek to retrospectively judge regulatory performance by applying a new regime to old time periods—rather it utilises historical data sets to inform understanding of hydrological processes affecting water quality and the current regulatory regime (this was also the approach for justifying the current regime). The paper focuses on the underlying scientific basis for the current approach and examines the complex inter-relationships of minesite water management, hydrology, climate, ecotoxicology, monitoring design and implementation and interpretation which are used to differentiate between natural variability and potential mine-derived solutes. The paper should therefore make a valuable case study for

the application of the ANZECC–ARMCANZ guidelines, especially for controversial projects such as U mining surrounded by a World Heritage- and Ramsar-listed region on indigenous land of the Mirarr-Gundjeihmi people. The outcomes are of clear relevance for many similar projects and contexts around the world.

2 Brief Historical Background

The Alligator Rivers Region was still very remote in the 1960s and was occupied by numerous indigenous groups mixing traditional living with part-time pursuits in pastoral activities and other minor industry in the area (Lawrence 2000). Due to the perceived environmental values of the ARR, a proposal for a major national park was first put forward in 1965 but not agreed upon, though debate and lobbying continued. The Ranger uranium deposits were first indicated by aerial radiometric surveys in October 1969. Field work quickly proved the existence of a large uranium prospect and work began in earnest, with the nearby Nabarlek, Koongarra and Jabiluka uranium deposits subsequently discovered over 1970 to 1973.

When the Ranger Uranium Project was formally proposed in February 1974 (RUM 1974), it argued the need for direct release of excess mine site waters into the adjacent Magela Creek during the wet season and that dilution and mixing during this time would be sufficient to minimise any potential ecological effects (e.g. pp. 61–62). The project was very controversial and then the Federal Labour government through Environment Minister Dr Moss Cass, in conjunction with Prime Minister Gough Whitlam, instituted the Ranger Uranium Environmental Inquiry (RUEI) in July 1975 to examine the issues of uranium mining, nuclear power, land rights and conservation in detail. In its second and final report (Fox et al. 1977), RUEI examined this proposed water management regime in great detail—especially with regards to the significant unknowns of ecotoxicity and potential environmental impacts. As the region had received scant environmental and biological research by this time, these issues were not taken lightly by the RUEI (especially given the severe acid mine drainage problems at the former Rum Jungle U mine, just south of Darwin; Mudd and Patterson 2010).

The final regime endorsed by the RUEI was for an interim ‘zero release’ water management regime for Ranger until such time as further scientific research could more accurately assess the potential ecotoxicological effects, bioaccumulation issues as well as potential human health issues (principally radium or ^{226}Ra) associated with water releases (D&M 1985; Riley 1991). The RUEI also recommended that, if water releases were to occur, they should be strictly controlled to minimise both the load and concentration of contaminants, as well as ensuring that the flow in Magela Creek was $>20\text{ m}^3/\text{s}$ at gauging station GS8210009 (‘009’) and continuous from Jabiru to the northern floodplains to minimise entrapment of discharged waters in billabongs and wetlands at the end of the wet season (see RUEI Recommendations 6.6 to 6.10, 7.5, 17.13, 17.16 to 17.21).

In order to achieve the extent of scientific research needed, the RUEI also recommended that a specific Commonwealth agency be established, known as the ‘Office of the Supervising Scientist’ (OSS), to undertake this work and advise of relevant environmental and radiological protection issues.

The Ranger project was formally approved in January 1979 and constructed over 1979 to 1981 on an interim ‘zero release’ basis. The mine consisted of four principal water management zones: (a) process water used in milling (the tailings dam and retention pond 3 (RP3)), (b) mine site runoff water which had been in contact with uranium-mineralised stockpiles (ore and low-grade waste containing $>0.02\%$ U_3O_8 ; water discharging to retention pond 2 (RP2)), (c) pond water containing water derived from runoff from non-mineralised stockpiles and mine-impacted catchments (retention pond 4, RP4), and (d) runoff water from relatively undisturbed catchments (retention pond 1 (RP1), or discharge to adjacent stream lines such as Corridor and Gulungul Creeks). An outline of these water management features for the Ranger project is included in Fig. 1.

The potential for discharge of accumulated RP2 and RP4 waters remained contentious, however, and by the mid-1980s, the issue again came to prominence. This followed several years of further experience in the ARR and the realisation that the average rainfall for the region was higher than originally expected. Annual rainfall, measured locally, was 1,565 mm versus a design value of 1,400 mm while evaporation was slightly lower (2,561 mm pan

evaporation times pan factor of 0.80 versus design value of 2,577 mm pan evaporation times pan factor of 0.85; D&M 1985; see also OSS-AR 1983, p. 25; Armstrong and Reid 1980). For comparison, RUM (1974) expected annual rainfall of 1,100 mm and pan evaporation of 2,700 mm (p. 16). This positive increase gave rise to serious problems with respect to the hydrologic water balance upon which the original water structures and regime were designed. Annual rainfall variability was also a key issue, with Ranger actually importing nearly 2 million m^3 of water from Magela Creek and nearby borefields between October 1982 to September 1983 due to a low rainfall wet season during 1982/1983 (D&M 1985; Riley 1991). Further complications arose due to the lower settled tailings density and the pumping of water from ponds to the tailings dam during the wet season (D&M 1985).

The waters from RP4 were commonly viewed as mildly turbid waters with only slightly elevated solutes compared to the ambient concentrations in Magela Creek (since it was excluded from capturing waters which contacted U-mineralised materials). As such, RP4 water was authorised for regular discharge through the Djalkmarra wetlands and hence to Magela Creek from the 1983/1984 wet season (excluding an earlier release from RP4 in February 1980 during construction; Malatt 1989; OSS-AR 1984; Armstrong and Reid 1980). There could be no direct release of process water (i.e. tailings dam and RP3 waters).

A technical working group comprised of Ranger, Northern Territory and Commonwealth representatives proposed that direct release of RP2 water, the largest water inventory with environmentally significant concentrations of U, Mg and SO_4 , was acceptable and could also be combined with the use of land application (or spray irrigation; Riley 1991; Johnston and Needham 1999). The expected frequency of RP2 releases was approximately every few years. The potential discharge of RP2 waters was still viewed as problematic by many in the broader community, especially Mirarr-Gundjeihmi and other local indigenous people (e.g. OSS-AR 1987, pp. 38–42; Leggate 1984).

