Australian Government

Department of the Environment

Supervising Scientist

SUPERVISING SCIENTIST

Annual Report

2013–14

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Australian Government
Department of the Environment
Supervising Scientist

Senator the Hon Simon Birmingham
Parliamentary Secretary to the Minister for the Environment
Parliament House
CANBERRA ACT 2600

16 October 2014

Dear Senator

In accordance with subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* (the Act), I submit to you the thirty-fifth Annual Report of the Supervising Scientist on the operation of the Act during the period of 1 July 2013 to 30 June 2014.

Yours sincerely

Richard McAllister

Acting Supervising Scientist

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Photos (from top left): Jabiru Field Station (JFS) staff member conducting site management of atmospheric monitoring; culture tubs at JFS, used to supply snails for SSD's wet season toxicity monitoring programme; SSD staff members shucking mussels prior to analysis for radionuclides and heavy metals; preliminary tests prior to flying the UAV in Kakadu National Park (KNP); Jabiluka billabong on the Magela floodplain in KNP; Red Bush Apple - *Syzygium suborbiculare*; Magela Creek continuous monitoring pontoon in KNP; SSD and JFS staff members setting croc exclusion nets prior to popnetting at Gulungul billabong KNP; monitoring calcium deficiency and shell erosion of snails at JFS; school-based apprentice supplying food to snails for toxicity monitoring programme.

CONTENTS

FOREWORD

Subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* requires the Supervising Scientist to provide an Annual Report to Parliament on the operation of the Act and on certain related matters. The Act requires the following information to be reported:

- all directions given to the Supervising Scientist by the Minister who, for this reporting period, was the Minister for Sustainability, Environment, Water, Population and Communities.
- information on the collection and assessment of scientific data relating to the environmental effects of mining in the Alligator Rivers Region.
- standards, practices and procedures in relation to mining operations adopted or changed during the year, and the environmental effects of those changes.
- measures taken to protect the environment, or restore it from the effects of mining in the region.
- requirements under prescribed instruments that were enacted, made, adopted or issued and that relate to mining operations in the Alligator Rivers Region and the environment.
- implementation of the above requirements, and
- a statement of the cost of operations of the Supervising Scientist.

SUPERVISING SCIENTIST'S OVERVIEW

The Supervising Scientist plays an important role in the protection of the environment of the Alligator Rivers Region of the Northern Territory through the supervision, monitoring and audit of uranium mines, as well as through the conduct of research into the possible impact of uranium mining on the environment of the Region.

Ranger is currently the only operational uranium mine in the Region, and is owned and operated by Energy Resources of Australia Ltd (ERA). Production commenced at Ranger in August 1981, with milling of stockpiled ore expected to continue through 2020. Mining of Pit 3 ceased in December 2012 and the pit is currently in the process of being backfilled with tailings deposition, expected to commence during 2015. A proposal to develop the Ranger 3 Deeps underground operation was referred under the *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act) in January 2013, and determined by the Minister to require assessment under the EPBC Act at the Environmental Impact Statement (EIS) level. At the time of writing a draft EIS had been completed and was in final preparation for public release towards the end of 2014. The proposal is not expected to impact on the closure of operations at Ranger. Mining and milling are currently required to cease by 2021 with closure of Ranger by 2026.

During the year there were three incidents investigated independently by the Supervising Scientist. On 3 November 2013, staff investigated circumstances around a vehicle taken from Ranger mine without authorisation, on 18 November 2013 an investigation was undertaken into four product drums found in bushland in the Darwin rural area that had originated from Ranger, and on 7 December 2013, following the collapse of Leach Tank No. 1, which resulted in a spill of approximately 1400m^3 of slurry into the processing area, the Supervising Scientist commenced a major investigation into the environmental impacts of the collapse. Findings of all three incidents determined that no detrimental impact to the surrounding environment had occurred. Detail on each of the incidents is contained in this report in Chapter 3. A separate report into the environmental impacts of the failure of Leach Tank No.1 was due to be released in August 2014.

The 2013–14 wet season was wetter than average following a dry year in 2012–13. Despite this, water inventories at Ranger are largely under control following the commissioning of a Brine Concentrator process water treatment plant towards the end of 2013. Following completion of mining in Pit 3 in November 2012, works on the preparation of the base of the pit, to receive the transfer of tailings from the tailings storage facility (TSF), are close to finalisation. Tailings transfer from the TSF to Pit 3 is expected to commence in Q2 or Q3 of 2015. Over the 2014 dry season capping of the tailings in Pit 1 will be completed and the pit removed from the process water catchment to further improve water inventories on site.

As in previous years, the management of the TSF remains a focus. Capacity increases over the past few years combined with a contingency pumping system, and the commissioning of the Brine Concentrator process water treatment plant, have resulted in increased capacity to manage process water within the TSF. Notwithstanding, it is expected that transfer of process water to Pit 3 will commence during January or February 2015 depending on the quantity of early wet season rain.

Works continue on the construction of an exploration decline into the Ranger 3 Deeps (R3D). Complications in tunnelling during 2014 led to alterations in the alignment of the decline due to poor ground conditions. Despite this, the construction continues on schedule. As discussed above, an EIS for the development of the R3D ore body has been drafted and is expected to be released to the public in late 2014.

The 2013–14 wet season represents the fourth season for which continuous monitoring of pH, electrical conductivity (EC) and turbidity in Magela and Gulungul Creeks upstream and downstream of the Ranger mine has been the primary early warning monitoring method employed by the SSD. The monitoring stations are equipped with autosamplers that collect water samples triggered by in-stream events, such as increases in conductivity or turbidity, exceeding defined threshold levels.

The SSD's surface water monitoring results, together with explanatory notes, were posted weekly on the internet throughout the wet season. Overall, the water qualities measured in Magela and Gulungul Creeks for the 2013–14 wet season were comparable with previous wet seasons, with the results indicating that the aquatic environment in the creek has remained protected from mining activities.

In situ toxicity monitoring using fresh water snails in Magela and Gulungul Creeks upstream and downstream of the mine, with test organisms deployed in containers immersed in the creek water, is a biological-based method that complements the finding from the continuous monitoring. The measured responses of the snails during the 2013–14 wet season, combined with the results from the monitoring of fish and macroinvertebrates conducted in the recessional flow period towards, the end of the wet season, continue to confirm that the downstream aquatic environment remains protected from the effects of mining.

As noted in previous years, work is continuing on further enhancing interpretation of the results from the Supervising Scientist's surface water monitoring program. Work to establish a quantitative relationship between the trigger value for Mg and exposure durations was finalised during 2012 to a point such that an applicable trigger value can be derived for any given pulse duration and magnitude detected by the continuous water quality monitoring system. This work has been published in peer-reviewed international journals, and been presented to the Minesite Technical Committee and has been accepted as part of the water quality regulatory regime for compliance in Magela Creek. This represents world's leading practice in applying ecotoxicological derived limits to continuous monitoring data. Determination of radionuclide levels in mussels from Mudginberri Billabong has been a continuing element of the SSD assurance monitoring programme downstream of Ranger. The results from the most recent sampling and analysis conducted in October 2013 show that the levels of uranium and radium in mussels collected downstream of Ranger continue to pose no risk to human health.

The Jabiluka project remains in long-term care and maintenance. Agreement was reached during 2012 between ERA and traditional owners on rehabilitation of the remaining infrastructure on site. The Interim Water Management Pond (IWMP) was removed and the site revegetated during 2013. SSD increased its monitoring of the site in response to the ground disturbance of the remedial activities and to date no impact has been detected.

The Nabarlek mine in western Arnhem Land was decommissioned in 1995 and the rehabilitation of this site remains under ongoing assessment. No further exploration activities were undertaken by the owner Uranium Equities Limited during 2013.

In May 2006, the Australian Government announced funding to undertake rehabilitation of former uranium mining sites in the South Alligator Valley, in the southern part of Kakadu National Park. This project has now been completed. SSD continues to provide advice and assistance to the Director of National Parks on aspects relating to ongoing monitoring of the work.

The Alligator Rivers Region Technical Committee (ARRTC) continues to play a vital role in assessing the key knowledge required, and the robustness of the science used, to make judgements about the protection of the environment from the impacts of uranium mining. During the year ARRTC continued to focus on the ERA closure plan with a view of informing the revision of the Key Knowledge Needs. This work is ongoing and will evolve as Ranger approaches closure, informing both closure criteria and key gaps in knowledge.

Detailed outcomes from the Environmental Research Institute of the Supervising Scientist (***eriss***) research program are published in journal and conference papers and in the Supervising Scientist and Internal Report series. Highlights of this work are described in this annual report.

During the reporting period, SSD provided advice to the Environment Assessment and Compliance Division of the Department on referrals submitted in accordance with the EPBC Act for proposed new and expanding uranium mines.

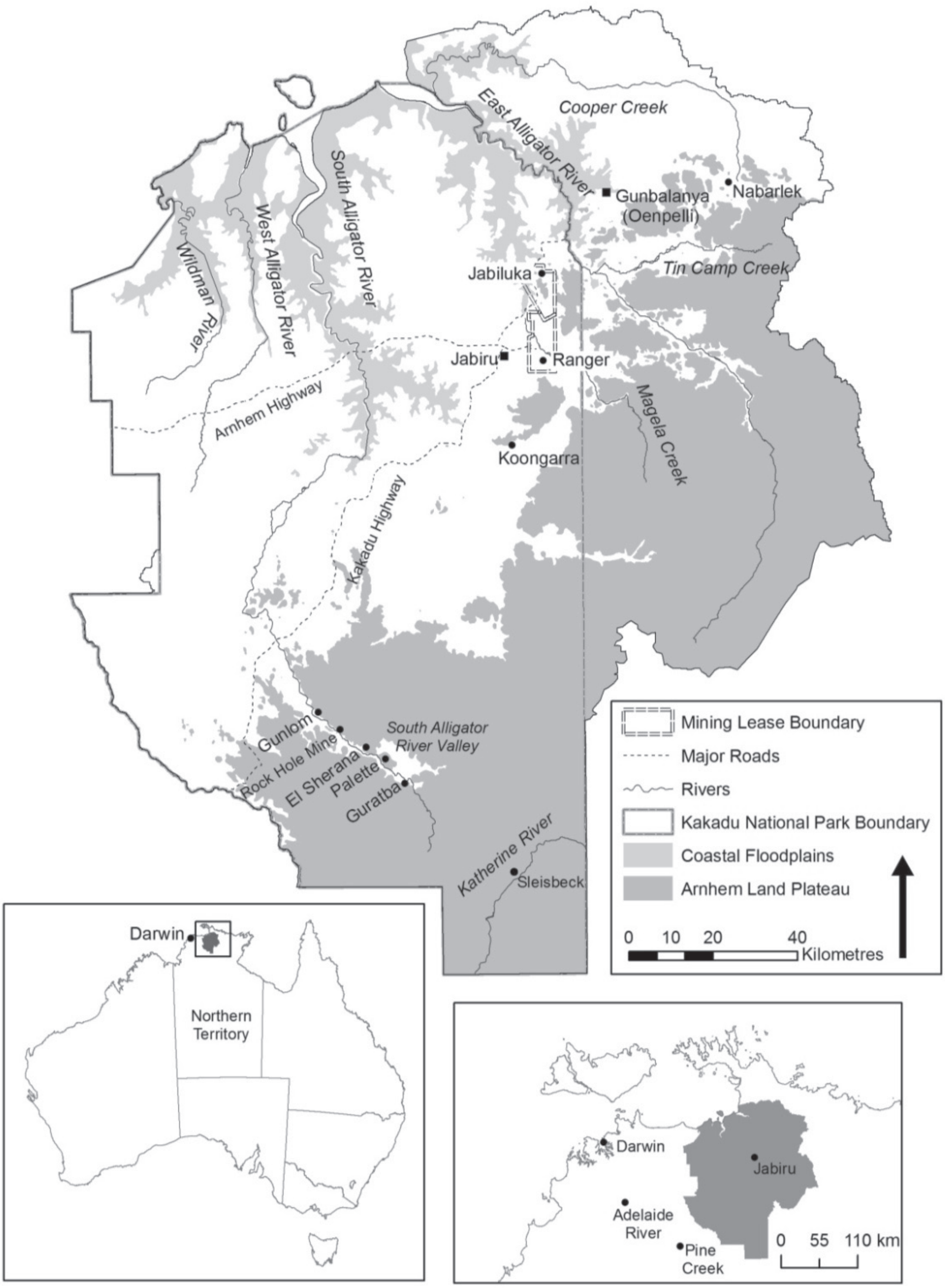
Funds were provided in the 2013–14 Federal Budget for continuation of a programme to develop contemporary site rehabilitation strategies at Rum Jungle under a national partnership agreement between the Northern Territory and the Australian Governments. The Rum Jungle Technical Working Group comprises representatives from the Northern Territory Department of Mines and Energy, Northern Territory Environment Protection Authority, Australian Government Department of Industry, the Northern Land Council and SSD. SSD continued to provide advice to the Rum Jungle Technical Working Group during the reporting period.

In closing I offer my personal thanks to all the staff of the Supervising Scientist Division for their continued enthusiasm and efforts during the year. The 2014 year has provided many challenges from a major incident investigation to departmental restructures that have seen the Supervising Scientist move from being a Division in its own right to forming a part of the much larger Science Division. This change will produce many opportunities and I encourage all the staff of the Supervising Scientist to embrace the new future.

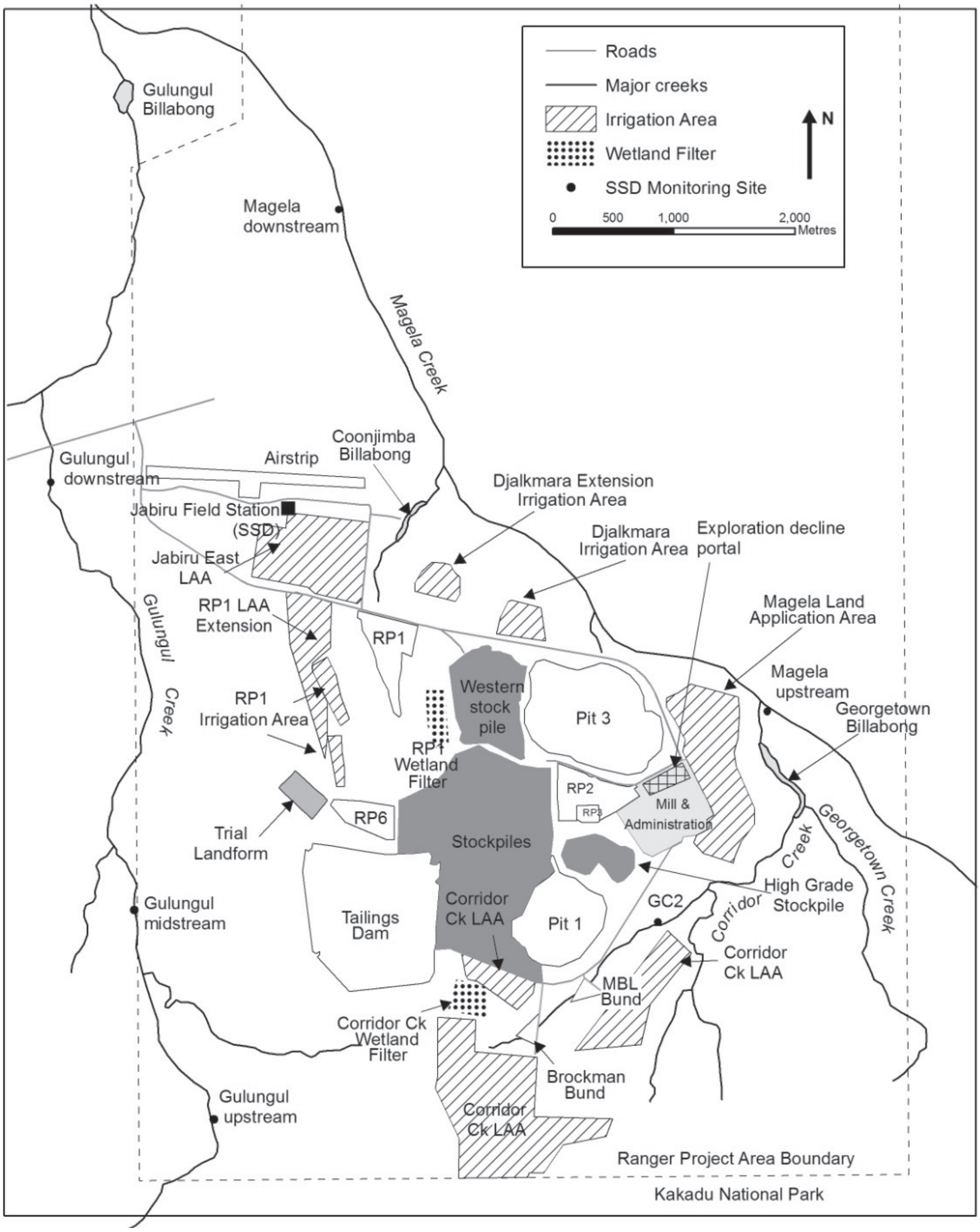
It is through the commitment and professionalism of the Division's staff that the Division is able to fulfil its role in ensuring the highest level of environmental protection is afforded to the Alligator Rivers Region. In particular I would like to highlight the efforts of those staff who have recently departed after many years of service, including Dave Walden who has been the backbone and major historian of the organisation and will be sorely missed for the character and professionalism he brought to the workplace over many years.

Richard McAllister

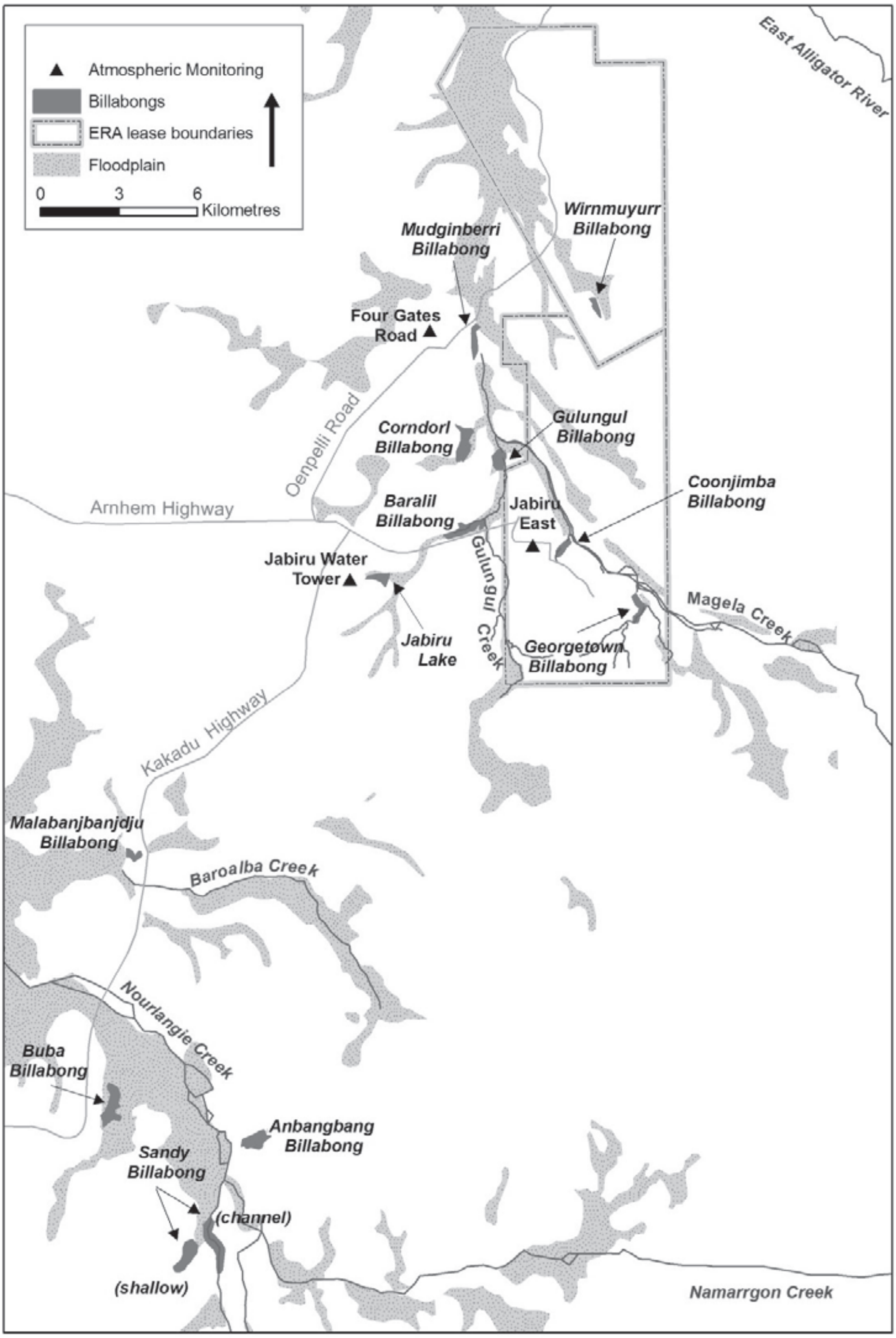
Acting Supervising Scientist



Map 1 Alligator Rivers Region



Map 2 Ranger minesite



Map 3 Location of waterbodies and atmospheric monitoring sites used in the SSD environmental research and monitoring programmes.

1 INTRODUCTION

1.1 Role and function of the Supervising Scientist

The position of Supervising Scientist was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* (the EPARR Act) in response to a recommendation of the second and final Fox Commission report in May 1977.

The roles and responsibilities of the Supervising Scientist are to:

- develop, coordinate and manage programmes of research into the effects on the environment of uranium mining within the Alligator Rivers Region
- develop standards, practices and procedures that will protect the environment and people from the effects of uranium mining within the Alligator Rivers Region
- develop measures for the protection and restoration of the environment
- coordinate and supervise the implementation of requirements made under laws applicable to environmental aspects of uranium mining in the Alligator Rivers Region
- provide the Minister for the Environment with scientific and technical advice on mining in the Alligator Rivers Region
- on request, provide the Minister for the Environment with scientific and technical advice on environmental matters elsewhere in Australia.

The Supervising Scientist heads the **Supervising Scientist Division (SSD)** within the Department of the Environment. The Division comprises two Branches.

The **Office of the Supervising Scientist** (***oss***) undertakes supervision, audit and assessment activities and provides policy advice to the Australian Government in relation to the environmental performance of uranium mines in the Alligator Rivers Region. The Branch also provides business and administrative support to the Supervising Scientist Division.

The **Environmental Research Institute of the Supervising Scientist** (***eriss***) undertakes environmental monitoring and scientific research into the impact of uranium mining on the environment within the Alligator Rivers Region to support the role of the Supervising Scientist.

1.2 Performance summary

As a Division of the Department of the Environment, SSD is funded under the Portfolio's departmental output appropriation and contributes to the delivery of Outcome 5:

> ensuring efficient and effective environmental regulation in cooperation with stakeholders, especially in relation to protecting matters of national environmental significance; improving the delivery of regulatory services under the EPBC Act; protecting and increasing awareness and enjoyment of the places and stories that make Australia special and are part of our heritage; and

ensuring that the environment and natural values of the Alligator Rivers Region are protected from the impacts of uranium mining.

Outcome 5 is divided into two programmes. During the 2013–14 financial year, the Supervising Scientist contributed to Program 5.2 Environmental Regulation.

Further details on SSD activities during 2013–14 contributing to Program 5.2 are provided in Chapters 2, 3 and 5 of this Annual Report.

Communicating the outcomes of research, monitoring and supervision activities to relevant stakeholders and the broader scientific community is a key part of the work of the Division. Of particular importance is the ongoing communication and consultation SSD undertakes with the Indigenous people living in the Alligator Rivers Region. Further details on SSD communications activities during 2013–14 are provided in Chapter 5.

1.3 Business planning

SSD undertakes a strategic business planning approach and inputs into Departmental strategic business planning processes to ensure outputs are achieved in the most effective and efficient way. SSD prepares an annual Business Plan that outlines the main goals and challenges for the Division over the coming year, the range of activities and programmes to be undertaken and associated performance measures. Progress against strategic priorities and key result areas is assessed on an ongoing basis as part of Departmental performance management processes.

1.4 The Alligator Rivers Region and its uranium deposits

The Alligator Rivers Region is located 220 km east of Darwin and encompasses an area of approximately 28 000 km^2 (see Map 1). The Region includes the catchments of the West Alligator, South Alligator and East Alligator Rivers, and extends into western Arnhem Land. The World Heritage listed Kakadu National Park lies entirely within the Alligator Rivers Region.

The Ranger and Jabiluka uranium deposits within the Alligator Rivers Region are not, and never have been, located within Kakadu National Park. The Koongarra project area was incorporated into the Kakadu World Heritage area in 2011. Commonwealth legislation incorporating the Koongarra project area into Kakadu National Park came into effect in March 2013. Nabarlek is situated to the east of Kakadu National Park within Arnhem Land.

Ranger is currently the only operational uranium mine in the Region. Mining at Ranger ceased in 2012, however processing of stockpiled ore is continuing. Mining ceased at Jabiluka in 1999 and the site is under long-term care and maintenance. Mining at Nabarlek ceased in 1980 and the site has been decommissioned and is subject to ongoing rehabilitation. There are also a number of former uranium mine sites in the South Alligator River Valley that operated during the 1950s and 1960s. The Australian Government funded the rehabilitation of these sites, which was completed in 2009.

1.4.1 Ranger

Energy Resources of Australia Ltd (ERA) operates the Ranger uranium mine, which is located 8 km east of the township of Jabiru. The mine lies within the 78 km^2 Ranger project area and is adjacent to Magela Creek, a tributary of the East Alligator River. Ranger is an open cut mine and commercial production of uranium concentrate (U_3O_8) has been under way since 1981. Orebody No 1 was exhausted in late 1994 and excavation of Orebody No 3 began in 1997. Mining in Pit 3 at Ranger ceased in 2012 and the pit is currently being backfilled. Processing of stockpiled ore is expected to continue until 2020.

In January 2013, ERA submitted a proposal for the development of an underground mine at Ranger under the NT *Environmental Assessment Act* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. In March 2013, it was determined that the Ranger 3 Deeps Underground Mine proposal requires assessment at the Environmental Impact Statement level under both the Commonwealth and Northern Territory environmental approval processes.

On 7 December 2013 leach tank 1 at Ranger uranium mine failed spilling uranium leach slurry into the plant area. Processing operations ceased at the time of the incident and were not resumed until 5 June 2014. Further details on the incident and the Supervising Scientist's response are provided in Section 3.

1.4.2 Jabiluka

The Jabiluka mineral lease abuts the northern boundary of the Ranger project area and the Jabiluka site is situated 20 km north of the Ranger minesite. It is also owned by ERA.

Unlike the Ranger and Nabarlek deposits, the Jabiluka orebody lies beneath a cover of cliff-forming sandstone. It is in the catchment of the East Alligator River, adjacent to Ngarradj (Swift Creek), which drains north to the Magela floodplain. The Australian Government completed its assessment of ERA's Environmental Impact Statement, which provided for milling of Jabiluka ore at Ranger, in 1997.

Development work at Jabiluka took place in the late 1990s but ceased in September 1999, at which time the site was placed in an environmental management and standby phase that lasted until 2003. During 2003, discussions commenced between ERA, the Commonwealth and Northern Territory Governments, the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) which represents the area's traditional Indigenous owners, the Mirarr people. Following these discussions, an agreement was reached between the parties that resulted in Jabiluka being placed in long-term care and maintenance.

This agreement included an undertaking by ERA not to engage in mining activities at Jabiluka without the consent of the Mirarr people. The agreement was endorsed by the NLC in 2004 and was approved by the then Australian Government Minister for Immigration and Multicultural and Indigenous Affairs in 2005.

1.4.3 Nabarlek

Nabarlek is about 280 km east of Darwin. Queensland Mines Ltd undertook mining at Nabarlek during the dry season of 1979 and milling of the ore continued until 1988. Some 10 857 t of uranium concentrate (U_3O_8) was produced while the mill was operational.

Decommissioning of the mine was completed in 1995 and the performance of the rehabilitation and revegetation programme continues to be monitored by SSD.

In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd thereby acquiring the Nabarlek lease. Since then UEL has undertaken further exploration on the lease as well as a range of weed control, revegetation and other rehabilitation works.

1.4.4 Koongarra

The Koongarra deposit is about 25 km south-west of Ranger, in the South Alligator River catchment. The Koongarra lease was owned by Koongarra Pty Ltd, a subsidiary of AREVA Australia Pty Ltd. In 2011, the Koongarra Project Area was added to the Kakadu World Heritage Area by the World Heritage Committee with the support of the Australian Government. The *Completion of Kakadu National Park (Koongarra Project Area Repeal) Act 2013*, which repealed the *Koongarra Project Area Act 1981*, and incorporated the lease area into Kakadu National Park, came into effect on 31 March 2013.

1.4.5 South Alligator Valley mines

During the 1950s and 1960s, a number of small uranium mines and milling facilities operated in the South Alligator River Valley, in the southern part of the Alligator Rivers Region. Mining occurred at several locations – principally at El Sherana, El Sherana West, Rockhole Creek and Coronation Hill (Guratba). Milling also occurred at Rockhole Creek within the South Alligator Valley and at nearby Moline which lies outside the Alligator Rivers Region.

Output from these mines was relatively small. It is estimated that less than 1000 t of uranium concentrate was produced at the Rockhole Creek and Moline mills from the ore mined in the South Alligator Valley during this period.

These sites, excluding Moline, are the responsibility of the Australian Government Director of National Parks and are administered through Parks Australia. In May 2006, the Australian Government provided funding over four years for the rehabilitation of a number of these sites. This rehabilitation work was completed in 2009. Moline lies outside Kakadu National Park, is the responsibility of the Northern Territory Government, and is administered by the Department of Mines and Energy.

During 2013–14, SSD continued to assist Parks Australia with technical advice related to the ongoing monitoring of these rehabilitated sites. Further details on SSD involvement in this work are provided in Section 3.5.1 of this Annual Report.

2 STATUTORY COMMITTEES

2.1 Introduction

During 2013–14, the Supervising Scientist Division provided secretariat and administrative support to two statutory committees: the Alligator Rivers Region Advisory Committee and the Alligator Rivers Region Technical Committee.

These committees play important roles in facilitating discussion and information exchange between stakeholders in relation to the environment effects of uranium mining in the Alligator Rivers Region, and the independent review of the outcomes of scientific research and monitoring undertaken by SSD, ERA and others.

2.2 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (ARRAC) was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978*.

ARRAC comprises an independent Chair and representatives from the following stakeholder organisations:

- NT Department of Mines and Energy (DME)
- NT Environment Protection Authority
- NT Department of Health
- Office of the Administrator of the NT
- Australian Radiation Protection and Nuclear Safety Agency
- Energy Resources of Australia Ltd
- Cameco Australia Pty Ltd
- Uranium Equities Ltd
- AREVA (formerly Afmeco Mining and Exploration Pty Ltd)
- Northern Land Council
- Gundjeihmi Aboriginal Corporation
- Environment Centre Northern Territory
- Australian Government Department of Industry
- Parks Australia, Australian Government Department of the Environment
- Supervising Scientist, Australian Government Department of the Environment

ARRAC provides a valuable forum for relevant stakeholders to exchange views and information relating to the protection and rehabilitation of the Alligator Rivers Region environment from the effects of uranium mining. Public disclosure of environmental performance data through ARRAC is an important means of ensuring transparency and enhancing trust between the various stakeholder organisations.

At each ARRAC meeting, stakeholder members provide an update report on their activities during the reporting period. SSD also provides a detailed report covering the outcomes of audit and assessment activities and the results from SSD environmental monitoring programmes to each meeting.

ARRAC met twice during 2013–14, in Jabiru, NT in September 2013 and in Darwin in April 2014. Key issues considered by ARRAC at these meetings included:

- The status of mine operations, planning and development at Ranger.
- The results of chemical, biological and radiological monitoring for Ranger and Jabiluka.
- SSD communication and research activities.
- The outcomes of environmental audits and assessments of Ranger, Jabiluka and Nabarlek.
- The outcomes of Minesite Technical Committee (MTC) meetings and other regulatory processes.
- The status of mine rehabilitation projects in the South Alligator Valley; and
- The Northern Land Council's work with the Alligator Rivers Region stakeholders and traditional owners.

ARRAC meeting minutes are available from the ARRAC website at www.environment.gov.au/ssd/communication/committees/arrac/meeting.html

2.3 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) was established under the *Environment Protection (Alligator Rivers Region) Act 1978*.

ARRTC plays an important role in ensuring the scientific research conducted by ***eriss,*** ERA, NT Government agencies and others into the protection of the environment from the impacts of uranium mining in the Alligator Rivers Region is appropriately targeted and of the highest possible standard. ARRTC also reviews the quality and adequacy of the science used for the regulatory assessment and approval of uranium mining related applications and proposals in the Alligator Rivers Region.

The membership of ARRTC comprises:

- an independent Chair
- the Supervising Scientist
- a number of independent scientific members (including the Chair) with specific expertise nominated by Science and Technology Australia – formerly the Federation of Australian Scientific and Technological Societies (FASTS).
- a member representing NGO interests

- a number of members representing other relevant stakeholders including the Northern Land Council, the NT Department of Mines and Energy, Energy Resources of Australia Ltd (for Ranger and Jabiluka), Uranium Equities Ltd (for Nabarlek) and Parks Australia.

The Committee is chaired by Dr Simon Barry, who is also the Independent Scientific Member with expertise in Ecological Risk Assessment.

ARRTC held two meetings in 2013–14, in November 2013 and May 2014. Key issues considered by ARRTC at these meetings included:

- Current and proposed scientific research activities for ***eriss*** and ERA, in the context of the ARRTC Key Knowledge Needs (KKN).
- Outcomes of chemical, biological and radiological research and monitoring being undertaken by SSD, ERA and DME.
- Scientific and technical issues relating to Ranger, Jabiluka and Nabarlek.
- The science underpinning Minesite Technical Committee (MTC) meetings and other regulatory decision making.
- The status of South Alligator Valley rehabilitation activities.
- Activity reports from the various stakeholder organisations.

At its meeting in May 2014, ARRTC endorsed the proposed ***eriss*** scientific research program for 2014–15. ARRTC also reviewed the status of the current ERA Rehabilitation/Closure Risk Assessment Project, the outcomes of which are being used to inform the ongoing revision of the ARRTC Key Knowledge Needs.

The ARRTC Key Knowledge Needs are included in Appendix 1 of this Annual Report. ARRTC meeting minutes are available on the ARRTC web site at www.environment.gov.au/ssd/communication/committees/arrtc/index.html

3 ENVIRONMENTAL ASSESSMENTS OF URANIUM MINES

3.1 Supervision process

The Supervising Scientist utilises a structured programme of audits and inspections, in conjunction with the Northern Territory Department of Mines and Energy (DME), Northern Land Council (NLC) and the Gundjeihmi Aboriginal Corporation (GAC), to supervise uranium mining operations in the Alligator Rivers Region (ARR). The outcomes of these activities are considered by the Supervising Scientist, together with environmental monitoring data and other information, to draw conclusions regarding the effectiveness of environmental management at uranium and exploration mining sites.

3.1.1 Minesite Technical Committees

Minesite Technical Committees (MTCs) have been established for Ranger, Jabiluka and Nabarlek. The MTC meetings provide an effective forum for stakeholders, including Supervising Scientist Division (SSD) staff, to discuss technical environmental management issues, especially in connection with the assessment of applications and reports submitted by mining companies for approval under Northern Territory and Commonwealth legislation. As such, each Ranger and Jabiluka MTC is made up of representatives from DME (which provides the Chair), SSD, NLC, Gundjeihmi Aboriginal Corporation (GAC) and Energy Resources of Australia (ERA). Representatives from the Australian Government Department of Industry (DoI) also participate in the Ranger and Jabiluka MTCs. Other organisations or experts may be co-opted from time to time as required to assist MTC members. The Nabarlek MTC is made up of representatives from DME, NLC, SSD and the relevant mining company (currently Uranium Equities Limited).

3.1.2 Audits and inspections

The Supervising Scientist, in consultation with the applicable MTC members, has developed and implemented a programme of environmental audits and inspections at the Ranger mine, the Jabiluka Mineral Lease and the Nabarlek mine. SSD staff also participate in audits of exploration operations throughout the ARR.

Routine Periodic Inspections (RPI) take place monthly at Ranger, being the only operating mine in the region, and quarterly at Jabiluka, which is currently in long-term care and maintenance. The RPIs are intended to provide a snapshot of the adequacy of environmental management activities on site as well as an opportunity for the inspection team to discuss current environmental management issues with staff on site. The discussions that occur during RPIs may include addressing any unplanned events or reportable incidents and any associated follow-up actions. The inspection team is made up of representatives from the SSD, DME, NLC and GAC.

The El Sherana Airstrip radiological containment facility at South Alligator Valley is also inspected at least annually by SSD in conjunction with Parks Australia.

Environmental audits are conducted by a team of qualified audit staff from SSD, DME, NLC and the GAC, and are undertaken in accordance with ISO Standard 19011:2011 (Guidelines for quality and/or environmental management systems auditing) and are consistent with current best practice methods for environmental assessments.

The annual environmental audits of Ranger and Jabiluka occur each May to assess the performance of each site against commitments taken from selected management plans or approval documents. The final audit report is tabled at the following meeting of the ARRAC. Audit findings are followed up as required through the RPI process. The Nabarlek programme is slightly different in that an inspection is carried out early in the dry season to assess the post wet season condition of the area, in order to provide recommendations that can be addressed during the dry season when the site is accessible. The annual environmental audit is conducted later in the year if required.

The audit outcomes for 2013–14 are described later in this annual report.