During this same time period, research was very active in assessing solute dispersion pathways along the Magela Floodplain system with a view to establishing a scientific basis for the regulation of water quality downstream of Ranger, especially with

respect to proposed direct RP2 releases (see OSS-AR [various](#); ARRI-ARS [various](#)). The issues of water resources monitoring, ecosystem and human health protection and associated water quality standards were the subject of numerous papers at a research workshop in May 1983 (OSS [1983](#)). There was significant debate between the various stakeholders, with both the OSS and the then NT Department of Mines and Energy (DME) each proposing regulatory standards for water quality downstream of Ranger in 1985, with the respective values compiled in [Table 1](#). In essence, the OSS approached water quality from the perspective of receiving water standards and concentrations required to protect human health and the environment (detailed by ARRI-ARS [1985](#), pp. 111–119), while the DME assumed RP2 water releases from Ranger and derived ‘maximum allowable additions’ to concentrations downstream based on anticipated solute loads and implied water quality standards (see OSS-AR [1985](#), pp. 22–25). As can be seen in [Table 1](#), the values are significantly different, with the OSS proposing higher values for Mg, SO₄, Mn and U.

To minimise the accumulated RP2 inventory and reduce the probability of direct release, trial land application (or irrigation) was first undertaken at Ranger between July to December 1985 and its perceived success as a treatment method led to significant expansion of RP2 land application in 1986 (Riley [1991](#)). The main irrigation area was known as the Magela Land Application Area (MLAA; included in [Fig. 1](#)).

The Commonwealth Government decided in late 1987 and re-confirmed in 1989 that direct release of RP2 waters was not preferable (after considering social issues), although if the conditions were appropriate then a release under high flow scenarios could occur approximately once every 10 years (Riley [1991](#); Johnston and Needham [1999](#)). To ensure this low water release frequency could be achieved, RP2 was increased in storage capacity by 0.36 million m³ (OSS-AR [1988](#), p. 46).

The use of land application formed the principal treatment method of the water management system until the introduction of constructed wetlands to treat RP2 water in 1994 (Jones et al. [1996](#)). In early 1995, Ranger proposed to undertake the first ever direct release of RP2 waters into Magela Creek, but after considerable public concern, this was subsequently

withdrawn. No deliberate direct release of RP2 waters to Magela Creek has yet occurred at Ranger by mid-2009 (though some notable accidental releases of waters from either the tailings water return circuit or contaminated RP1 water have occurred; see Johnston and Needham [1999](#); SECITARC [2003](#)). A concise timeline of water management at the Ranger project is compiled in [Table 2](#), with RP2 water volumes treated by land application or wetlands is shown in [Fig. 2](#).

During 2002, a major inquiry was conducted by a standing committee of the Australian Senate into the environmental regulation of the Ranger uranium mine and then Jabiluka Project (see SECITARC [2003](#)). At this inquiry, a range of concerns was raised by and on behalf of local indigenous land owners, the Mirarr-Gundjeihmi clan, including the spatial and temporal frequency of water quality sampling, the relatively small number of aquatic species upon which the uranium trigger was estimated, the ongoing Mg-SO₄ signature downstream from Ranger and the potential links between water quality and hydrologic flow conditions in the Magela Creek, amongst many others.

The remainder of this paper aims to provide a thorough assessment of water quality issues for the Ranger project to 2004 with respect to hydrologic and natural variability through the application of the ANZECC–ARMCANZ guidelines, as these were key concerns raised during the Senate Inquiry and remain ongoing issues with respect to water quality regulation.

3 Methodology, Data Sources and Analysis

Approach

This section summarises the current approach to water quality assessment (i.e. the ANZECC–ARMCANZ guidelines), the sources of water quality monitoring data for the Ranger Uranium Project and associated issues and presents the analytical approach used to interpret the water quality data, hydrology and overall performance with respect to the regulatory regime for water quality.

3.1 ANZECC/ARMCANZ Water Quality Guidelines

The ‘Australian Water Quality Guidelines’ (ANZECC and ARMCANZ [2000](#)) are the principal standard now applied across Australia to assess and manage water quality in freshwater and marine ecosystems (known

Table 1 Typical water quality monitoring and ANZECC-derived triggers for the Magela Creek downstream of the Ranger Uranium Project (as applied for the 2004/2005 wet season)

ANZECC level	pH	EC ($\mu\text{S}/\text{cm}$)	Mg (mg/L)	SO ₄ (mg/L)	Mn ($\mu\text{g}/\text{L}$)	U ($\mu\text{g}/\text{L}$)	²²⁶ Ra (mBq/L)	Reference(s)
Focus	5.9–6.5 ^b	21 ^c	Use EC ^d	Use EC ^d	7 ^e	0.3 ^f	Not set	
Action	5.6–6.7 ^b	30 ^c	Use EC ^d	Use EC ^d	11 ^e	0.9 ^f	Not set	
Guideline/limit	5.0–6.9 ^b	43 ^c	Use EC ^d	Use EC ^d	26 ^e	6 ^f	10 difference ^b	
Retention pond 1 (1980 to 1999) ^a	6.3–7.7	2.5–500	2.3–28	1–100	<2–37	0.2–10	No data	ERA 2000, 2002
Retention pond 2 (September 2001 to August 2004)	6.0–9.3	1,030–1,785	130–250	500–1,100	10–1,600	2,750–14,800	No data	ERA 2005
Process water (November 1989 to August 2000)	3.9–6.7	8,900–40,000	2,400–10,000	6,700–61,000	710,000–4,200,000	420–3,900	No data	ERA 2000
OSS pre-ANZECC concentrations	5.5–6.5 ^{mean} (statistical)	Not set	20 ^{limit} (ecological)	200 ^{limit} (drinking)	50 ^{limit} (human)	10 ^{limit} (toxicology)	Not set	OSS-AR 1985/1986, pp. 24/71
DME pre-ANZECC maximum allowable additions	Not set	Not set	1.0	19	24	3.8	Not set	OSS-AR 1986, p. 20
Pre-ANZECC loads	Not set	Not set	Not set	Not set	6 tonnes/year	~3.5 tonnes/year ^g	13 GBq/year	OSS-AR 1985, p. 24

^aYears 1999–2004 are excluded due to elevated concentrations caused by runoff from the northern tailings dam wall stockpiles. Note that in the long-term EC, Mg and SO₄ are generally increasing

^bAn lower/upper range is specified for pH to reflect natural variation in water quality processes