3.1.3 Assessment of reports, plans and applications

The Authorisations for Ranger and the Jabiluka are issued under the *Northern Territory Mining Management Act 2001*. The Act provides for alterations to the Authorisation to be issued by the Northern Territory Government. The Authorisations require that ERA seeks approval for certain activities from the Northern Territory regulatory authority, through DME, which then considers applications after SSD, NLC and GAC have assessed the proposal and provided feedback. This provides the primary mechanism for the Supervising Scientist's participation in the regulatory processes of the Northern Territory Government and is supported by section 34 of the Act which requires the Northern Territory Government to act in accordance with the advice of the Commonwealth Resources Minister for issues related to uranium mining.

The main reports and plans assessed by the Supervising Scientist during 2013–14 included:

- Ranger Amended Plan of Rehabilitation No 39
- Ranger Mine Water Management Plan
- Ranger Mine and Jabiluka Annual Environmental Reports
- Ranger Mine and Jabiluka Wet Season Reports
- Ranger Mine Annual Tailings Dam Inspection Report
- Ranger Mine and Jabiluka Radiation Protection and Atmospheric Monitoring Program annual report and quarterly data submissions
- ERA weekly environmental monitoring data and quarterly reports submitted in accordance with the Authorisations
- Applications by ERA for amendments to their Authorisations (refer to 3.2.2.5 and 3.3.2.4)

3.2 Ranger

3.2.1 Developments

Mining in Pit 3 at Ranger Mine ceased in November 2012, with backfill of the pit from the western stockpile commencing shortly thereafter. The mill produced 1 113 tonnes of uranium oxide (U_3O_8) during 2013–14 from 1 164 000 tonnes of ore (Table 3.1). Production statistics for the milling of ore and the production of U_3O_8 at Ranger for the past five years are shown in Table 3.2.

TABLE 3.1 RANGER PRODUCTION ACTIVITY FOR 2012–2013 BY QUARTER[1]

	1/07/2013 to 30/09/2013	1/10/2013 to 31/12/2013	1/01/2014 to 31/03/2014	1/04/2014 to 30/06/2014
Production (drummed tonnes of U_3O_8)	610	503	0	0
Ore treated (‘000 tonnes)	632	486	0	46

[1]ERA data

TABLE 3.2 RANGER PRODUCTION ACTIVITY FOR 2009–2010 TO 2013–2014[1]

	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014
Production (drummed tonnes of U_3O_8)	4222	2679	3282	4313	1113
Ore treated (‘000 tonnes)	2283	1305	2404	2487	1164

[1]ERA data

3.2.1.1 On-site activities

Ranger 3 Deeps Underground Mine

On 16 January 2013, ERA submitted a referral under the Environment Protection and Biodiversity Conservation Act (EPBC Act) for the development of the Ranger 3 Deeps underground mine to be constructed on the site of the existing Ranger uranium mine. On 13 March 2013, the Minister determined that the proposal would be assessed at the EIS level with final guidelines for the EIS issued on 2 August 2013.

ERA has advised that they expect to lodge the EIS in the third quarter of 2014.

Ranger Exploration Decline Project

In April 2009, ERA submitted an application for the proposed construction of an exploration decline to provide exploration access to mineralisation in the Ranger 3 Deeps area. The application was approved by the NT Resources Minister in early September 2011, with construction of the exploration decline commencing on 1 May 2012. Mineralised material intersected in the development of the decline is not processed and is stockpiled separately. As of 30 June 2014 approximately 1 600 tonnes of material had been stockpiled as potentially mineralised material. The vertical distance below the surface was 340 metres and the current length of the decline is 2 216 metres from the decline portal, with a total of 153 000 tonnes of material removed.

Ranger Exploration Decline Phase 2

An application to construct a second phase of the exploration decline was approved on 4 June 2013. Phase 2 included a single vent raise, an extension of the decline by approximately 1 000 m and a cross cut through the ore body to obtain a 10 000 tonne bulk sample for metallurgical test work. On 5 December 2013, DME approved an application for modification of the vent shaft raise following consideration by the Ranger MTC. Following an ERA presentation and consideration by the MTC in February 2014, approval was given by DME on 14 March 2014 for a further realignment of Phase 2 to avoid additional unstable ground.

ERA has stated that the ore obtained from the bulk sample will not be processed through the Ranger mill and will be set aside for return to the decline should the Ranger 3 Deeps underground mine not progress.

Brine concentrator

As part of the strategy to manage and reduce the process water inventory on site, ERA has constructed a brine concentrator on site to treat process water. The brine concentrator is located at the site of the now-demolished acid plant adjacent to the power station. The brine concentrator was commissioned in September 2013 and has the capacity to treat 1.83 GL of process water per year. SSD initially undertook a range of ecotoxicological tests on distillate produced from a brine concentrator pilot plant campaign that was run at Rio Tinto’s research centre in Melbourne using process water transported by tanker from the mine. These tests indicated the distillate was of a very high quality, but potentially lacking in trace elements.

These results were confirmed by SSD with further toxicity testing completed using water from the full-scale plant. This testing showed ammonia as the only toxicant of environmental significance in the distillate.

On 29 August 2013, ERA submitted an application to dispose of distillate produced from the brine concentrator to the Ranger Mine pond water system and Corridor Creek wetland filter during the 2013 dry season. SSD provided water quality criteria to DME for the release of brine concentrator distillate to the pond water system on 13 September 2013 and to the Corridor Creek Wetland Filter on 27 September 2013.

On 6 December 2013, ERA submitted an application for an ongoing brine concentrator distillate disposal strategy. This application proposed dry season irrigation and wet season discharge to the managed release system. On 24 January 2014, SSD provided to DME, and other stakeholders, the conditions of approval for the release of brine concentrator distillate.

Since commissioning in September 2013, a total of 470 ML of distillate has been produced over 181 operational days, of which 386 ML of distillate has been produced over 152 operational days since January 2014.

Pit 3 backfill

Mining in Pit 3 was completed in November 2012 with backfill of the pit from the Western Stockpile commencing shortly thereafter. As of 30 June 2014, approximately 31.16 M tonnes of waste rock required to form a level base for tailings deposition had been returned to the pit.

Pit 1 preload

ERA applied to the Ranger MTC in May 2013 to place a 2.5 m thick layer of rock over the tailings within Pit 1. This application was approved by DME on 13 August 2013. This loading is intended to activate the 7 499 wicks installed in 2012 and accelerate the dewatering of the tailings. Approximately 70% of the tailings surface was covered with the initial layer of rock prior to the 2013–14 wet season. Due to some of the remaining tailings surface still being waterlogged, the remainder of pre-load was not completed before the wet season and is planned for completion over the 2014 dry season. The information gained from this project will provide valuable data for the validation of tailings consolidation and seepage modelling.

3.2.2 On-site environmental management

3.2.2.1 Water management

All water on site is managed in accordance with the Water Management Plan which is updated annually and subject to assessment by the MTC before approval. The 2013–14 Water Management Plan was submitted for approval by ERA on 11 October 2013. SSD endorsed the plan on 23 December 2013, and the document was formally approved by DME on 24 December 2013. The plan describes the systems for routine and contingency management of the three categories of water on site: process, pond and release water.

As shown in Figure 3.1, the 2013–14 wet season was an above average rainfall year with a total of 1 963 mm recorded at Jabiru Airport to 30 June 2014 (annual average 1 550 mm). Water management, especially that of process water, remains a critical issue at Ranger.

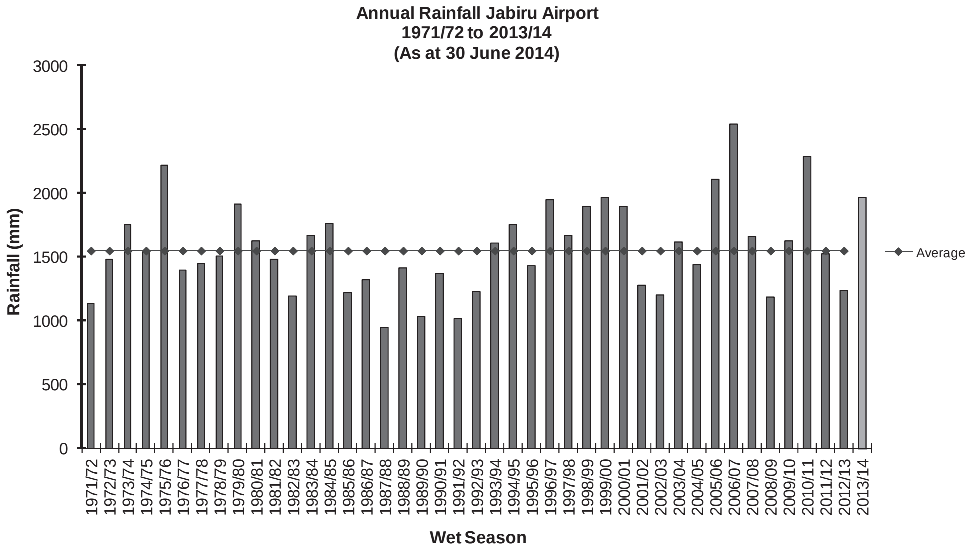


Figure 3.1 Annual rainfall Jabiru Airport 1971–72 to 2013–14 (data from Bureau of Meteorology).

Process water system

Under the Commonwealth Environmental Requirements, water that is in direct contact with uranium ore during processing (process water) must be maintained within a closed system. It may only be released by evaporation or after treatment in a manner and to a quality approved by the Supervising Scientist. Process water is currently stored in the TSF and in Pit 1. On 30 June 2014, the process water inventory was 10 419 ML, which was stored in the TSF. This represents an increase of 1 507 ML over the previous year's total of 8 912 ML due in a large part to the above average rainfall in the 2013–14 wet season. Pit 1 is almost dry with only a small (immeasurable) volume remaining.

There was a release of process water to Retention Pond 2 (RP2), which is part of the pond water system, during the reporting period. At 00:54 on 7 December 2013, Leach Tank No. 1 at the Energy Resources of Australia Ltd Ranger uranium mine collapsed, spilling approximately 1 400 m^3 of slurry containing ground uranium ore, water and sulphuric acid into the processing area. (section 3.2.2.6).

During 2012–13, ERA constructed a brine concentrator to treat process water, which was commissioned in September 2013 (section 3.2.1).

Pond water system

The pond water system contains water that has been in contact with stockpiled mineralised material and operational areas of the site other than those contained within the process water system. Water is managed within this system by quality. The pond water system consists primarily of Retention Pond 6 (RP6), RP2, Retention Pond 3 (RP3) and Pit 3. ERA has previously committed that pond water will not be released without prior treatment through wetland filtration or the on-site microfiltration/reverse osmosis treatment plants. At the end of the reporting period 2 431 ML was contained within the pond water system, representing an increase in the volume stored compared to the same time last year, which was (1 718 ML). The increased pond water inventory is primarily due to the wetter than average wet season during 2013–14. Also, some residual water was still retained in Pit 3 as pumping access is not easily attained during backfill operations.

The first 200 mm of incident rainfall on sheeted stockpiles continues to be diverted into the pond water system each year. This initial runoff generally contains higher levels of mine-derived solutes due to the leaching of solutes from rock that occurs in the early stages of the wet season. The runoff after the first 200 mm of rain is directed into the wetland filter system prior to discharge to the environment.

Methods of disposal of pond water

Passive release water

Rainfall runoff discharges from the Ranger site during the wet season primarily via Corridor Creek and Coonjimba Creek with lesser amounts via Gulungul Creek, and minor amounts via overland flow direct to Magela Creek. RP1 and the Corridor Creek wetland filter act as sediment traps and solute 'polishing' systems prior to outflow from the site. Due to reduced performance, ERA has ceased utilisation of the RP1 wetland filter to 'polish' pond water.

The Corridor Creek wetland filter receives runoff from specially prepared sheeted areas of low grade ore and waste rock stockpiles. The surfaces of these stockpile areas are compacted to reduce infiltration and hence minimise contribution of additional water to the pond water system.

An interception trench was installed around the western and northern perimeter of the western stockpile in 2010 to capture poor quality seepage that was previously reporting to RP1, and to redirect stockpile runoff away from RP1. This measure, combined with input of pond water permeate into RP1, has resulted in a substantial improvement to water quality in RP1 over the past four years. Water is passively released from RP1 via a sluice gate when the water level in RP1 exceeds the height of the spillway.

In Corridor Creek, passive release of waters originating from upstream of GC2 occurred throughout the 2013–14 wet season.

Managed release water

A total of 1.06 GL of RP1 water was discharged via the sluice gate/pumping over the weir on twenty occasions during the 2013–14 wet season, between December 2013 and May 2014, to reduce the overall pond water inventory during periods of higher flow in Magela Creek.

ERA manually controls the discharge of runoff from areas adjacent to the Pit 3 rim via four sluice gates along the Ranger access road. Release from these gates occurred on seventeen occasions during the 2013–14 wet season, between December 2013 and May 2014. A total volume of approximately 14 ML of water was released via the Pit 3 sluice gates.

ERA was again granted interim approval through the Water Management Plan for the discharge of RP1 water to Magela Creek from the MG001 site (see Map 2 for location) over the 2013–14 wet season. Discharge is managed to ensure electrical conductivity within Magela Creek is maintained within the specified limits. Controlled discharge occurred on sixteen occasions between December 2013 and May 2014 during high flow conditions in Magela Creek. A total volume of approximately 600 ML of RP1 water was released via MG001.

Pond water treatment

Pond water is treated via three microfiltration/reverse osmosis water treatment plants (WTP), with WTP1 and WTP2 each having a 7 ML/day capacity and WTP3 an 11 ML/day capacity.

All three water treatment plants were in operation during the reporting period. Volumes of water treated and permeate produced are reported in Table 3.3.

TABLE 3.3 POND WATER TREATMENT PLANT (WTP) VOLUMES[1]

WTP	Volume treated (ML)	Permeate produced (ML)
1	1609	1073
2	1641	1200
3	1532	1038

[1]ERA data

Treated permeate was discharged either to the Corridor Creek wetland filter or RP1 and from there passively released to Magela Creek during the wet season, or irrigated on land application areas during the dry season.

Land application areas

The locations of land application areas (or irrigation areas) at the Ranger mine are shown on Map 2. Direct irrigation of RP2 water ceased from 2009. All water disposed of via the land application areas is now treated or polished through a wetland filter prior to irrigation.

All land application areas, other than the Magela land application area which was taken out of service for rehabilitation trials, were utilised during the 2013 dry season with a total volume of 454.3 ML irrigated. Irrigation for the 2014 dry season commenced on 11 June 2014. Volumes of water disposed of to each irrigation area are shown in Table 3.4.

TABLE 3.4 IRRIGATION VOLUMES BY LOCATION (ML)[1]

RP1 LAA	Djalkmarra LAA	Jabiru East LAA	RP1 Extension LAA	Corridor Creek LAA
27.8	38.9	131.5	25.8	162.3

[1]ERA data

3.2.2.2 Tailings and waste management

Tailings

From August 1996 to December 2008 no process residue from the milling of ore was deposited into the TSF, with Pit 1 being the sole receptor. Over this period 20 million m^3 of tailings were deposited in Pit 1 including 1.8 million m^3 transferred from the TSF by dredging. Transfer of tailings into Pit 1 ceased in December 2008 when tailings reached the maximum permitted level of -12 mRL, and deposition of tailings in the TSF resumed. Tailings are discharged to the TSF via a floating discharge pipe that is moved regularly to achieve an even deposition across the footprint of the dam.

Processing was suspended between 7 December 2013 and 5 June 2014 following the leach tank incident (section 3.2.2.6). ERA continued to progress plans for the closure of Pit 1 during the 2013–14 reporting period with pre-loading of the surface with coarse rock material completed to activate the installed dewatering wicks and assist in consolidation of the tailings

The average density of tailings in Pit 1 at June 2013 was 1.45 tm^3, which exceeds the minimum target density of 1.2 tm^3. The average density of tailings in the TSF at the end of reporting period was 1.05 tm^3.

3.2.2.3 Audit and Routine Periodic Inspections (RPIs)

Eleven inspections and one audit were undertaken at Ranger during the 2013–14 reporting period. The grading system used in the audit, shown in Table 3.5, is the same as that used by DME. Use of this ranking system ensures the outcomes of the Ranger auditing process are consistent with that for other mines in the Northern Territory.

TABLE 3.5 GRADING SYSTEM

Category 1 Non-Conformance (CAT 1)	A category 1 non-conformance refers to a situation where an identified activity is not in compliance with the Authorisation, approval document or applicable legislation and could result in a high risk or is a persistent Category 2 non-conformance.
Category 2 Non-Conformance (CAT 2)	A category 2 non-conformance relates to an isolated lapse of control or an identified activity that is not in compliance with the Authorisation, approval document or applicable legislation that could result in a low or moderate risk.
Conditional (C)	This includes items that have been identified during planning that meet the established criteria and have commenced but are yet to be completed.
Acceptable (A)	This includes items that have been identified during planning that meet the established criteria and have been completed.
Not Verified (NV)	This is where compliance with the item has not been assessed. This may also include items that have been identified during planning but have yet to commence.
Observation (O)	An area that has notably improved or has the potential to be improved, or is outside the scope of the audit but is notable.

Findings from the May 2013 environmental audit were followed up through the RPI process over the 2013–14 reporting period. The 2014 environmental audit of the Ranger mine was undertaken in May 2014. RPIs were carried out for each month of the 2013–14 reporting year with the exception of May. Table 3.6 shows the focus areas for the audit and RPIs for the year.

TABLE 3.6 AUDIT AND RPI

Date	Foci
18 July 2013	Fine crushing circuit, bioremediation area, Pit 1 tip head, land application areas.
15 August 2013	Brine concentrator, surface exploration area 19, western stockpiles.
19 September 2013	R3 Deeps exploration decline, CCD corridor, Pit 1.
17 October 2013	TSF contingency transfer system, Pit 1 backfill, GCBR, fine grinding, RP2.
14 November 2013	Pit 3 levee, surface exploration, brine concentrator, tailings storage facility (TSF) contingency pumping, Pit 1 backfill, GCBR/CCWLF status.
12 December 2013	Leach tank incident area.
16 January 2014	Leach tank incident cleanup, southern stockpile drainage, GC2 doppler installation, TSF contingency pump system, Pit 3 backfill, Pit 3 levee, bulk diesel unloading facility.
20 February 2014	Leach tank incident cleanup, levee borrow pit pumping, GCMBL/GCBR, TWWS sump, GCT2 area, Pit 1.
20 March 2014	Leach tank incident, exploration decline, brine concentrator.
10 April 2014	TSF, GCT2 area water management, Pit 3 backfill, Simon Carves yard.
12–15 May 2014	Audit: 2014 Ranger Radiation Protection Program, actions arising from the Light Vehicle Incident 03 November 2013, 2013 Surface Exploration Program, 2013 1 Year Weed Management Plan.
19 June 2014	TSF dredge ramp, Pit 3 levee, vent rise, Pit 3 backfill.

Audit outcomes

Closeout of findings from the May 2013 environmental audit

The May 2013 annual environmental audit delivered one category two Non-Conformance (see Table 3.5 for definitions). This was followed up via the monthly RPI process and closed out prior to the 2014 annual audit.