^cThis is a combination of statistical analyses of MCUS and 009 data and is intended to provide a compromise between existing water quality impacts, the practicality of dilution variability with each wet season and the desire to work towards the express wishes of the Mirarr traditional owners for no change in water quality

^dDue to the Mg-SO₄ signature at 009 and the results emerging from research into the ecotoxicological effects of the Ca/Mg ratio, EC is used as a surrogate for Mg and SO₄

^eBased on flow in the middle of the wet season due to the seasonal behaviour of Mn in the Magela Creek catchment

^fAs discussed in the text, the initial limit trigger of 5.8 $\mu\text{g}/\text{L}$ was rounded to one significant figure (6 $\mu\text{g}/\text{L}$) for regulatory simplicity

^gBased on human health criteria from a total ²³⁴U and ²³⁸U activity of 88 GBq/year (OSS-AR 1985, p. 24; i.e. as specified in the Ranger Authorisation)

^hRadium standards are primarily considered with respect to human health and radiological exposure assessments, especially through uptake of ²²⁶Ra by species favoured as ‘bush tucker’ by indigenous people

Table 2 Key events and water management timeline for the Ranger Uranium Project

October 1969	Ranger uranium deposits discovered
February 1974	First proposal for direct release of mine site waters as part of the Ranger project
July 1975	Establishment of the Ranger Uranium Environmental Inquiry
October 1976	First report of the Ranger Uranium Environmental Inquiry (mainly focussed on nuclear power and nuclear weapons)
May 1977	Second report of the Ranger Uranium Environmental Inquiry, recommending against direct water release, but if it was to proceed, setting strict guidelines subject to ongoing research
January 1979	Federal approval of the Ranger Project; site construction begins immediately
August 1981	Commercial uranium production begins
1983/1984 wet	Regular discharges from retention pond 4 begin (RP4 contains relatively benign waters)
Late 1985	Land application of retention pond 2 begins (RP2 contains very mildly contaminated waters, mainly Mg, SO ₄ , U and some ²²⁶ Ra)
Late 1987	Federal Government announce their preference against direct release of RP2 waters in to the Magela (unless high flow conditions prevailed)
1989	Federal Government re-confirmed their preference against direct release of RP2 waters in to the Magela; storage capacity of RP2 increased to reduce probability of the need for direct release
1994	Introduction of engineered wetlands to treat RP2 waters; continued use of land applications areas
Early 1995	Proposed RP2 release to Magela Creek, subsequently withdrawn due to public concern

hereafter as the ‘Guidelines’). They are designed to provide a framework to assess and monitor national water quality objectives at a local scale.

The Guidelines are now commonly used as a basis for consistent regulatory approaches to monitor and assess the potential impacts of a project, e.g. uranium mining in a region of high conservation value. They also emphasize the importance of combined biological, physical and chemical indicators in devising any

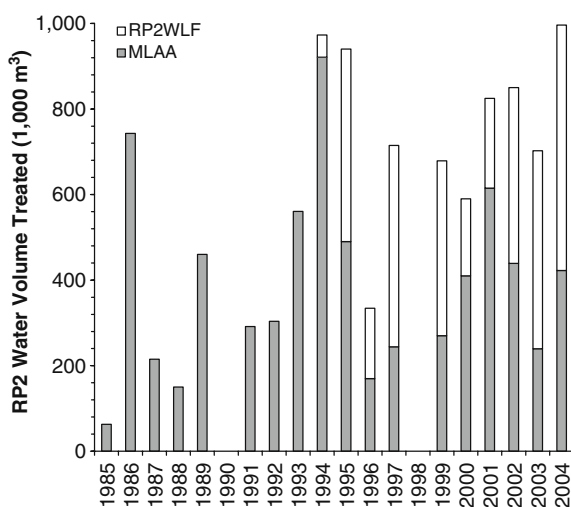


Fig. 2 RP2 water volumes treated by land application or wetlands (1985 to 2004)

management regime. A three-tiered approach to water quality assessment is recommended, using focus, action and guideline (or ‘limit’) values to indicate any increasing variation from baseline or background levels, ideally leading to a more objective assessment of water quality data with respect to potential impacts. A hierarchical approach to setting the values for the water quality triggers is proposed:

- Base maximum allowable limits on ecotoxicological data
- Base management triggers—focus, action and guideline levels—on statistical distributions of reference site data
- If triggers based on reference site data are inappropriate to guide management of water quality, then refer to knowledge of the system, based on extensive chemical and biological monitoring, to adjust the triggers

A more detailed description is given in the Guidelines. Further discussion relevant to Ranger is given by OSS (2002) and Iles (2003). The application of the Guidelines to the monitoring and regulation of the Ranger Uranium Project first occurred in the wet season of 2001/2002, following a detailed statistical analysis of historic data sets by Klessa (2001). The water quality trigger values for Ranger are reviewed and updated regularly by the OSS (e.g. Iles 2003).

3.2 Water Quality Data Sources

The quality of surface water resources around the Ranger Uranium Project has been investigated and monitored since the early 1970s by a variety of groups, principally:

- Ranger Uranium Project (owned and operated by Energy Resources of Australia Ltd (ERA), in turn 68.4% owned by Rio Tinto Ltd)
- Northern Territory Department of Water Resources (now NT Department of Natural Resources, Environment and the Arts)
- Northern Territory Department of Mines and Energy (now NT Department of Regional Development, Primary Industry, Fisheries and Resources)
- Commonwealth Office of the Supervising Scientist (OSS)

The data sets from each organisation are of varying quality, methodological consistency and continuity. The primary data set is derived from statutory monitoring undertaken by ERA, with check monitoring performed by Department of Primary Industry, Fisheries and Mines and more recently additionally by the OSS. The principal period over which good quality data exist is from 1980 to 2004 (monitoring is ongoing; however, data since 2004 are not analysed in this paper due to the timing of this research work). A number of issues arise with such extensive data over this period and include dissolved versus particulate concentrations, changes in detection limits (DLs) over time (generally declining), treatment of DLs in statistical analyses (especially the equivalence of differing DLs), sample or analytical contamination, as well as changes in sampling site locations over time (see Iles et al. 2004). Although there are data available prior to 1980, they are generally accepted as poor quality due to problems associated with sampling and analytical methodologies, especially filtering of particulate matter and whether acidification was used to preserve samples (e.g. Lucas 1983).

For the purposes of this paper, water quality data for the Ranger U Project have been provided by ERA and the OSS. Additionally, hydrological flow data for Magela Creek have been provided by the OSS.