May 2014 environmental audit

The 2014 environmental audit of Ranger mine was held on 12–15 May 2014. The audit team was made up of representatives from the NLC, DME, GAC and SSD. The following documents were the subject of the 2014 audit:

- 2014 Ranger Radiation Protection Program
- Actions arising from the Light Vehicle Incident 03 November 2013 comprising:
    - ERA's list of improvements submitted to DME on 24 December 2013
    - DME's letter to ERA sent 11 March 2014
- 2013 Surface Exploration Program
- 2013 One Year Weed Management Plan

One hundred and thirty one commitments taken from the above documents and communications were audited against the grading system shown in Table 2.5. The following significant findings were determined:

- Four Category2 Non-Conformances
    - a non-exempt radioactive source omitted from the source inventory
    - no formal process for recording random radiation checks
    - no signage on laboratory radioactive source store room
    - no surface radiation management of exploration drill sites.
- Twenty two conditional findings

The audit team provided a further 37 observations throughout the audit and reported to ERA in the closing meeting and via an audit report. All other findings were ranked as acceptable or not verified. SSD will continue to follow up on all identified issues and ensure the close-out of corrective actions through the RPI process.

3.2.2.4 Minesite Technical Committee

The Ranger MTC met six times during 2013–14. Dates of meetings and issues discussed are shown in Table 3.7. Significant agenda items discussed at MTCs included updates from ERA on site activities including water management and inventories, exploration decline and brine concentrator projects, TSF to Pit 3 tailings dredging, updates from the Ranger Closure Criteria Working Group, the findings of the Independent Surface Water Working Group, Pit 3 levee, Pit 3 backfill and Pit 1 preload. The Ranger MTC meeting of 13 December 2013 was specially convened to discuss the Leach Tank incident of 7 December 2013.

3.2.2.5 Authorisations and approvals

There were no changes to the Ranger Authorisation during the reporting period.

The following applications were approved by the MTC during the reporting period:

- Pit 1 pre-load stage 2 (July 2013)
- Approval to discharge brine concentrator distillate

  - to RP2 (September 2013)
  - to Corridor Creek Wetland Filter (CCWLF) (November 2013)
  - to RP1 and CCWLF (January 2014)
- Surface exploration additional drilling (October 2013)
- Application to increase the wet season TSF MOL (December 2013)
- Exploration decline phase 2 design realignment (March 2014)
- TSF dredge ramp pre-load (May 2014)

TABLE 3.7 RANGER MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items in addition to standing items
6 September 2013	ISWWG recommendations and outcomes, brine concentrator, pond water brine treatment, contingency pumping.
15 November 2013	Brine concentrator distillate release, contingency pumping system, exploration decline ventilation shaft modifications, surface exploration programme.
13 December 2013	MTC update on leach tank incident.
17 February 2014	ISWWG recommendations and outcomes, Pit 1 settlement, dredge access to TSF, Gulungul Creek EC spikes, Ranger Water Quality Objectives, exploration decline update and phase 2 footwall access.
28 March 2014	ISWWG recommendations and outcomes, dredge access to TSF, Gulungul Creek EC spikes.
9 May 2014	Exploration decline, 2014 surface exploration programme, CCWLF vegetation.

3.2.2.6 Incidents

Background to incident investigation

Since 2000, ERA has undertaken to provide stakeholders with a comprehensive list of environmental incidents reported at its Ranger and Jabiluka operations on a regular basis. The regular monthly environmental incident report is additional to reports made to meet the statutory requirements for incident reporting. This regime of reporting all recorded environmental incidents is undertaken voluntarily by ERA in response to concerns expressed by stakeholders about the establishment of suitable thresholds of incident severity for reporting.

During the 2013–14 reporting period, a total of 41 environmental incidents were reported to SSD.

Immediately upon receipt of notification of any incident, SSD assesses the circumstances of the situation and a senior officer makes a decision on the appropriate level of response. Dependent on the assessment, this response will range from implementation of an immediate independent investigation, through to seeking further information from the mine operator before making such a decision. In those cases where immediate action is not considered to be required, the situation is again reviewed on receipt of a formal incident investigation report from the operator.

Prior to each RPI (see section 3.2.2.3), the inspection team reviews the previous month's environmental incident report summary (EIRS) and any open issues. Where an incident is considered to have any potential environmental significance or represents a repetition of a class of occurrences, an on-site review of the circumstances is scheduled as a part of the routine inspection agenda.

SSD determined that the following incidents that occurred during the reporting period were of a serious enough nature to warrant a separate independent investigation.

Light Vehicle Incident

On the night of 3 November 2013, a controlled vehicle was taken from the Ranger mine without authorisation through a gap in the tailings dam fence. The vehicle was clean and presented no risk to the environment or human health. The incident was investigated independently by SSD including conducting a site visit, collecting documentary evidence and interviewing key staff.

It was determined that the staff members in question had received adequate training, were aware that they were breaking company procedure and actively sought to avoid detection. Notwithstanding, the report made several recommendations which may assist in the prevention of a similar incident occurring in the future.

Product Drum Incident

On 18 November 2013, SSD received notification from ERA that four suspected Ranger uranium mine product drums had been found in bushland off Malachite Road in Noonamah, approximately 40 km south east of Darwin.

The independent investigation by SSD determined that the drums originated from Ranger, but had not been used for storage of uranium. The drums had been cleared prior to release from site in accordance with site clearance procedures and taken off site by an individual in October 2005 and subsequently discarded, at the location they were found, in 2010. Analysis by SSD of soil and drum contents for radionuclides and metals did not detect any evidence of anomalous radioactive material.

Leach Tank Incident

At 00:54 on 7 December 2013, Leach Tank No. 1 at Ranger mine collapsed, spilling approximately 1 400 m^3 of slurry containing ground uranium ore, water and sulphuric acid into the processing area. The Supervising Scientist was advised of the incident at 06:20 on 7 December 2013, with SSD staff on-site that morning to assess the scale of the incident and begin analyses of potential environmental impacts.

No one was injured as a result of the incident and the spill remained within the processing area with an unknown quantity of slurry reporting to RP2.

A joint Commonwealth/NT Government Taskforce, with representation from the SSD, the Australian Government Department of Industry, DME, Northern Territory WorkSafe, NLC and GAC, was established to coordinate the various incident investigations.

The SSD investigation was confined to the assessment of the potential impacts on human health and the off-site environment, including Kakadu National Park, as a result of the incident. The SSD investigation did not consider the cause of the leach tank failure, nor did it consider issues related to the condition of the Ranger uranium mine processing facility, as these were the subject of ongoing investigations by DME and Northern Territory WorkSafe.

In assessing the environmental impacts from this incident, SSD undertook a comprehensive array of monitoring activities that included both on-site and off-site sampling and analyses of surface water, groundwater, radiation and soils. In addition, Geoscience Australia was commissioned by SSD to investigate the potential impacts to groundwater and to the off-site environment via the groundwater pathway as a result of the spill.

Based on the results of the investigation, it was the conclusion of the Supervising Scientist that the leach tank failure did not result in any adverse impacts to human health or the surrounding environment, including Kakadu National Park.

Dose to workers involved in the cleanup activities was low and of no consequence to human health. No increase in airborne radionuclide concentrations as a result of the incident was detected at the SSD monitoring stations in Jabiru town or at Jabiru East, indicating no impact to residents in the surrounding area.

Chemical and biological monitoring by SSD in Magela Creek did not detect any effects related to the incident. Limited groundwater data available in the area of the spill, and the six week timeframe for ERA to commence the requested groundwater monitoring programme, restricted the level of groundwater analysis that could be undertaken. However sufficient information was available to conclude that only a small volume of contaminants may have entered the groundwater due to the generally compacted nature of soils in the plant area. Therefore, infiltration of leachate would not have had any significant impact on groundwater quality in the off-site environment.

The report included two recommendations: one from Geoscience Australia's groundwater assessment; and one from the Supervising Scientist's soil contamination investigation works. The report also notes that the release of a substantial volume of process material is not in accordance with the *Environmental Requirements of the Commonwealth of Australia for the operation of the Ranger Uranium Mine.*

The Supervising Scientist published a report, Supervising Scientist's Report 207 (SSR207), on 28 August 2014.

3.2.3 Off-site environmental protection

3.2.3.1 Surface water quality

Under the Authorisation, ERA is required to monitor and report on water quality in Magela and Gulungul creeks adjacent to the Ranger mine. Specific water quality objectives must be achieved in Magela Creek.

The Authorisation specifies the sites, frequency of sampling and the analytes to be reported. Each week during the wet season, ERA reports the water quality to the major stakeholders (SSD, DME, NLC and GAC) at key sites, including Magela and Gulungul Creeks upstream and downstream of the mine. A detailed interpretation of water quality across the site is provided at the end of each wet season in the ERA Ranger Annual Wet Season Report.

In addition to ERA's monitoring programme, SSD conducts an independent surface water quality monitoring programme that includes measurement of chemical and physical variables and biological monitoring in Magela and Gulungul creeks, as well as other reference creeks and waterbodies in the region. Key results are presented in time-series charts throughout the wet season on the internet at www.environment.gov.au/ssd/monitoring/index.html. The highlights of the monitoring results from the 2013–14 wet season are summarised below.

Chemical and physical monitoring of Magela Creek

Since the 2010–11 wet season, SSD has used continuous monitoring of EC, turbidity and water temperature coupled with event-based automatic sampling as their primary water quality monitoring method. In comparison to the less effective weekly grab sampling method, the continuous monitoring method has substantially enhanced SSD's ability to independently detect changes in water quality through time. Manual grab samples are still collected during routine site visits for the purposes of quality control and to analyse radium. Map 2 shows the location of the upstream (MCUGT) and downstream (MCDW) monitoring sites and key Ranger mine features.

Flow was first recorded at the Magela Creek upstream and downstream monitoring stations on 28 November 2013, which is also when the water quality sensors at the downstream site were first submerged. Only the turbidity sensors at the upstream site were submerged on 28 November 2013 (Figure 3.2), with the EC and pH sensors, which are located above the turbidity sensors, becoming submerged on 2 December 2013 (Figures 3.3 and 3.4).

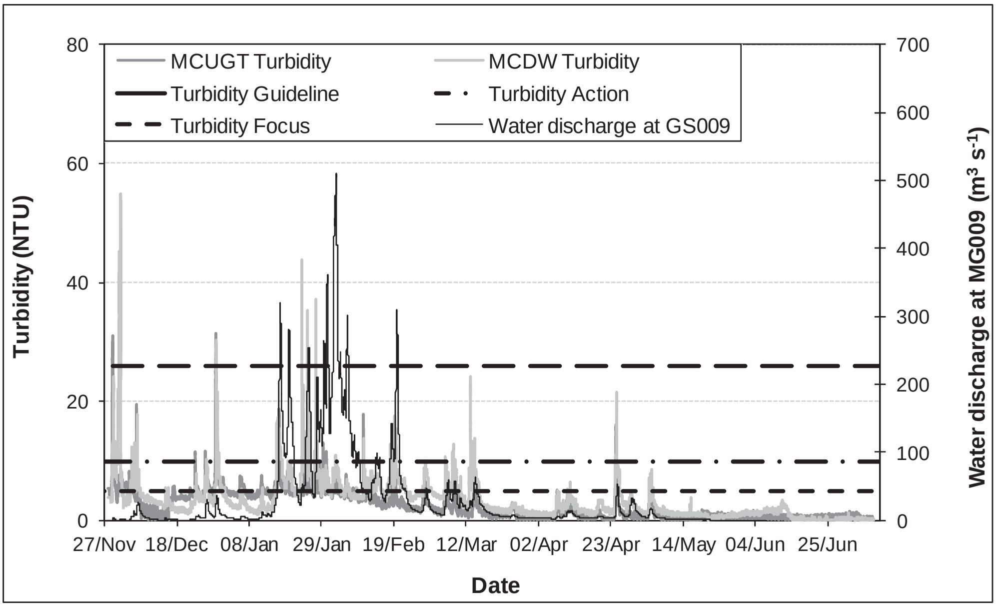


Figure 3.2 Continuous monitoring of turbidity and water discharge in Magela Creek during the 2013–14 wet season.

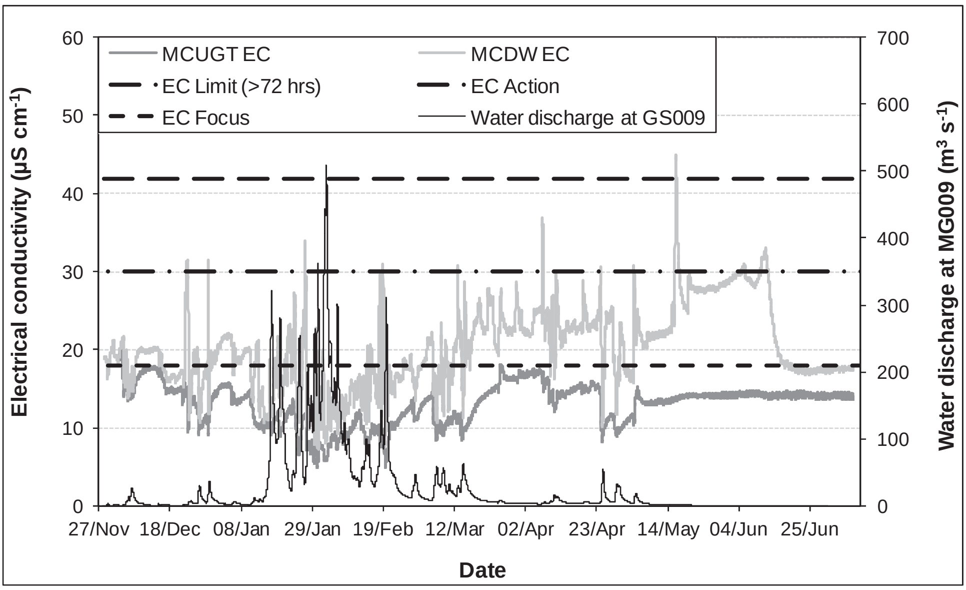


Figure 3.3 Continuous monitoring of electrical conductivity (EC) and water discharge in Magela Creek during the 2013–14 wet season.

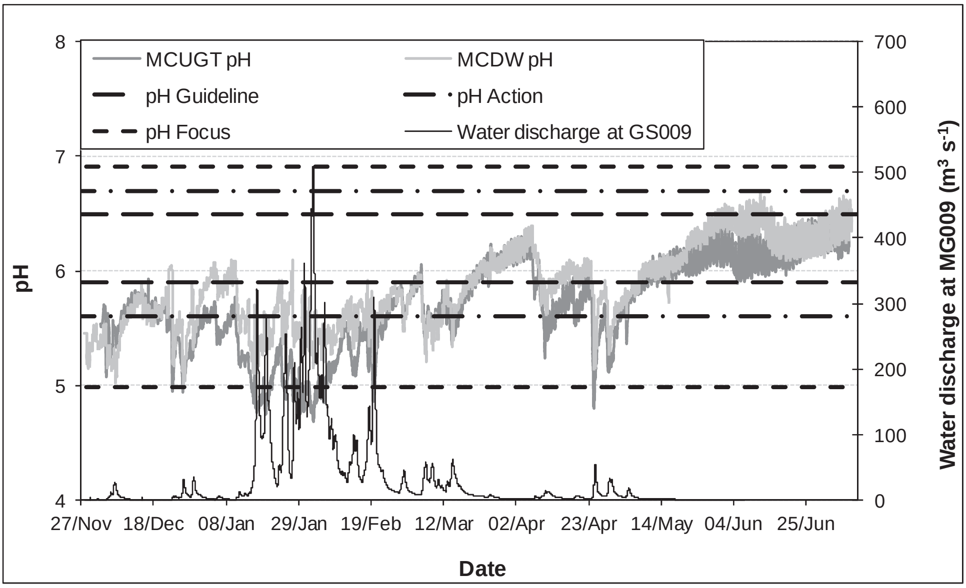


Figure 3.4 Continuous monitoring of pH and water discharge in Magela Creek during the 2013–14 wet season.

In response to the leach tank failure at Ranger mine on 7 December 2013 (section 3.2.2.6), SSD increased the monitoring frequency within Magela Creek. This was part of the incident investigation to confirm that there was no impact on the external environment or human health, and that the surrounding environment, including Kakadu National Park, remained protected. Results received showed that concentrations of uranium, manganese and magnesium remained significantly below the ecotoxicologically-derived water quality objectives.

On 22 December 2013, an isolated heavy rainfall event occurred in the Georgetown Creek catchment with 64 mm recorded by ERA at GC2 compared to only 22 mm at the Jabiru Airport. This resulted in an influx of surface water down the Georgetown system, with an EC of around 130 µS cm^{-1} at ERA's monitoring site GC2 and 94 µS cm^{-1} in Georgetown Billabong. The flow in Magela Creek was less than 5 cumecs and the pulse of surface water from Georgetown Billabong was observed at the downstream site where the EC peaked at 31 µS cm^{-1} (Figure 3.3). The corresponding EC measured at the upstream site during this period was 16 µS cm^{-1}. During this EC event an automatic sample was triggered at MCDW, which had elevated magnesium (1.7 mg L^{-1}) and sulfate (3.0 mg L^{-1}) concentrations. The event remained below the chronic exposure limit for magnesium of 3.0 mg L^{-1}. Uranium concentration was low at 0.19 µg L^{-1}, which is approximately 3% of the ecotoxicologically-derived limit of 6 µg L^{-1} (Figure 3.5).

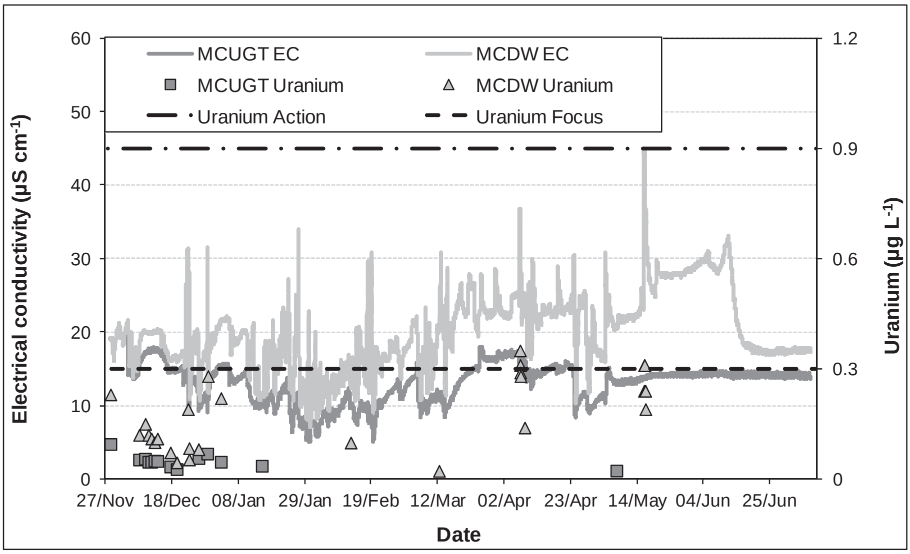


Figure 3.5 Continuous EC and total uranium concentrations in Magela Creek during the 2013–14 wet season.

Manganese concentrations were also below the ecotoxicologically-derived trigger values (Figure 3.6).

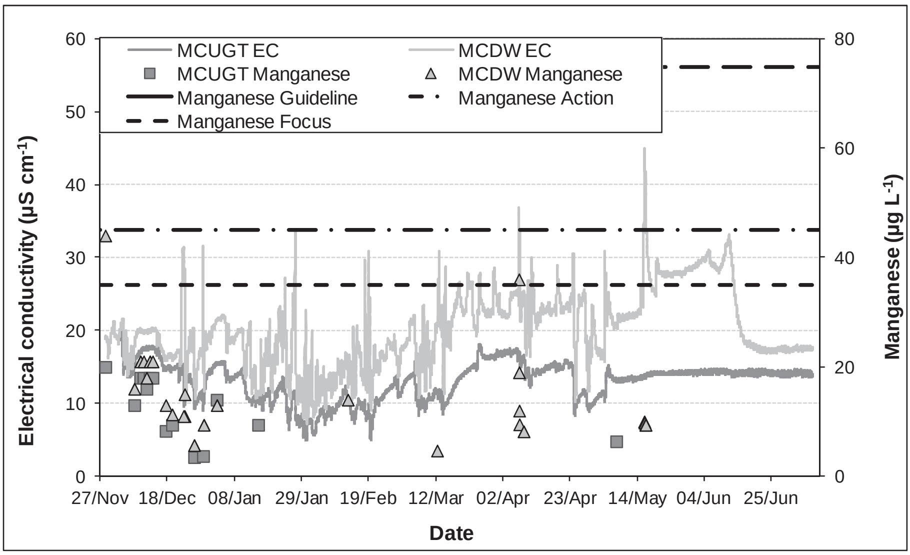


Figure 3.6 Continuous EC and total manganese concentrations in Magela Creek during the 2013–14 wet season.

On 29 December 2013, elevated EC was observed at the downstream site, with EC peaking at 36 µS cm^{-1} with a corresponding upstream EC of 12 µS cm^{-1} (Figure 3.3). This increase in EC downstream of the mine was also observed by ERA, at its continuous monitoring sites located in all three channels of Magela Creek (MG009E, MG009C, MG009W). The fact that the EC signal occurred prior to managed release of RP1 waters and was observed in all three channels downstream of the mine (indicating mixing), suggests that the likely source was surface water from Georgetown Billabong which at the time, had an EC of around 95 µS cm^{-1}.

Sampling was automatically triggered by a timer, with two samples collected, over the Christmas period on 29 December 2013, as shown in Figure 3.7. The upstream sample was triggered at 03.33 am and the downstream sample was triggered at 09.15 am. The magnesium and sulfate concentrations were higher in the downstream sample as would be expected with the higher EC at the time. The uranium concentration downstream was marginally higher at 0.28 µg L^{-1} however this is still low at approximately 5% of the ecotoxicologically derived limit.

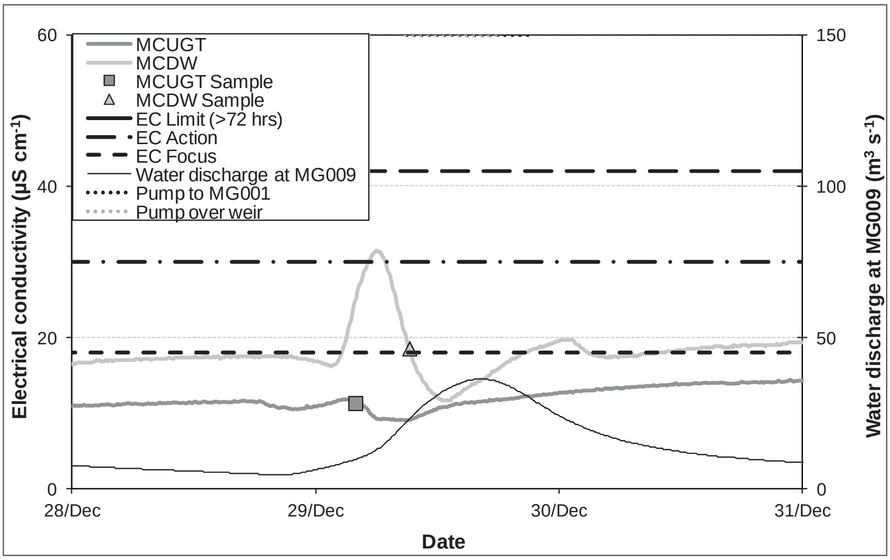


Figure 3.7 Magela Creek continuous monitoring data showing a peak in EC at the downstream monitoring site (MCDW) during late December 2014.

From late December 2013, the EC downstream of the mine diverged from the background EC measured upstream of the mine, which occurs each wet season once flows from Coonjimba and Georgetown billabongs into Magela Creek are established.

On 27 January 2014, there was an EC peak of 34 µS cm^{-1} at the downstream monitoring site (Figure 3.8). The peak occurred during a decrease in Magela Creek water level and is likely to be due to Coonjimba Billabong inflow to Magela Creek. At the time, the EC of Coonjimba Billabong was around 150 µS cm^{-1} and the EC of RP1 was around 270 µS cm^{-1} (ERA monitoring data). As the EC peaks were below the auto-sampler activation trigger of 42 µS cm^{-1} no samples were collected.

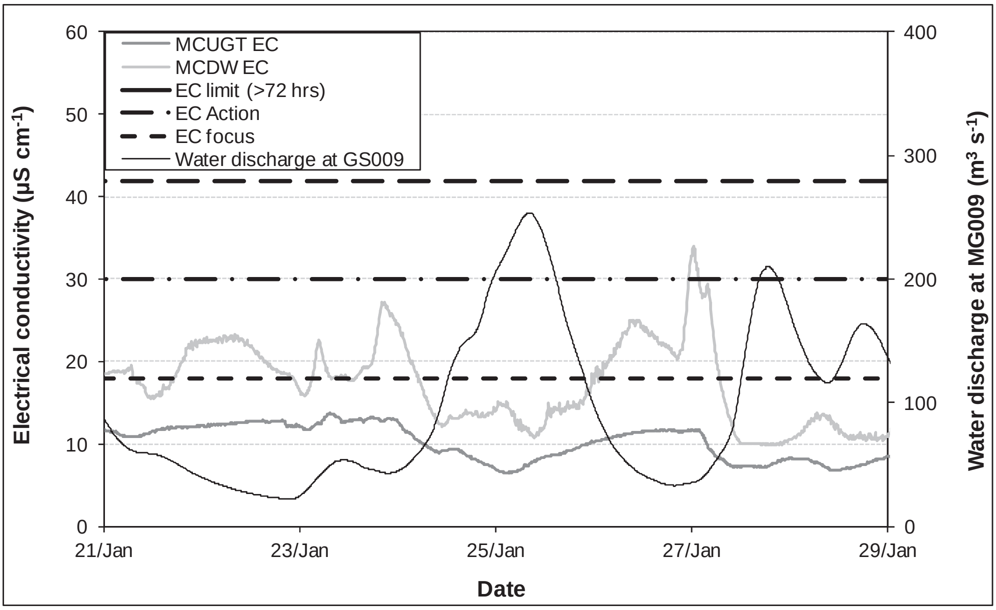


Figure 3.8 Magela Creek continuous monitoring data showing peaks in electrical conductivity at the downstream monitoring site (MCDW) during late January 2014.

High turbidity levels are common in Magela Creek during the early wet season due to first flush effects. Historically, the mine site does not contribute substantial amounts of suspended sediment to Magela Creek and, therefore, has little influence on the turbidity at the downstream site. Occasionally, turbidity spikes are observed at the downstream site without an accompanying spike at the upstream site, indicating that the source of suspended sediment lies between the two sites. From 23–28 January 2014, there were three turbidity peaks which occurred at MCDW, but which were not detected upstream at MCUGT (Figure 3.9). These coincided with intermittent rainfall events associated with the monsoonal trough over northern Australia during late January, and were due to surface run-off from localised rainfall. Water quality objectives are currently being developed for continuously monitored turbidity.

There was little rainfall over the first two weeks of February 2014, and the decrease in stream discharge led to increased pH levels. The inverse relationship between pH and water level in the creek is explained by the slightly acidic nature of the incident rainfall in the region (Noller et al. 1990[1]). Water quality objectives are currently being developed for continuously-monitored pH.

[1] Noller BN, Currey NA, Ayers GP & Gillett RW 1990. Chemical composition and acidity of rainfall in the Alligator Rivers Region, Northern Territory, Australia. Science of the Total Environment 91, 23–48.

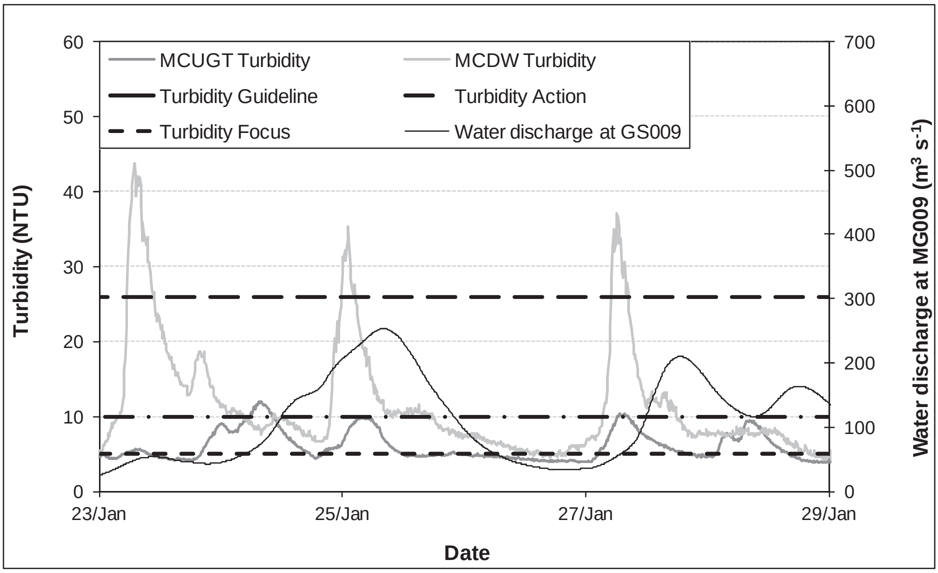


Figure 3.9 Magela Creek continuous monitoring data showing peaks in turbidity at the downstream monitoring site (MCDW) during late January 2014.

Uranium concentrations recorded within Magela Creek were all below the Focus trigger value of 0.3 µg L^{-1} with the exception of two samples collected on 6–7 April 2014, which contained 0.35 µg L^{-1} and 0.31 µg L^{-1}, respectively (Figure 3.5). This is approximately 6% of the ecotoxicologically-derived limit.

Manganese concentrations were also very low (Figure 3.6). Only two samples at MCDW were recorded above the Focus trigger value of 35 µg L^{-1} with concentrations of 44 µg L^{-1} on 28 November 2013 and 36 µg L^{-1} on 6 April 2014. The manganese trigger values only apply when creek flow is above 5 cumecs. At the time of sample collection, on both occasions creek, flow was below 3.5 cumecs and, thus, the trigger values are not relevant.

During late February and March, the water level in Magela Creek had decreased leading to increased EC levels, generally fluctuating with each rainfall event. Automatic samples were triggered during two EC events in April and May 2014.

EC peaked at 37 µS cm^{-1} (above the Action trigger value) at 00:40 hours on 7 April 2014 in response to surface water run-off from a rainfall event flushing solutes into the creek. A total of 41 mm of rainfall was recorded at Jabiru Airport. Despite the EC peak remaining below the chronic (>72 hour) Limit, four samples were collected based on the rate of rise of the EC sample trigger. These samples contained magnesium concentrations above the Action trigger value of 2 mg L^{-1}, with a maximum magnesium concentration of 2.4 mg L^{-1}.

A localised rainfall event occurred during the night of 15 May 2014, with 76 mm of rainfall recorded at the Jabiru Airport. This rainfall flushed higher conductivity water from Georgetown and Coonjimba Billabongs (95 µS cm^{-1} and 182 µS cm^{-1} respectively, as sampled on 12 May 2014), resulting in an increase of EC at the Magela Creek downstream site. The EC event lasted for 5 hours and peaked at 45 µS cm^{-1}. Given the EC toxicity limit for an event of 5 hours is 580 µS cm^{-1}, it is unlikely this event was of environmental significance. Five samples were collected due to an automatic triggering caused by the EC event, two of which contained magnesium concentrations equal to or above the Chronic Limit trigger value of 3 mg L^{-1}, with a maximum magnesium concentration of 3.1 mg L^{-1} (Figure 3.10). The corresponding results for sulphate are shown in Figure 3.11.

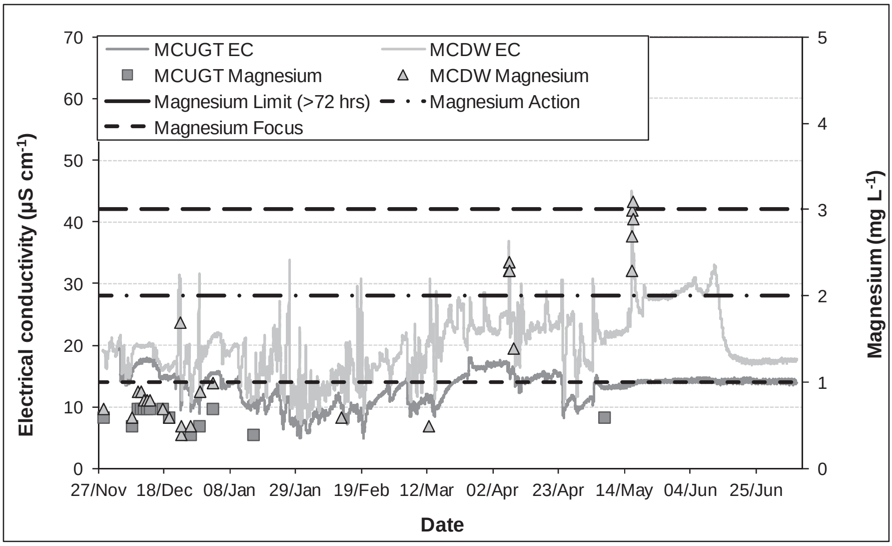


Figure 3.10 Continuous EC and total magnesium concentrations in Magela Creek during the 2013–14 wet season.

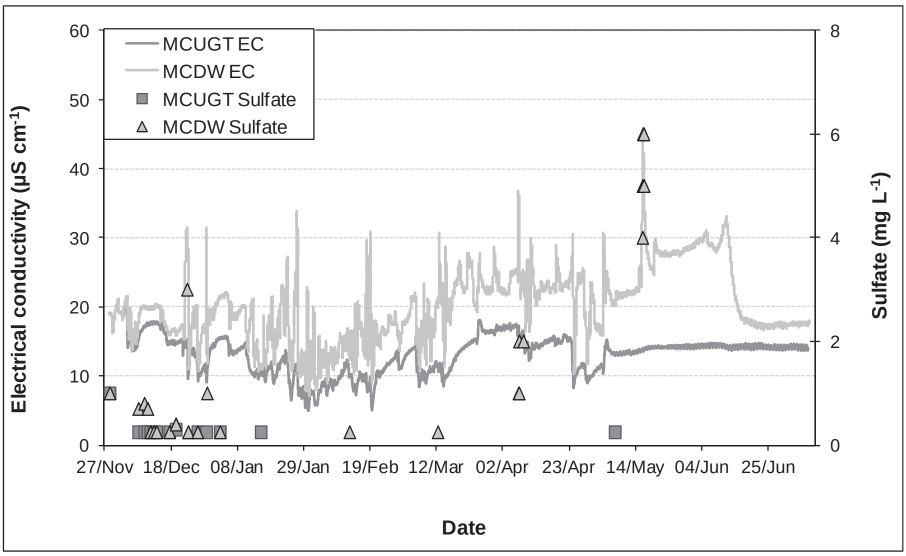


Figure 3.11 Continuous EC and total sulfate concentrations in Magela Creek during the 2013–14 wet season.

In December 2013, ecotoxicologically-derived water quality objectives for total ammonia nitrogen (TAN) were formally adopted for Magela Creek as part of the regulatory approval for brine concentrator distillate release. Results received to date have shown that levels of

TAN in Magela Creek are very low with a highest recorded concentration of 0.016 mg L^{-1} at MCDW on 12 December 2013, which is approximately 2% of the 0.7 mg L^{-1} Guideline trigger value (Figure 3.12).

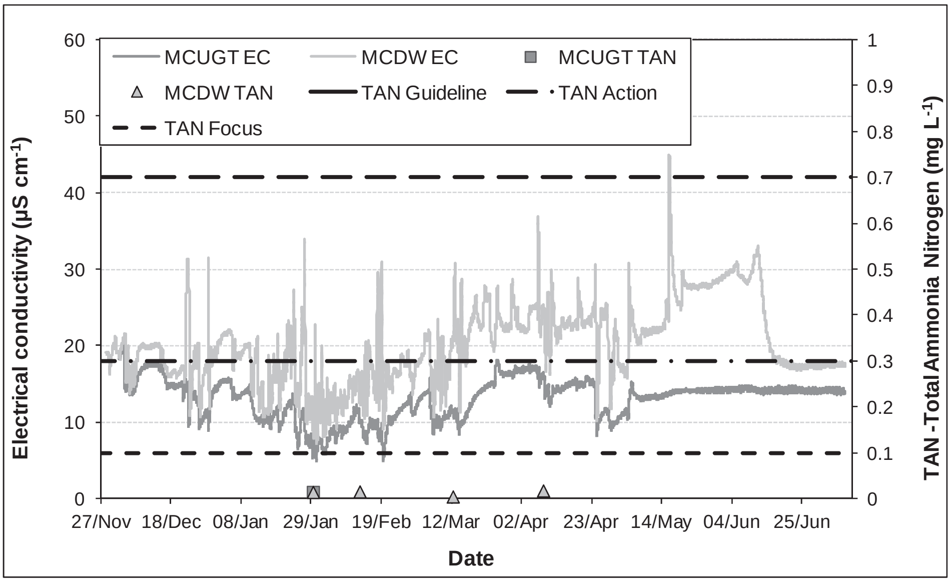


Figure 3.12 Continuous EC and total ammonia nitrogen concentrations in Magela Creek during the 2013–14 wet season.

Recessional flow conditions commenced in late May. Historically recessional flow has resulted in a gradual convergence of EC at MCUGT and MCDW. It was noted on 10 June 2014 that EC at the downstream site was still diverging from the upstream site. The higher EC at MCDW and ongoing divergence with MCUGT was caused by low flow in Magela Creek coupled with water entering from Georgetown Billabong. This late flow from Georgetown Billabong resulted from WTP system permeate being released to the CCWLF. Following a query from the Supervising Scientist, ERA ceased the release of WTP permeate on 10 June 2014 resulting in the almost immediate convergence of EC at MCUGT and MCDW.

Continuous monitoring continued until cease to flow was agreed by stakeholders on 21 July 2014.