The data and analysis presented in this paper are based only on the statutory compliance point downstream of Ranger, gauging station GS8210009 or '009', as well as the available data for upstream water

quality (MCUS; noting the issues involved with the change of upstream sampling sites over time; Iles et al. 2004). These locations are indicated in Fig. 1.

3.3 Trigger Values as Applied to the Ranger Uranium Project

The OSS, through their role in advising the Commonwealth Government of environmental protection issues for the ARR, periodically reviews and sets the guideline trigger values for key parameters of concern with respect to water quality and/or environmental impacts. The values approved by the OSS as of mid-2004 are outlined in Table 1 (including radium-226, although this is outside the analysis scope of this paper).

Based on the methodology recommended by the Guidelines and the long-term research on toxicology and ecosystem behaviour, the OSS has derived a site-specific ecotoxicological concentration for uranium (van Dam 2000; van Dam et al. 2002; Hogan et al. 2003). The testing used is based on five local aquatic species of different ecosystem trophic levels, namely *Chlorella* sp. (green algae), *Lemna aequinoctialis* (duckweed), *Moinodaphnia macleayi* (water flea), *Hydra viridissima* (green hydra) and *Mogurnda mogurnda* (purple-spotted gudgeon fish). The derived trigger limit of 5.8 µg/L is estimated to protect 99% of aquatic biodiversity, though the limit is rounded to 6 µg/L for regulatory application. For other key solutes, Mg, SO₄ and Mn, trigger values are based primarily on statistical variation and in this case are considered guidelines only and not absolute limits (Iles et al. 2004). Although there is a range of toxicity testing completed for other metals, such as copper and zinc, these are not significant mine-derived solutes and are excluded from the scope of this paper.

3.4 Analysis Approach

The compiled water quality data set has been analysed with respect to the week of the wet season. For each wet season, all concentrations have been assigned a week since the onset of first flow in Magela Creek at 009 (i.e. first flow would be week 1 of that wet season). All data are subsequently analysed graphically utilising four approaches:

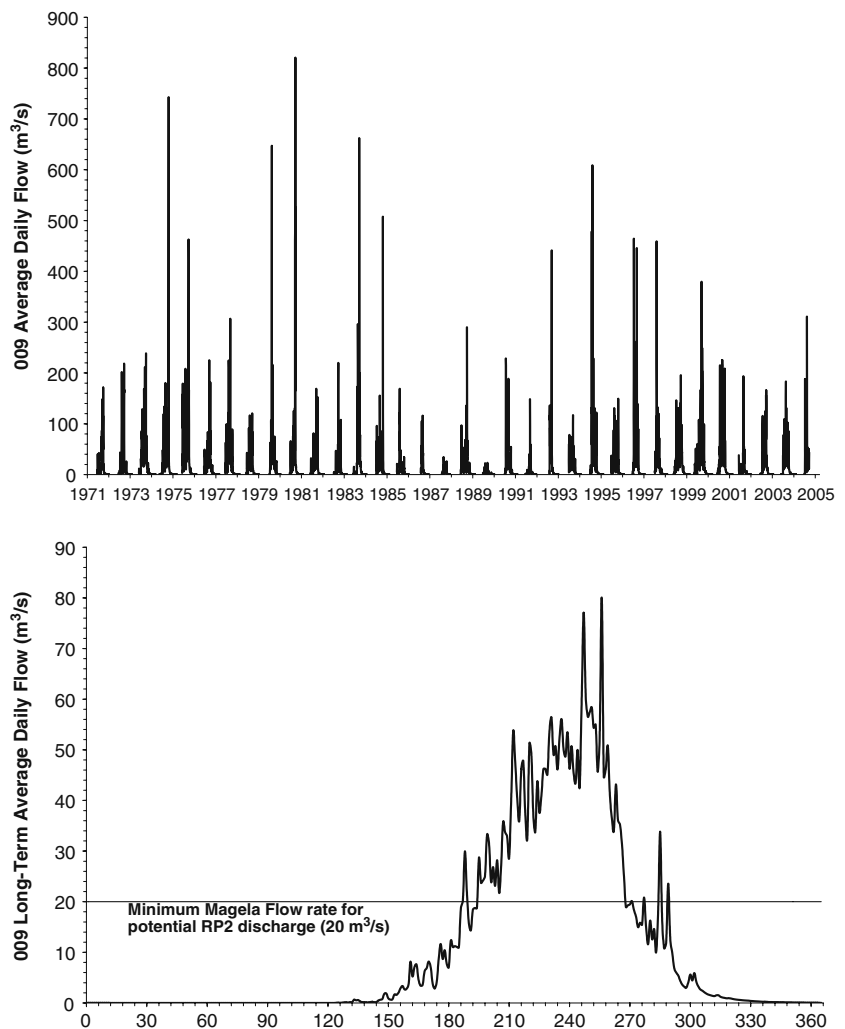
- Time-continuous data (i.e. as monitored, 1980 to 2004)

- Flow and downstream concentrations versus time for the 2000/2001 to 2003/2004 wet seasons
- Downstream concentrations versus assigned week of wet season (data 1980 to 2004)
- Upstream–downstream concentration difference versus assigned week of wet season (for recent years 2000/2001 to 2003/2004)

4 Results

This section makes brief comments on each figure for clarity. The monitored daily flows in Magela Creek at 009 over time and an estimated average daily flow over the available wet season are shown

Fig. 3 Average daily flow in Magela Creek at ‘009’: 1971/1972 to 2004/2005 (*top*); long-term average daily flow over the wet season, plotted as days since 1 July (*bottom*)

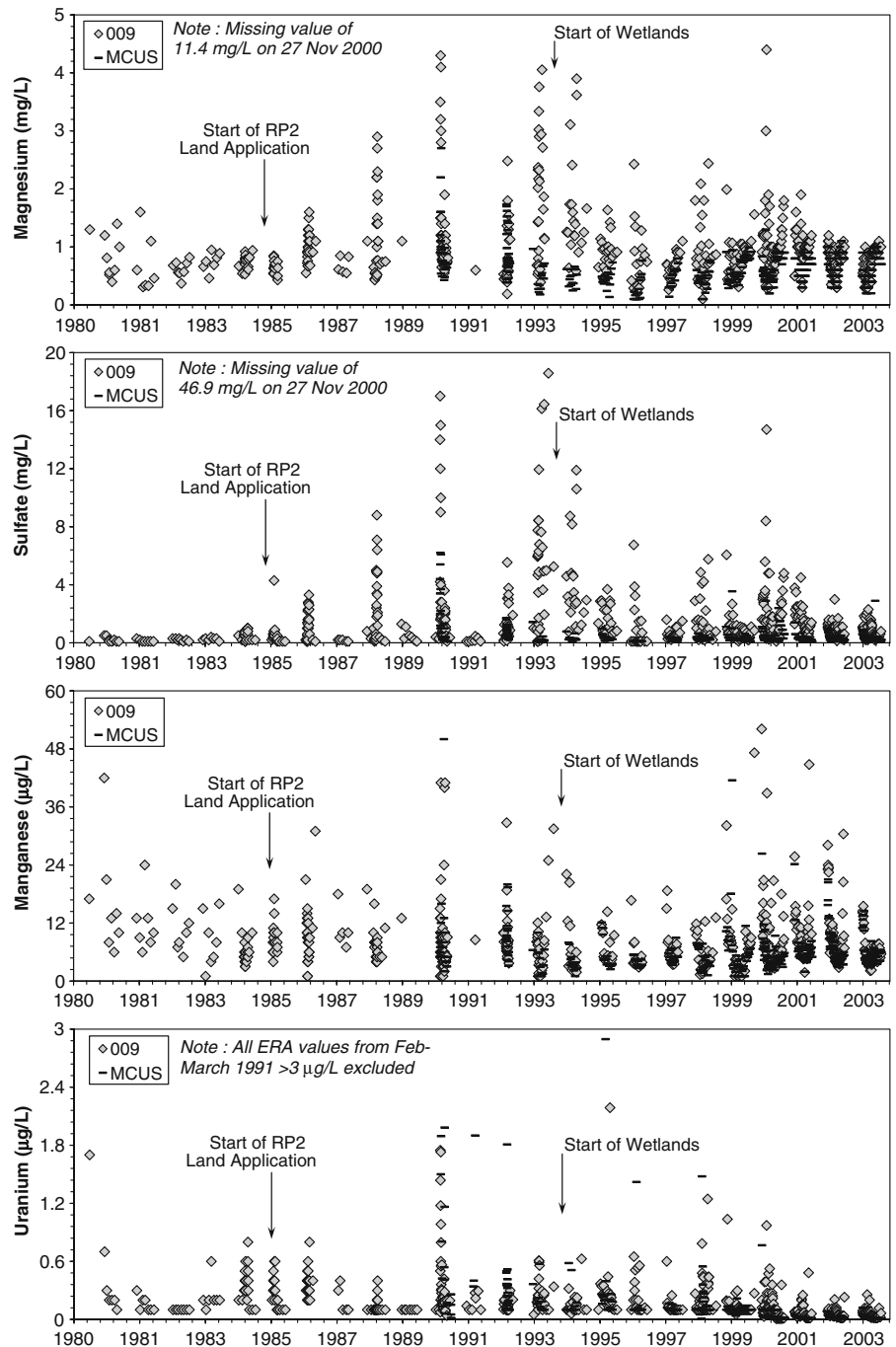


in Fig. 3. The strong seasonality and highly episodic nature of flow events is clearly evident, related to the region’s wet–dry monsoonal climate.

The ERA and OSS monitoring data for 009 and MCUS have been compiled and plotted in time-continuous format in Fig. 4, including Mg, SO₄, Mn and U. The time that land application and wetland treatment of RP2 water commenced is indicated for Mg and SO₄.

The ERA and OSS monitoring data for 009 for the 2000/2001 to 2003/2004 wet seasons have been compiled and plotted with flow rate in Fig. 5. The ERA and OSS monitoring data for 009 have been compiled and plotted versus week of the wet season in Fig. 6 for Mg, SO₄, Mn and U. The

Fig. 4 Water quality of Magela Creek at 009 and MCUS over time



difference in ERA and OSS monitoring data between 009 and MCUS has been compiled and plotted versus week of the wet season in Fig. 7 for Mg, SO_4 , Mn and U. Indicative arrows for broad trends have been included in Figs. 6 and 7, based on visual observation.

5 Discussion

The data compiled and analysed herein on the evolution of water quality management, monitoring and regulation for the Ranger Uranium Project demonstrate a range of issues and complexities and

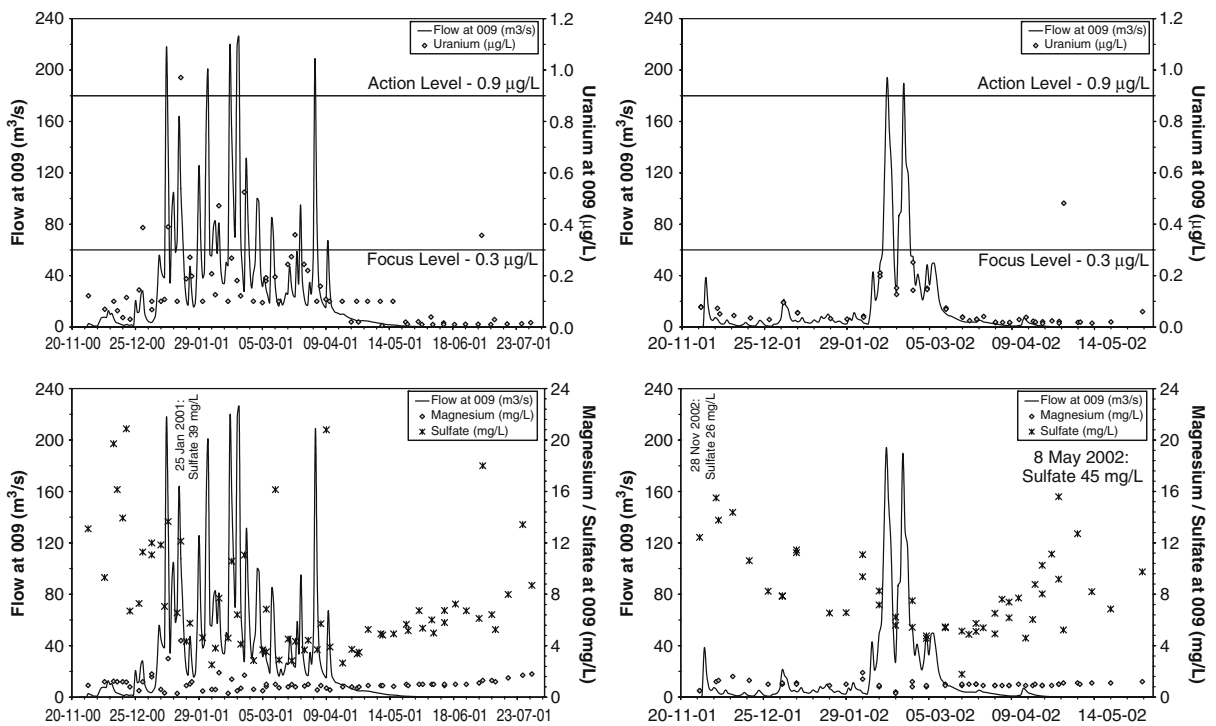


Fig. 5 Flow rate versus Mg-SO₄ and U concentration at 009 for the 2000/2001 to 2001/2002 wet seasons