Overall, the water quality measured in Magela Creek for the 2013–14 wet season showed higher EC at the downstream monitoring site compared to 2012–13. This is not surprising as the 2012–13 wet season featured below average rainfall and a low volume of water discharged from the mine site (185 ML compared to 1670 ML in 2013–14). However the observed EC was within ranges observed in previous wet seasons of average (and above average) rainfall. Analysis of the current and historic EC peaks at the downstream monitoring site show that the EC peaks are substantially below the Limit for EC pulses < 72 hours, which indicates that the aquatic environment in the creek has remained protected from mining activities (Figure 3.13).

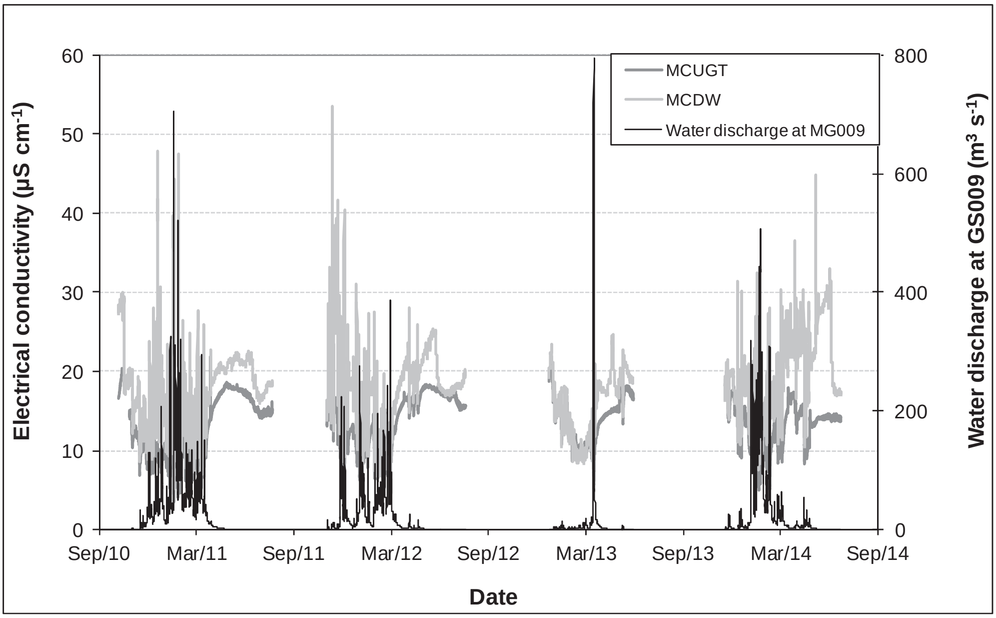


Figure 3.13 Continuous electrical conductivity and discharge in Magela Creek for each wet season between September 2010 and June 2014 (values averaged over a 90 minute period of measurement).

Radium in Magela Creek

Surface water samples are collected fortnightly from Magela Creek upstream and downstream of the Ranger mine. The fortnightly samples are combined to give monthly composite samples for each site. Total radium-226 (^{226}Ra) is measured in these samples and results for the 2013–14 wet season are compared with previous data ranging back to the 2001–02 wet season in Figure 3.14. The sample results for 2013–14 were within the historic range observed in Magela Creek since 2001.

During 7–13 December 2013, ^{226}Ra samples were collected in response to the leach tank incident and analysed individually. A routine composite sample was not obtained during this time. Consequently, the average ^{226}Ra activity concentration of these samples has been included as a proxy composite sample for December 2014 and used in the calculation of the 2013–14 wet season median difference.

Since 2010, ^{226}Ra analyses on composited event-based samples (collected during EC-triggered events) have also been performed. A single composite sample, comprising five samples collected during an EC event on 15–16 May 2014, was analysed during the 2013–14 wet season. The result is shown in Figure 3.14, together with the results from the incident sampling and routine radium analyses. The EC-triggered event data are not included in the calculation of the wet season median difference, because these EC events are short-lived and their impact on seasonal ^{226}Ra loads is very small.

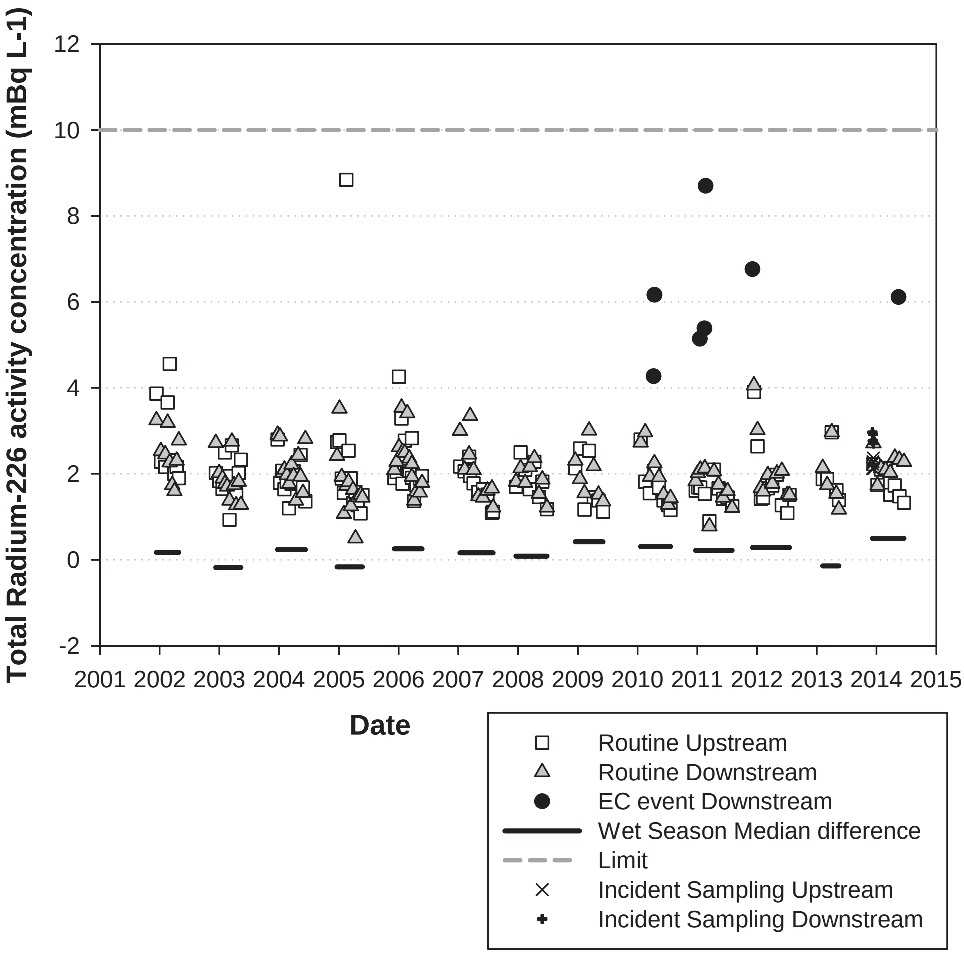


Figure 3.14 ^{226}Ra in Magela Creek 2001–2014.

The data from monthly sample composites show that the levels of ^{226}Ra are very low in Magela Creek, both upstream and downstream of the Ranger mine. An anomalous ^{226}Ra activity concentration of 8.8 mBq L^{-1} measured in a sample collected from the control site upstream of Ranger in 2005 was probably due to a higher contribution of ^{226}Ra-rich soil or finer sediments that are present naturally in Magela Creek. This has previously been discussed in the 2004–05 Supervising Scientist's Annual Report.

The limit value for total ^{226}Ra activity concentrations in Magela Creek has been defined for human radiological protection purposes, and is based on the median difference between upstream and downstream ^{226}Ra activity concentrations over one entire wet season. The median of the upstream ^{226}Ra data collected over the current wet season is subtracted from the median of the downstream data. This difference value, called the wet season median difference, quantifies any increase at the downstream site, and should not exceed 10 mBq L^{-1}.

A wet season median difference of 10 mBq L^{-1}would result in a mine origin ingestion dose from ^{226}Ra bioaccumulated in mussels of about 0.3 mSv, if 2 kg of mussels were ingested by a 10 year old child. Wet season median differences (shown by the horizontal lines in Figure 3.14) from 2001 to 2014 are close to zero, indicating that the great majority of ^{226}Ra is coming from natural sources of ^{226}Ra located in the catchment upstream of the mine. The wet season median difference for the entire historical monitoring period (2001–14) is 0.1 mBq L^{-1}.

The wet season median difference for the 2013–14 wet season is 0.5 mBq L^{-1}, indicating a slightly higher median ^{226}Ra value for the downstream monitoring site than for the upstream monitoring site. This result is approximately 5% of the 10 mBq L^{-1}Limit. Whilst being the greatest wet season median difference since 2001, the result was only marginally increased compared to the range of variation observed in previous years and the individual sample results for 2013–14 were well within the historic range.

Chemical and physical monitoring of Gulungul Creek

Flow was first recorded at the Gulungul Creek upstream monitoring site (GCUS) on 28 November 2013. Flow was not recorded at the downstream monitoring site (GCDS) until 4 December 2013. The multi-probes at GCDS were only partially submerged in mid-December, which resulted in gaps in the continuous EC data (Figure 3.15).

During 21–23 December 2013, Jabiru Airport received 22.4 mm of rain. This resulted in increased surface run-off with EC and turbidity peaks recorded at both GCUS and GCDS. This is typical of first flush effects observed early in the wet season, and the increased water level submerged all water quality sensors at GCDS. The EC peaked at 46.5 µS cm^{-1} at GCUS and 34.8 µS cm^{-1} at GCDS. Turbidity fluctuated, reaching 11.3 NTU at GCUS and 6.1 NTU at GCDS (Figure 3.16). A number of event-based samples were triggered at the upstream site and the analysis results show corresponding peaks in magnesium and manganese concentrations, but little change in uranium and sulfate concentrations. In distinction from the dominant mine site signature of magnesium sulfate, the major ions (anions and cations) of the upstream Gulungul catchment are dominated by magnesium hydrogen carbonate [or magnesium bicarbonate - $Mg(HCO_3)_2$]. Hence, the lack of change in the sulfate concentrations during this event indicates a natural catchment influence rather than a mine site input.

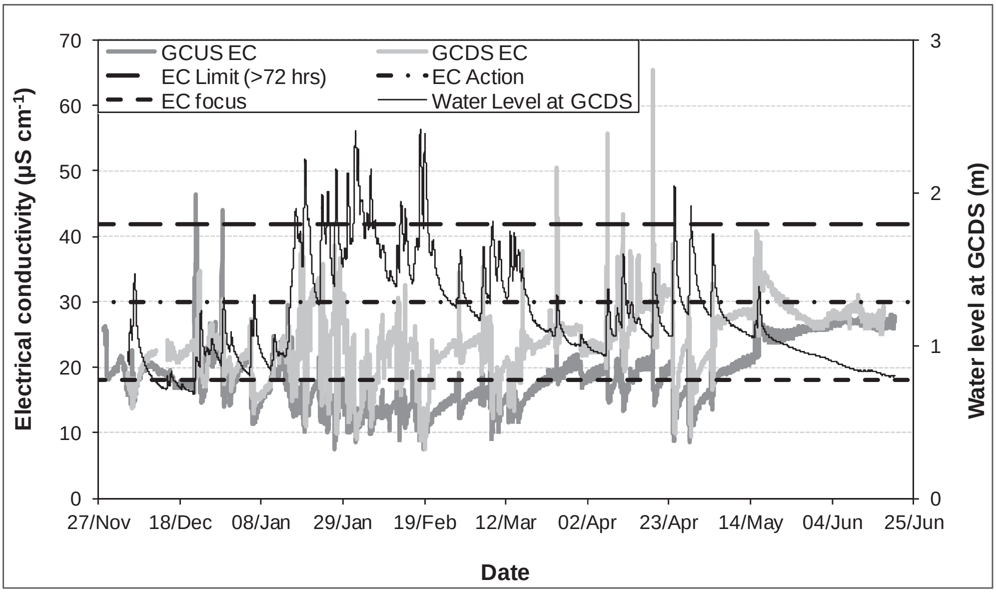


Figure 3.15 Continuous monitoring of EC and water level in Gulungul Creek during the 2013–14 wet season.

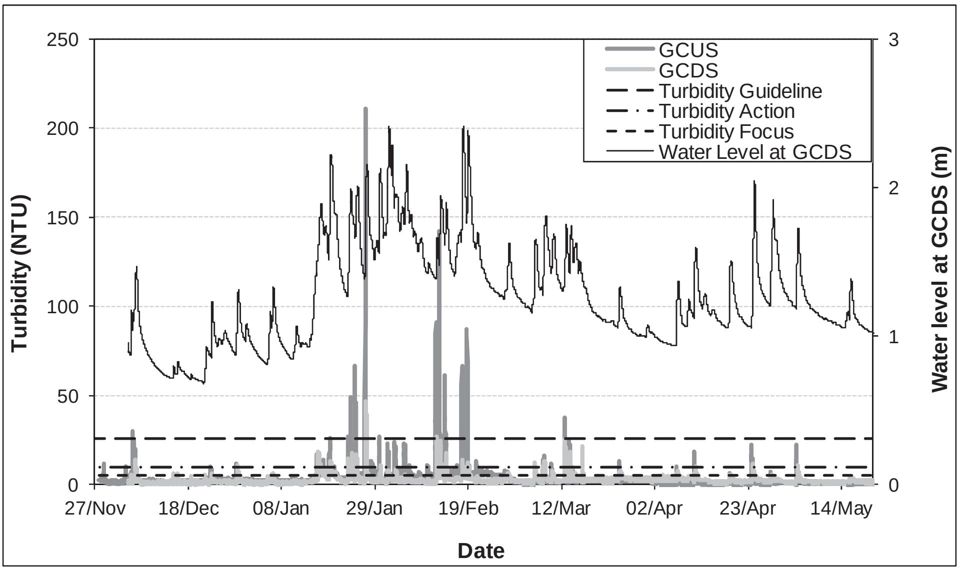


Figure 3.16 Continuous monitoring of turbidity and water level in Gulungul Creek during the 2013–14 wet season.

An EC event was measured at GCDS on 18 January 2014, with a peak of 41.1 µS cm^{-1}. The event-based samples collected showed a maximum uranium concentration of 0.22 µg L^{-1}, which is approximately 4% of the ecotoxicologically-derived limit. Further EC peaks > 30 µS cm^{-1} were observed at GCDS from 20–28 January 2014 (Figure 3.18) and 12–14 February 2014 (Figure 3.19). On 19 January 2014, the ERA continuous monitoring at

Gulungul Creek left bank (GCLB) recorded a 3 hour EC event that peaked at 184.2 µS cm^{-1} (Figure 3.17). However, the ecotoxicologically-derived framework for EC pulses provides an EC limit of 1040 µS cm^{-1} for a 3 hour EC event, indicating that the environment is unlikely to have been impacted. Nevertheless, such EC events are of some concern and, hence, prompted additional investigations by SSD, as detailed below.

The SSD continuous monitoring station GCDS, which is located approximately 1 km downstream of the ERA station, GCLB, typically detects all EC events that are detected at GCLB (Figure 3.17). However, the peak of 184.2 µS cm^{-1} observed at GCLB on 19 January 2014 was not detected at GCDS, which recorded an EC of < 25 µS cm^{-1} throughout the duration of the event. This indicates poor mixing of Gulungul Creek waters, as SSD's monitoring station is located on the western bank of the creek and GCLB is located on the eastern bank. It also indicates that the source of the high EC waters is from the mine side of the creek and, after entering the creek, the water may have flowed downstream close to the eastern bank, hence, not being detected at GCDS. The poor mixing in the creek may have been exacerbated by incoming flows from the left bank tributary located upstream of GCDS (Figure 3.17).

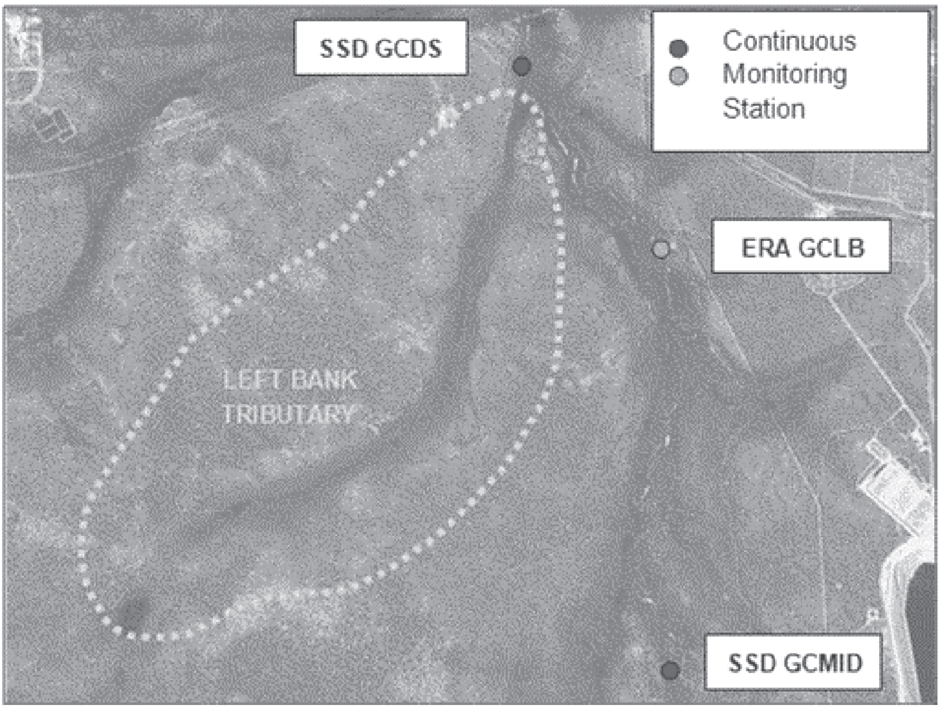


Figure 3.17 Gulungul Creek continuous monitoring stations.

SSD is undertaking a number of investigations to determine the source of the solutes causing the EC peaks at the downstream sites and to better understand the extent and nature of the cross channel variation in EC at GCDS. To inform these investigations, a number of small data loggers, measuring conductivity, temperature and depth (CTD), were deployed at key sites in the Gulungul catchment during the 2013–14 wet season.

The first CTD logger was installed on the eastern bank, opposite the GCDS monitoring station (GCDS East Bank) on 23 January 2014. The recorded data showed that Gulungul Creek water is generally well mixed, with similar EC measured at both banks. However, occasionally the east bank EC was up to 15 µS cm^{-1} greater than the west bank EC (Figures 3.18 and 3.19). This indicates that the source of solutes is likely to be from the eastern bank, being the mine side, of the creek.