raise a variety of ongoing challenges. First, the water management system at Ranger has undergone near-continual change and evolution and is presently operating under an engineered regime which was unforeseen by the Ranger Uranium Environmental Inquiry. That is, the Ranger project uses a combination of land application and wetlands to control and reduce minesite water inventories on site to obviate the need for direct release to the Magela Creek (RP2 water treatment by a new water treatment plant has now been implemented after the period of review for this paper).

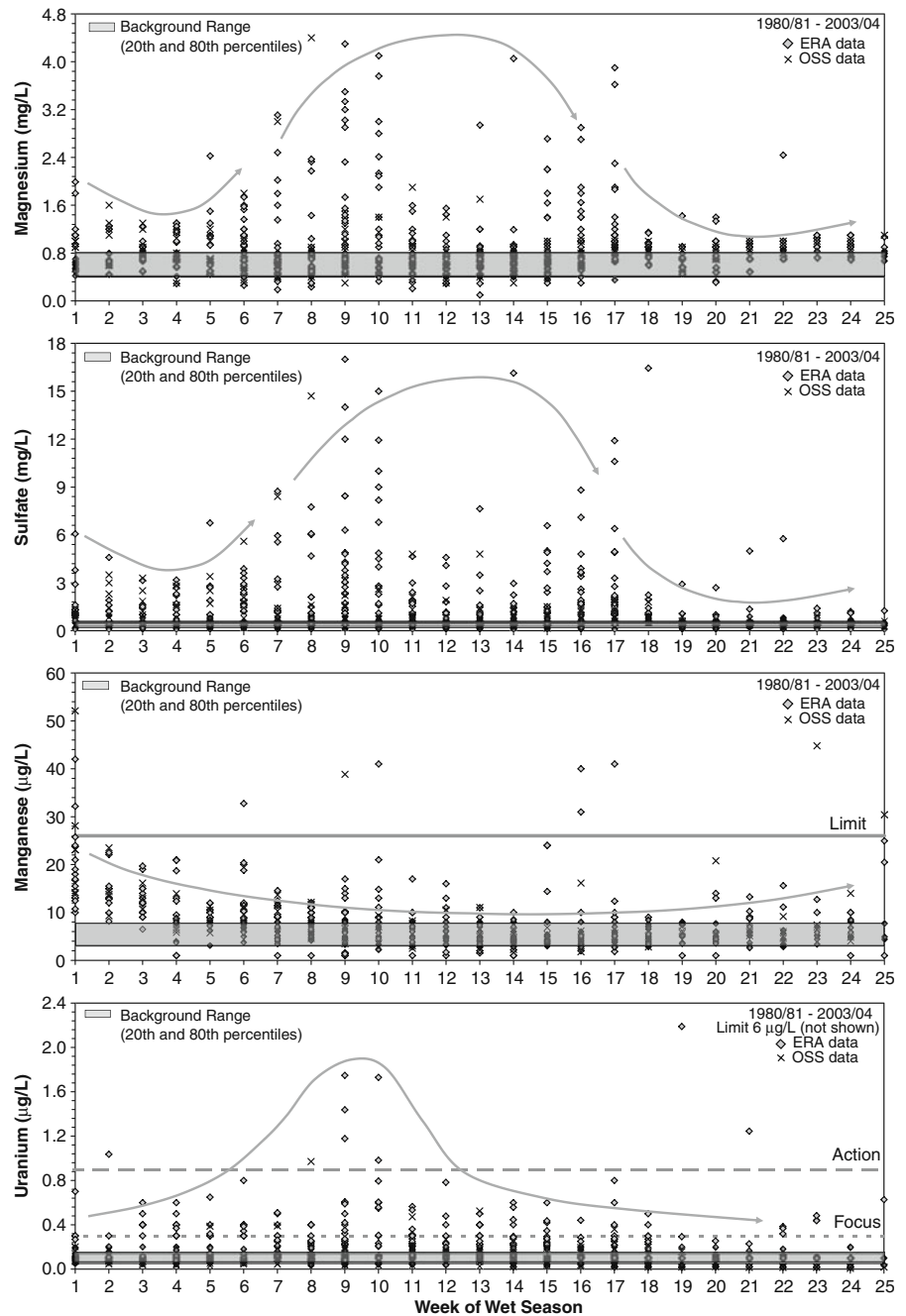
Over time (Fig. 4), it can be seen that concentrations of chemically non-reactive (conservative) species, Mg and SO₄ (and thereby EC), began to increase following the advent of large scale land application in 1985 but declined following the introduction of wetlands treatment in 1995. This can be explained by the combination of surface wash-off and the presence of fracture zones which act as preferential groundwater pathways beneath the MLLA, allowing Mg and SO₄ transport to the Magela Creek (see Brown et al. 1998). Additionally, Mg-SO₄ evaporite (i.e. epsom) salts have been observed along the banks of the Magela Creek adjacent to the MLLA

(OSS-AR 1994, pp. 35–37; Brown et al. 1998, p. 300).

For the environmentally sensitive metals, Mn and U, there is no apparent link over time (Fig. 4) between the evolution of the water management system and concentrations observed downstream at 009. For U in particular, this is also complicated by the improved sampling protocols and lower analytical detection limits over time, which makes the comparison of historical below detection limit results with modern results awkward (e.g. Figs. 4 and 5). The construction of a highly controlled and engineered hydrologic regime for the Ranger uranium mine in place of a previously natural rainfall–runoff regime, in which a natural U signature was clearly present in the Magela Creek, also complicates interpretation of U downstream. Furthermore, pre-mining U concentrations in water are not of a sufficient technical standard for comparison to modern data.

Secondly, there is a clear difference in seasonal behaviour at 009 between the principal mine-derived solutes of Mg, SO₄ and U and that of Mn (Fig. 5). This is most likely due to the fact that Mn is essentially a natural signature while Mg and SO₄ are clearly mine-related. The behaviour of Mn shows a

Fig. 6 Water quality at 009—Mg, SO₄, Mn and U versus week of wet season

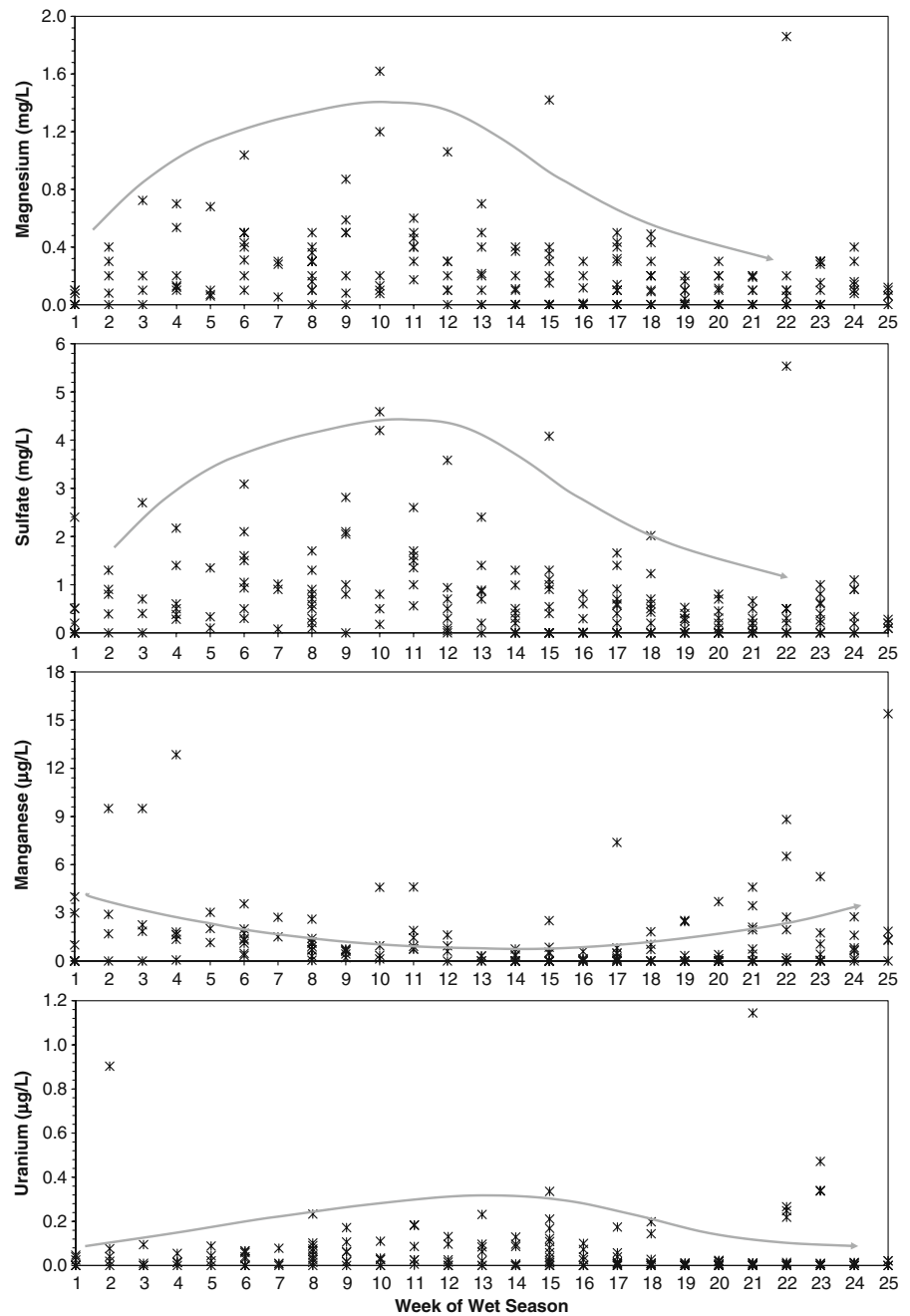


broad concave behaviour with a mild first flush effect at the start of a wet season, a decrease during the middle of wet season and an increase towards the end of the wet season. Overall Mn concentrations do not vary considerably. The behaviour of Mg, SO₄ and U, however, are consistent and, in general, show an increase or convex behaviour during the middle of the wet season. There are mild first flush effects for Mg

and SO₄, although these concentrations are not as significant as those during the middle of the wet season. This broad seasonal behaviour for solutes is also demonstrated by the difference between the upstream and downstream monitoring points (MCUS and 009), shown in Fig. 6.

As such, there is evidence that the behaviour of key solutes in the Magela Creek is seasonal and that it

Fig. 7 Water quality difference between 009 and MCUS—Mg, SO₄, Mn and U versus week of wet season (1998/1999 to 2003/2004 data only)



is critical to consider the downstream concentrations with respect to those upstream. The linking of water quality to hydrologic flow conditions, however, is less clear. As observed in Figs. 3 and 7, flow in the Magela Creek is highly episodic (related to major rainfall events), yet sampling is only undertaken on a regulated timeline (e.g. weekly from the start of flow as per the statutory authorisation). Detailed hydrolog-

ic research at Jabiluka, 20 km north of Ranger, has demonstrated that peak sediment pulses generally occur on the rising limb of a hydrograph, which is intimately linked to the lag time between rainfall and surface runoff (Moliere and Boggs 2005). This is critical since it is sediment which can carry a large fraction of solutes during major rainfall–runoff events (e.g. Hart et al. 1982; Wasson 1992; Moliere 2005).

Based on Fig. 5, there are insufficient data to accurately analyse the extent of time lag between upstream and downstream monitoring sites and the implications this has for water quality monitoring at 009. This is an area for improvement in the current regulatory regime for monitoring water quality.