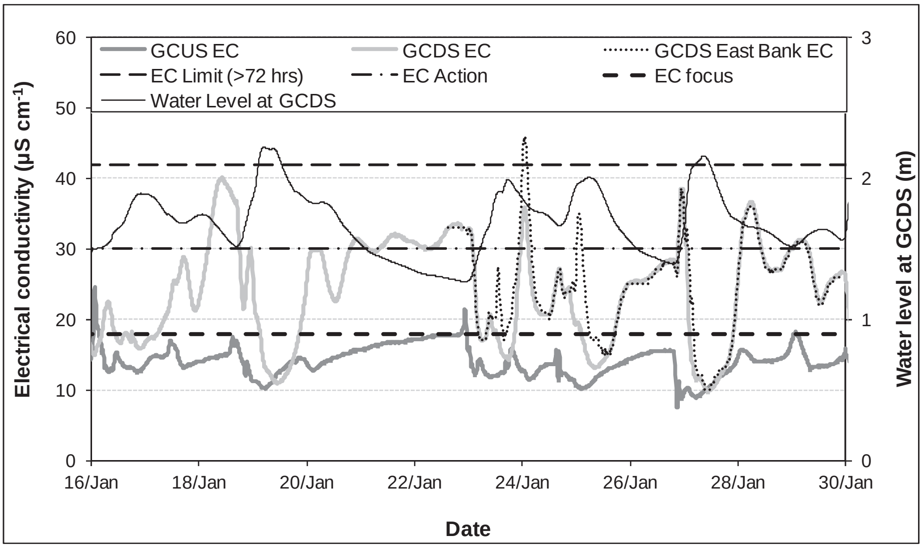


Figure 3.18 Gulungul Creek continuous monitoring data showing peaks in electrical conductivity at GCDS and GCDS East Bank during mid-late January 2014.

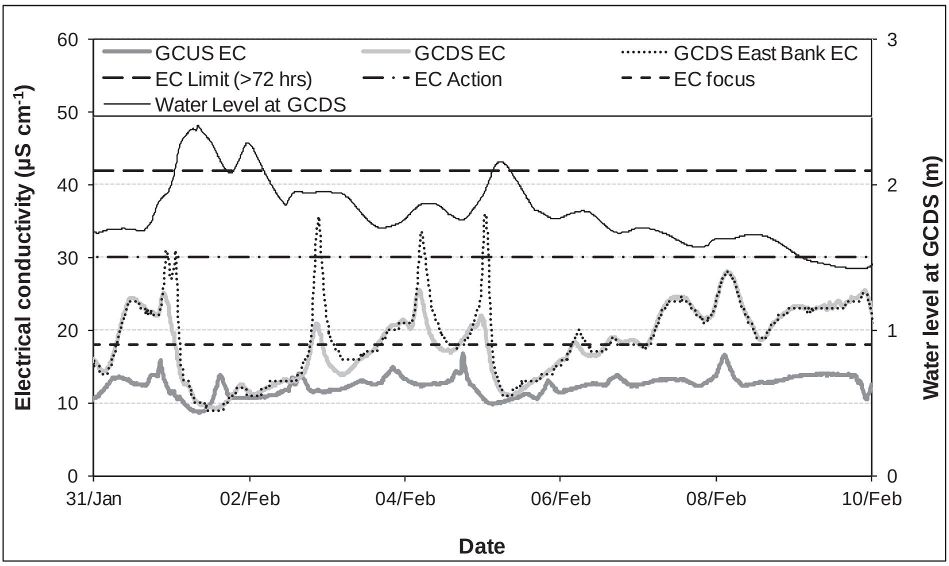


Figure 3.19 Gulungul Creek continuous monitoring data showing peaks in electrical conductivity at GCDS and GCDS East Bank during early February 2014.

On Monday 3 March 2014, SSD staff visited the Gulungul Creek area to the west of the Ranger TSF to investigate the source of recent EC events noted at the ERA downstream site.

EC readings were taken at a number of locations in the standing water along the Radon Springs track, with a range of 15–25 µS cm^{-1} observed. Location 1 in Figure 3.20, is the intersection point of the Gulungul Creek Tributary Site 2 (GCT2) drainage line and the Radon Springs track. Recorded EC in the small flowing stream at location 1 was in the range of 1250–1300 µS cm^{-1}. This stream was tracked to its confluence with Gulungul Creek (location 2, Figure 3.20) and an EC reading of approximately 500 µS cm^{-1} was obtained at that location. The low volume of in-flow from the high EC tributary was quickly diluted once it entered the main Gulungul Creek channel. SSD collected water samples and deployed a CTD logger at locations 1 and 2.

The data collected during these investigations are currently being analysed and will be reported in the near future. To ensure that the surface water chemistry monitoring programme carried out by SSD detects and samples all EC events occurring downstream of the mine, a new continuous monitoring station will be installed on the eastern bank of the creek, just downstream of GCLB, prior to the 2014–15 wet season. This station will be equipped with duplicate EC sensors and an auto-sampler.

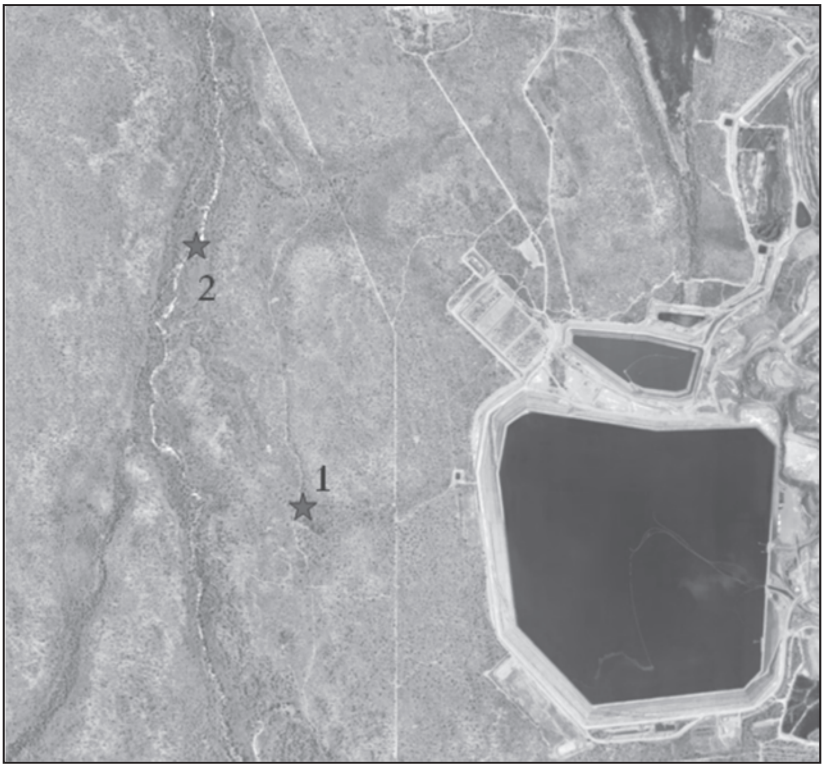


Figure 3.20 Location of SSD EC loggers installed on 3 March 2014 to investigate the water quality of GCT2.

On 26 January 2014, a large turbidity event occurred at the upstream monitoring site GCUS in response to a rainfall event, with 68 mm recorded at GCUS, and subsequent rising creek flow. The magnitude of the turbidity peak at GCUS was 211 NTU occurring at 20:40 hours (Figure 3.21). This is the sixth time that a turbidity peak >150 NTU has been recorded at GCUS since continuous monitoring of turbidity began in the 2003–04 wet season. At 02:20 hours on 27 January 2014, the turbidity signal from the event reached GCDS and was substantially diluted, with a maximum turbidity of 49 NTU. The SSD is currently undertaking a geomorphological assessment to identify the source of the turbidity.

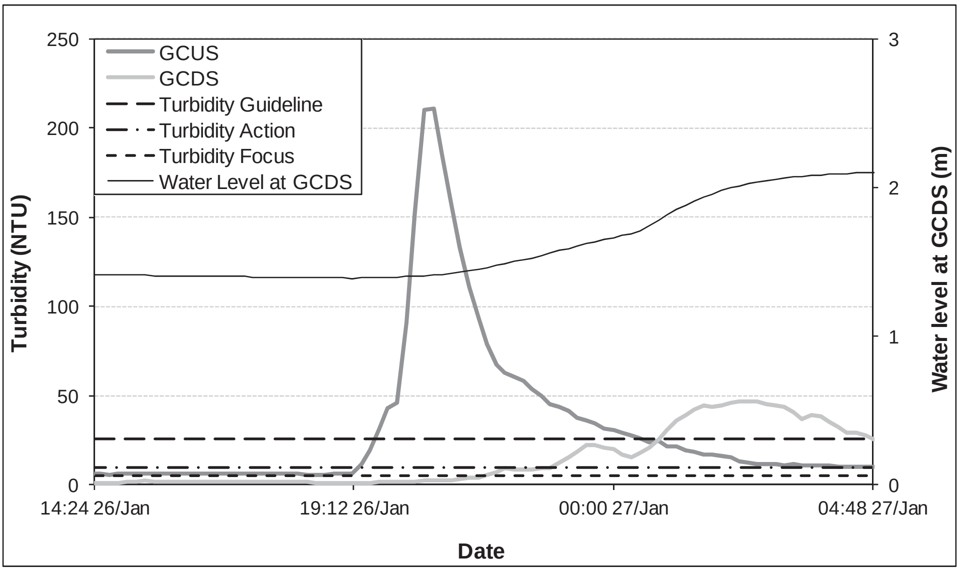


Figure 3.21 Gulungul Creek continuous monitoring data showing a peak in turbidity at the upstream monitoring site (GCUS) on 26 January 2014.

Uranium concentrations recorded within Gulungul Creek were all below the Focus trigger value of 0.3 µg L^{-1} (Figure 3.22). The maximum uranium concentration was 0.29 µg L^{-1} recorded at GCUS on 21 December 2013 at 20:25 hours. This is approximately 5% of the ecotoxicologically-derived Limit.

Manganese concentrations were also very low in Gulungul Creek, with all samples recording concentrations below the Focus trigger value of 35 µg L^{-1} (Figure 3.23). The maximum manganese concentration was 12 µg L^{-1} recorded at GCDS on 12 December 2013 at 10:48 hours. This is 16% of the ecotoxicologically-derived limit.

Magnesium concentrations measured during 2013–14 were generally low with the exception of automatic samples triggered for an EC peak at GCDS on 18 April 2014. The GCDS EC event had two samples with magnesium concentrations above the chronic (>72 hour) Limit trigger value of 3 mg L^{-1}. The maximum magnesium concentration was 4.0 mg L^{-1} at 20:30 hours (Figure 3.24). The corresponding sulfate concentration was 12 mg L^{-1} (Figure 3.25). EC remained above the chronic (>72 hour) Limit of 42 µS cm^{-1} for 3 hours duration. The ecotoxicologically derived framework for EC pulses provides a magnesium limit of

94 mg L^{-1} for pulses under 4 hours duration so this magnesium concentration of 4.0 mg L^{-1} is unlikely to have impacted the environment.

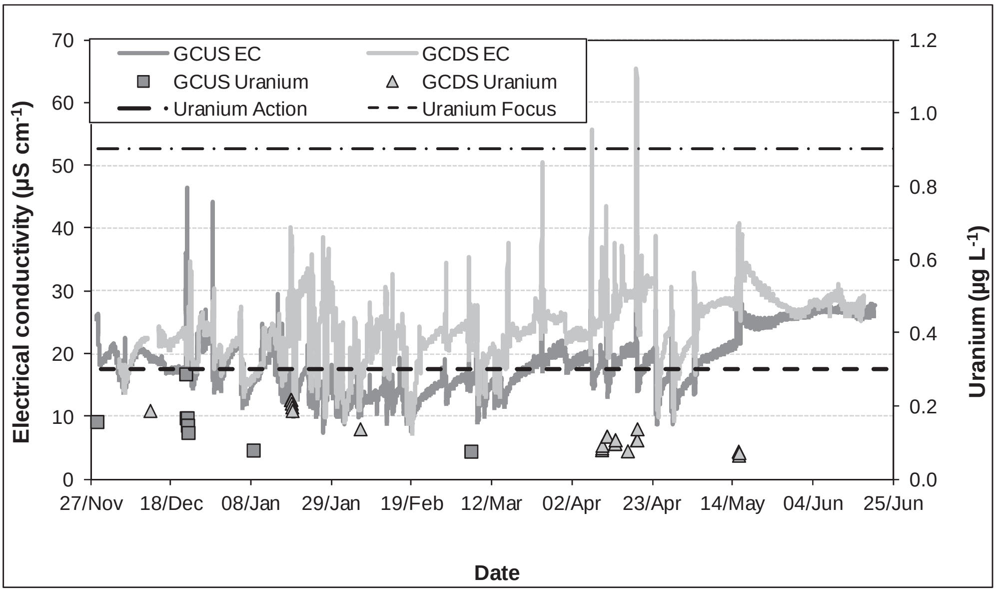


Figure 3.22 Uranium concentration and continuous monitoring of EC in Gulungul Creek during the 2013–14 wet season.

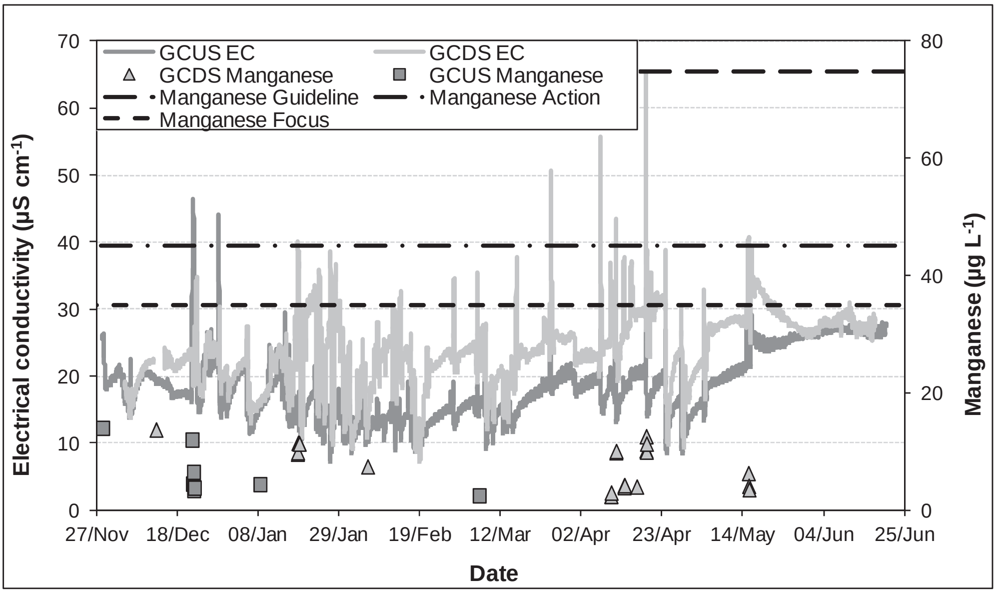


Figure 3.23 Manganese concentration and continuous monitoring of EC in Gulungul Creek during the 2013–14 wet season.

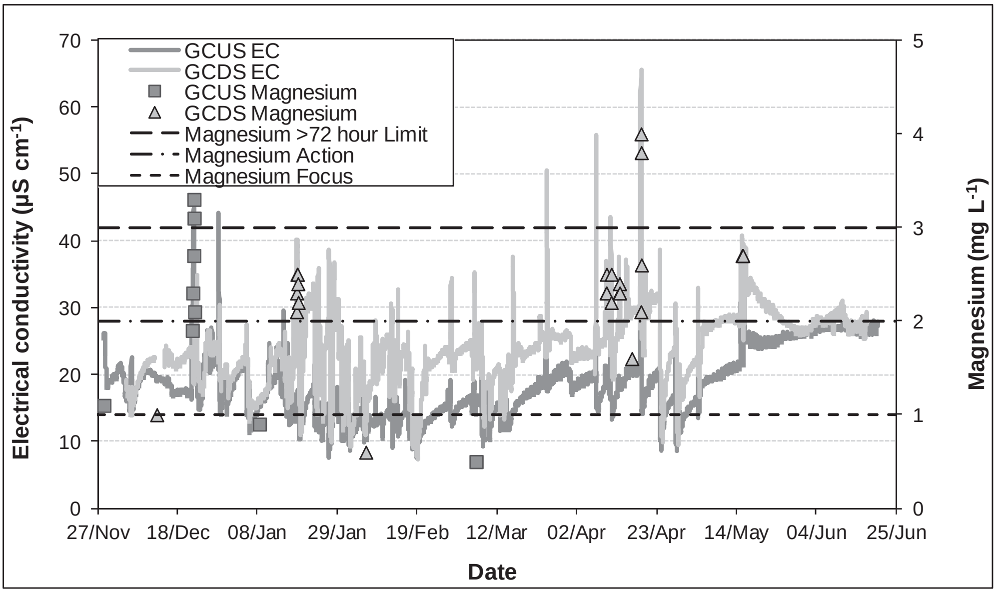


Figure 3.24 Magnesium concentration and continuous monitoring of EC in Gulungul Creek during the 2013–14 wet season.

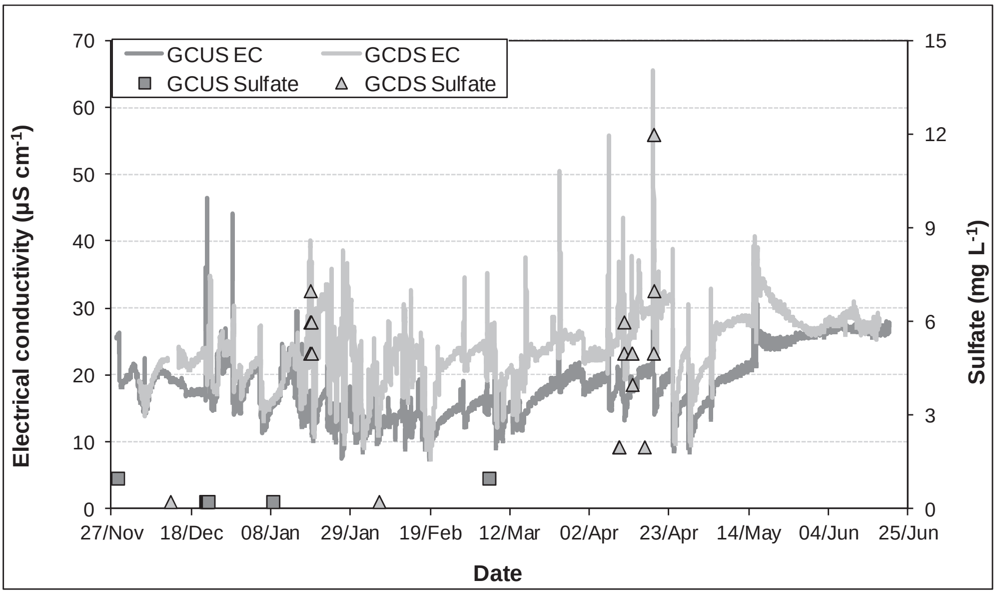


Figure 3.25 Sulfate concentration and continuous monitoring of EC in Gulungul Creek during the 2013–14 wet season.

During late February and March, the water levels within Gulungul Creek decreased, leading to gradually increasing EC levels, fluctuating with each rainfall event.