Thirdly, a major issue is that of peak concentrations in water quality and the loads (or mass) of solutes being transported down the Magela Creek system. The new ANZECC–ARMCANZ approach has moved away from a single, absolute concentration to a three-tier trigger structure. This has clearly improved the ability to discern between the significance of various concentrations, but it has unwittingly removed the need to be cognisant of solute loads also being transported into the environment. For example, the maximum operating storage capacity of RP2 is about 1 million m³ (ERA 2002, p. 21) and most recently has averaged a uranium concentration of ~2.75 to ~14.8 mg/L (ERA 2005, p. 17), thereby containing some 3 to 15 tonnes of uranium. In comparison, the previous regulatory load limit for uranium was approximately 3.5 tonnes of U, while natural loads of uranium in the Magela Creek system can be estimated to range from 20 to 100 kg U (based on flow data and U concentrations; see also Hart 1983; Johnston and Needham 1999).

Under any conceivable direct release scenario for RP2, U concentrations could be allowed to reach between 2 and 5 µg/L and still be below the limit value of 6 µg/L. Based on flows at 009 of between 20 and 50 m³/s over a period of about 60 days (see Fig. 3) and RP2 U concentrations ranging from 2.75 to 10 mg/L, this would lead to discharge volumes from 17,600 to 444,000 m³ and U loads from 207 to 1,298 kg (similar to RP2 volumes and loads recently treated through land application or wetlands). That is, rather tens of kilograms of U per wet season, this could increase up to hundreds of kilograms (or higher). Although it could be argued that the triggers imply upper load limits (e.g. 1.3 tonnes of U is lower than 3.5 tonnes of U), the principal objective of ecosystem protection by maintaining natural variability could be compromised by realistic release scenarios which allow U concentrations below the limit trigger but consequently allow an order of magnitude increase in U loads.

Fourthly, although the range of local ecotoxicological research is considerably more extensive than

most mine sites, there is concern that it is still insufficient given the high conservation value status of the region (see Breitholtz et al. 2006). At present, the U limit is based on chronic toxicity testing of five species of different trophic levels, chosen as expected indicator species for the aquatic ecosystems. It remains unclear, however, whether these species are the most sensitive indicators of their trophic level. Furthermore, the Guidelines do not explicitly take into account the potential for bioaccumulation of various toxicants, especially U. In any case, based on the statistical methodology in the Guidelines, this toxicity testing has been used to derive the limit value of 5.8 µg/L. A close inspection of the graph (Fig. 3; van Dam et al. 2002, p. 509) shows that the 95% confidence intervals to protect 99% of species give a U concentration range from 0.3 to 85 µg/L. The adopted limit value of 6 µg/L is therefore clearly very susceptible to further species testing and could increase or decrease substantively, a sensitivity noted by Hogan et al. (2003) as related to the small size of the data set and extrapolation beyond experimental concentrations (pp. 15–17).

It remains contentious as to whether there is scientific merit in further ecotoxicological testing; however, the local indigenous people have consistently expressed a view to see water quality remain within natural variability and not be influenced by mine-derived solute loads (e.g. SECITARC 2003). Core objectives for the Guidelines are the protection of aquatic ecosystems and to maintain and enhance the natural variability and ecological processes in water, especially for high conservation value regions (e.g. ANZECC and ARMCANZ 2000, pp. 3.1–2). If this was the principle adopted for a limit value, rather than an ecotoxicological approach, analysis of 009 data would give rise to a different limit value. Using only ERA and OSS U data at 009 for the 2000/2001 to 2003/2004 wet seasons, since this is the most recent and highest quality data (and avoids problems with evolving detection limits over the past 25 years), the average U concentration is estimated at 0.082 µg/L with a standard deviation of 0.101 µg/L (from 248 samples). If the limit trigger was therefore adopted as the mean plus three standard deviations (e.g. OSS 2002, p. 12; see also the Guidelines), this would give a value of 0.385 µg/L, which could be rounded to 0.4 µg/L for regulatory purposes. In the data analysed, only four samples are greater than this

value, representing 1.6% of the data set (0.971, 0.472 and 0.525 $\mu\text{g/L}$ over January–February 2001 and 0.482 $\mu\text{g/L}$ in May 2002). A limit of 0.4 $\mu\text{g/L}$, however, is clearly substantially lower than that applied currently. Although 0.4 $\mu\text{g/L}$ would achieve the desire of local indigenous people to protect natural water quality and variability with respect to U, it could be argued as impractical or unreasonable given the limit of 6 $\mu\text{g/L}$ derived from existing ecotoxicological testing and knowledge. This issue is therefore a matter of perspective, with the prevailing judgement at present being to apply a limit of 6 $\mu\text{g/L}$ at 009.

Based on current monitoring protocols, analytical standards and low U detection limits, it is clearly not appropriate to judge past water quality monitoring and ‘re-assess’ regulatory performance. For example, the mean U of 0.082 $\mu\text{g/L}$ over the 2000/2001 to 2003/2004 wet seasons is lower than the U detection limit of 0.1 $\mu\text{g/L}$ which prevailed up until 2000. Given the analytical issues involved, it is only reasonable to employ the water quality standards as they then applied. Excluding the February–March 1991 period when U concentrations were often greater than 3 $\mu\text{g/L}$ at both 009 and MCUS, the Ranger project has met its regulatory requirements for U in terms protecting water quality at 009. There remains, however, an ongoing issue with Mg-SO_4 at 009, the signatures for which are clearly mine-derived. Further research is presently being conducted by the OSS on this issue, especially with respect to the ratio between Mg and calcium which is important in protecting biodiversity (see van Dam et al. 2008).

A promising area for future analyses of water quality downstream in Magela Creek is the application of more comprehensive statistical and trend analysis techniques (e.g. McNeil 2002); however, they are outside the scope of this paper.

6 Summary and Conclusion

The application of the ANZECC–ARMCANZ Guidelines has clearly improved the regulation and interpretation of water quality protection downstream from the Ranger Uranium Project. The scientific basis is more coherent than the previous regulatory regime; however, for U (a key parameter of indigenous and public concern), concentrations that are higher than those observed through natural variability and the

influence of mine-derived solute loads are still allowed. In addition, there are currently no linkages made between the monitoring of water quality and hydrologic flow conditions. This is an aspect of the current regulatory regime for water quality that could be improved, particularly as research has demonstrated that peak sediment pulses (which can carry a large fraction of solutes during major rainfall–runoff events) generally occur on the rising limb of a hydrograph. Further, there is no evidence to show that excluding first flush effects from the Guidelines trigger system is justified, even for U (assuming the 6- $\mu\text{g/L}$ limit was retained). Overall, the Ranger project, to date, has met the prevailing water quality protection regime, but there remain legitimate concerns over sensitive contaminants such as uranium and trends in magnesium and sulphate.

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