EC peaked at 51 µS cm^{-1} at 03:30 hours on 25 March 2014 and at 55 µS cm^{-1} at 02:00 hours on 7 April 2014 in response to rainfall events flushing solutes into the creek. The total rainfall recorded at Jabiru Airport for these events was 20 mm and 41 mm, respectively. During late March and early April, hardware malfunctions occurred in the auto sampler trigger mechanism and then the turbidity probe, which meant that no water samples were collected during these EC events. SSD is looking to increase the capacity of the autosampling equipment at GCDS by installing an additional sampler for the 2014–15 wet season so there are dedicated EC and turbidity samplers, as used in Magela Creek downstream.

The duration of the EC peaks above the chronic (>72 hour) Limit of 42 µS cm^{-1} was 4 hours 10 minutes on 25 March 2014 and 3 hours 15 minutes on 7 April 2014. The ecotoxicologically-derived framework for EC pulses provides EC limits of 1040 µS cm^{-1} for pulses under 4 hours EC peak duration and for the 4 hour 10 minute duration the derived Limit is 1010 µS cm^{-1}. Thus, with recorded EC peaks of 51 µS cm^{-1} and 55 µS cm^{-1} respectively, the environment is unlikely to have been impacted.

On 18 April 2014 at 21:00 hours, EC peaked at the downstream monitoring site (GCDS) at 65 µS cm^{-1} and remained above the chronic (>72 hour) Limit of 42 µS cm^{-1} for 3 hours duration (Figure 3.26). The ecotoxicologically-derived framework for EC pulses provides EC limits of 1040 µS cm^{-1} for pulses under 4 hours EC peak duration so this EC peak of 65 µS cm^{-1} is unlikely to have impacted the environment. The source of these EC events is likely to be rainfall flushing solutes from the GCT2 drainage line as discussed above.

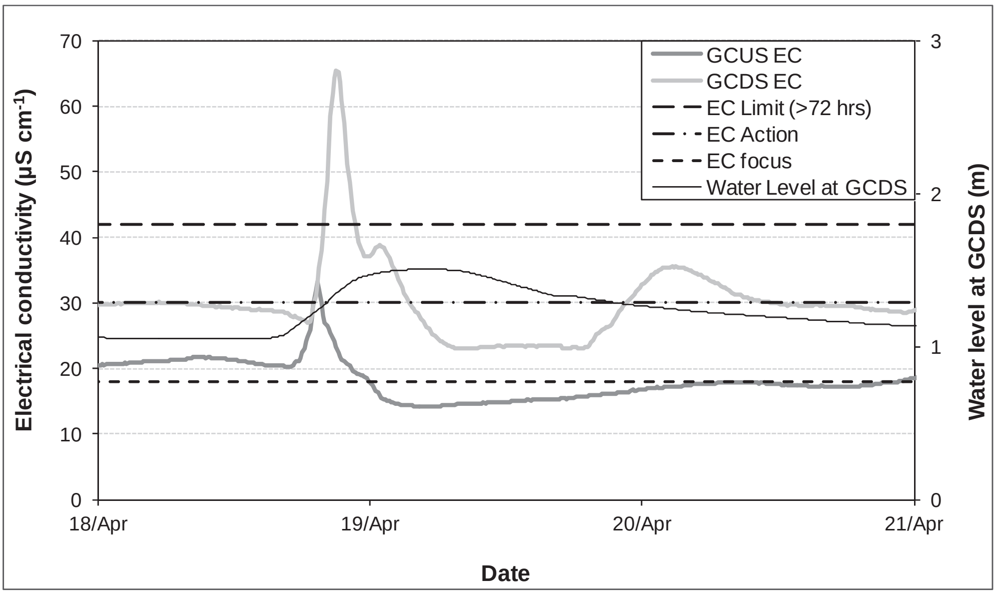


Figure 3.26 Gulungul Creek continuous monitoring data showing a peak in EC at the downstream monitoring site (GCDS) on 18 April 2014.

Rainfall events during April and early May increased flow levels and resulted in small decreases in EC and increases in turbidity.

A localised rainfall event occurred during the night of 15 May with 76 mm of rainfall recorded at the Jabiru Airport. Runoff from this rainfall event caused an increase in EC at the Gulungul Creek downstream site, peaking at 41 µS cm^{-1}. This is below the chronic toxicity limit of 42 µS cm^{-1} and not of environmental significance.

Recessional flow conditions became established in May 2014. Continuous monitoring continued until 20 June 2014 when the multi-probes were out of the water and could not be lowered any further. Cease to flow was agreed by stakeholders on 23 June 2014.

Overall, the water quality measured in Gulungul Creek for the 2013–14 wet season showed higher EC at the downstream monitoring site compared to previous wet seasons due to high EC inputs from the GCT2 tributary. However, analysis of the EC peaks at the downstream monitoring site show that the EC peaks are substantially below the Limit for EC pulses < 72 hours, which indicates that the aquatic environment in the creek has remained protected from mining activities (Figure 3.27).

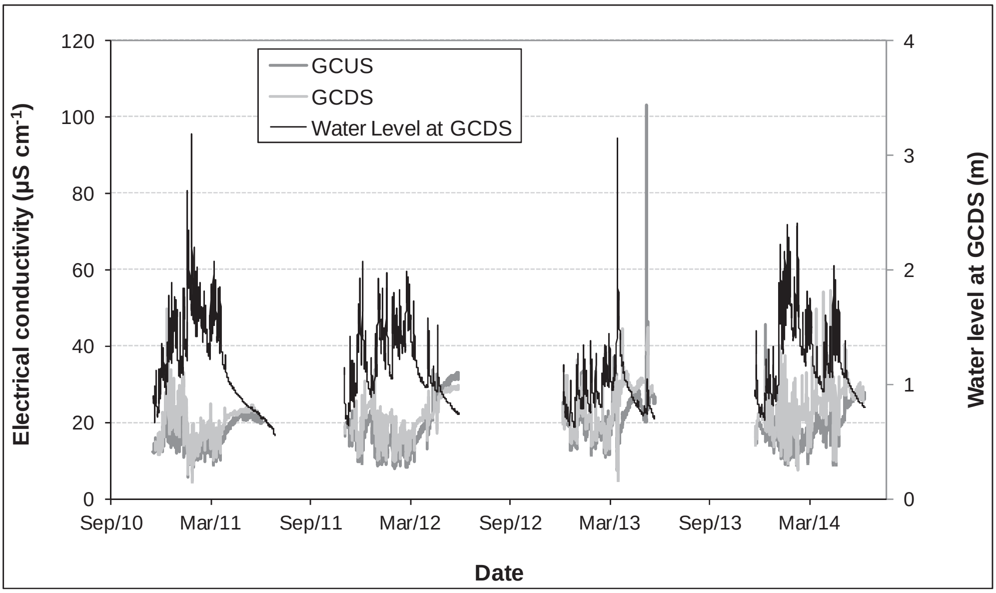


Figure 3.27 Continuous electrical conductivity and discharge in Gulungul Creek for each wet season between September 2010 and June 2014 (values averaged over a 90 minute period of measurement).

3.2.3.2 Biological monitoring in Magela Creek

Research conducted by ***eriss*** since 1987 has been used to develop biological techniques to monitor and assess the potential effects of uranium mining on aquatic ecosystems downstream of Ranger mine. Two broad approaches are used: (1) early detection, and (2) assessment of overall ecosystem-level responses at the end of the wet season.

Early detection of effects in Magela Creek is performed using two techniques: (i) *in situ* toxicity monitoring for detection at a weekly timescale of effects arising from inputs of mine waters during the wet season, and (ii) bioaccumulation, used to measure over a seasonal timescale a potential developing issue with mine-derived solutes (metals and radionuclides) measured in aquatic biota.

For ecosystem-level responses, benthic macroinvertebrate and fish community data from late wet season sampling at sites in Magela and Gulungul creeks are compared with historical data and data from control sites in streams unaffected by contemporary mining.

The findings from toxicity monitoring, bioaccumulation, and fish and macroinvertebrate community studies conducted during the 2013–14 reporting period are summarised below.

In situ toxicity monitoring

In this form of monitoring, effects on receiving waters of water dispersed from the Ranger minesite are evaluated using responses of aquatic animals exposed *in situ* to creek water. The response measured is reproduction (egg production) in the freshwater snail, *Amerianna cumingi*. Each test runs over a four-day (96-hr) exposure period. In such sub-chronic, continuous exposure situations, this species has been shown to be among the most sensitive, to both uranium and magnesium, of SSD's suite of six local species, as determined using standardised laboratory toxicity test protocols.

For the 1990–91 to 2007–08 wet seasons, toxicity monitoring was carried out using the 'creekside' methodology (Figure 3.28A). This involved pumping a continuous flow of water from the adjacent Magela Creek through tanks containing test animals located under a shelter on the creek bank. In the 2006–07 wet season, an *in situ* testing method commenced, in which test animals are placed in floating (flow-through) containers located in the creek itself (see section 3.2 of the 2007–08 Supervising Scientist Annual Report for details). Thus, for the 2006–07 and 2007–08 wet seasons, creekside and *in situ* testing were conducted in parallel, to evaluate the effectiveness of the *in situ* method. For current data analyses, creekside data up to and including the 2005–06 wet season and in situ data from the 2006–07 wet season onward (Figure 3.28) are combined. The most recent refinement to this programme has been the extension of toxicity monitoring to Gulungul Creek, with testing commencing in the 2009–10 wet season (Figure 3.28B).

The first of 12 tests in Magela Creek commenced on the 5 December 2013, seven days after the establishment of continuous flow in both creeks. The leach tank failure that occurred on 7 December 2013 (see references to the incident in earlier sections of this report) thus coincided with the first test in Magela Creek. Following the incident, three more weekly tests in Magela Creek followed before the commencement of the first of nine Gulungul tests (from 9 January 2014). Thereafter, the Gulungul tests alternated weekly with Magela tests. A combined total of 21 tests were completed over 22 wet season weeks, the highest number of tests yet for a wet season, with the final test completed in Magela Creek on the 28 April 2014. Upstream and downstream egg production and difference values for both creeks are displayed in Figure 3.28B.

In the previous (2012–13) wet season, a marked increase in overall egg production was observed compared to the previous five wet seasons. This above-average increase in egg production continued in both creeks in the 2013–14 wet season (Figure 3.28B). As reported in the 2012–13 Supervising Scientist Annual Report (sections 3.2.3.2 and 4.4) and in section 4 of the current report, a significant factor contributing to this appears to be a more effective culturing regime for the snails at the laboratory aquaculture facility.

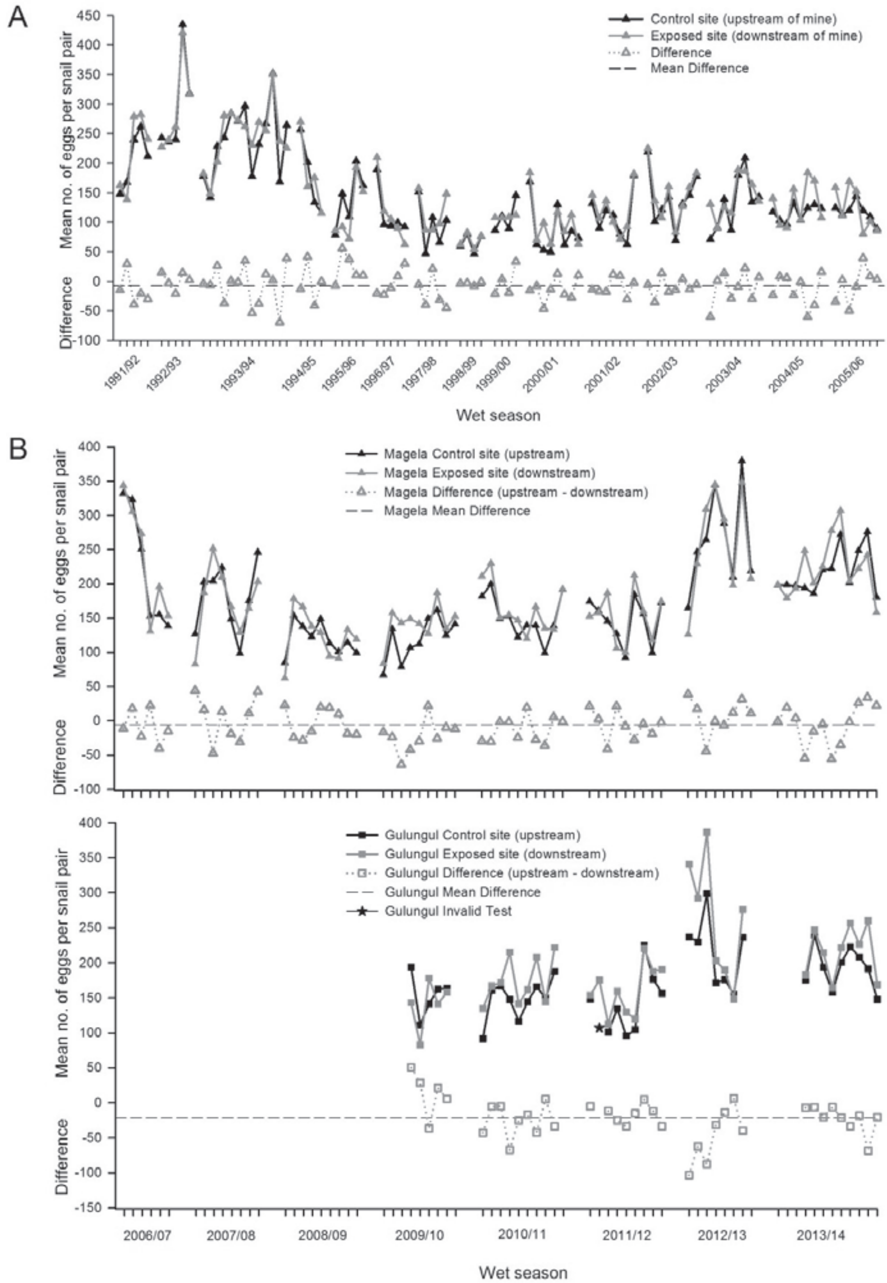


Figure 3.28 Time-series of snail egg production data from toxicity monitoring tests conducted in Magela Creek using A: creekside tests, and B: *in situ* tests with Gulungul tests commencing in 2009–10.

Analysis of results

After each wet season, toxicity monitoring results for the tests are analysed, with differences in egg numbers (the 'response' variable) between the upstream (control) and downstream (exposed) sites tested for statistical change between the wet season just completed and previous wet seasons. This Before-After Control-Impact Paired (BACIP) design, with analysis of variance (ANOVA) testing, is described further in the Supervising Scientist's Annual Report for 2007–2008 (section 2.2.3).

Magela Creek

The historical trend of greater downstream egg production was evident for the 2013–14 wet season, with a mean difference value of -5.21 (mean difference value across all wet seasons of -7.17). ANOVA results for the 2013–14 wet season, together with results from the past several wet seasons, are displayed in Table 3.8. No significant difference was observed between the difference values derived from the 2013–14 wet season and those from previous wet seasons (p = 0.865). The (near-)significant differences observed in previous years, associated with particularly high egg production at the downstream site relative to the upstream site in the 2009–10 wet season, and lower egg production at the downstream site relative to the upstream site in the 2012–13 wet season (Table 3.8), are discussed in the respective Supervising Scientist annual reports.

TABLE 3.8 RESULTS OF ANOVA TESTING COMPARING MAGELA UPSTREAM-DOWNSTREAM DIFFERENCE VALUES FOR MEAN SNAIL EGG NUMBER FOR DIFFERENT 'BEFORE VERSUS AFTER' WET SEASON SCENARIOS

Before	After	Probability value (*P*)	Significance
All previous seasons	2009–10	0.043	at 5% level
All previous seasons	2010–11	0.436	NS
All previous seasons	2011–12	0.916	NS
All previous seasons	2012–13	0.076	NS
All previous seasons	2013–14	0.865	NS

NS = Not significant

Gulungul Creek

The mean difference value across all Gulungul Creek tests for 2013–14, of -22.5, continued the trend of greater egg production downstream reported in previous years. ANOVA testing found no significant difference between the 2013–14 difference values and those recorded in previous wet seasons (p = 0.898).

Apart from the primary Before/After factor and associated hypothesis, the particular two-factor ANOVA model used for toxicity monitoring also allows variation amongst years (or wet seasons) and among tests within a wet season to be estimated separately. The second 'Season' factor can be used to determine whether, within the Before and After periods, any set of difference values for a wet season is significantly different. For Gulungul Creek, the Season factor has been significant since the 2011–12 wet season (inclusive), with a significant value of 0.003 for the 2013–14 wet season (cf Magela Creek where this factor has never been significant). A significant Season factor does not in itself imply potential mine-related impact; in this (Gulungul) case, it highlights the high inter-annual variation observed in seasonal difference values, as shown in Figure 3.28B and as reported in the previous Supervising Scientist Annual Report (2012–13).

Assessment and conclusions for both creek systems

As reported in both the last Supervising Scientist Annual Report (2012–13) and in section 4.4.2 of this report, water temperature and EC influence snail egg laying response in Magela and Gulungul creeks. (Values of water temperature and EC representing each test are the median of 10 minute continuous readings taken across the four-day exposure period at each of the creek sites.) An interacting effect between water temperature and EC has been observed (section 4.4.2). As EC increases (generally across the range ~7-30 $\mu S\ cm^{-1}$), egg production:

- increases at lower water temperature ranges (27–30°C), and
- decreases (i.e. negative effect) at higher water temperatures (>30°C) (see Figure 4.7).

These findings may usefully be applied to interpreting annual toxicity monitoring results in Magela and Gulungul creeks. While the water quality relationships have limited use in explaining the *magnitude* of egg production at a site, they can generally explain the *difference*, + or –, in egg production between the paired upstream and downstream sites. Unlike the below-average rainfall in the 2012–13 wet season, rainfall during the 2013–14 wet season was above average (Figure 3.1), which resulted in both greater minesite runoff (and thus generally higher downstream EC in both creeks) and generally cooler water temperatures (median values <30°C). This explains why, for most tests in the creeks, there was a return to the typically higher downstream egg production. In six Magela Creek tests (#1–4, 10–11), however, median water temperatures at (usually) both sites exceeded 30°C and for all but the fourth test, lower downstream (compared to upstream) egg production was observed.

A (four-day) downstream median EC in Magela and Gulungul creeks greater than 20 $\mu S\ cm^{-1}$, represents a value typically associated with mine waste water discharges (Supervising Scientist Annual Report 2012–13). Five of the 12 Magela tests and eight of the nine Gulungul tests were conducted under these minewater exposure regimes. Such elevated EC in two Magela tests conducted at median water temperatures >30°C appear to have contributed to reduced downstream (compared to upstream) egg production while elevated EC in another Magela and eight Gulungul tests conducted at median water temperatures <30°C appear to have contributed to greater downstream (compared to upstream) egg production. At this stage these mine-related ‘effects’, representing enhancement in snail reproductive activity in most cases, are not regarded as constituting environmental concern.

Bioaccumulation in freshwater mussels

Some metals and radionuclides bioaccumulate in aquatic biota, in particular, freshwater mussels of Magela Creek and tributaries. Due to this ability to bioaccumulate, it is essential to check that food items collected from Magela Creek are fit for human consumption and that the concentration of metals and radionuclides in organism tissues attributable to Ranger remain within acceptable levels. Enhanced body burdens of mine-derived solutes could also potentially reach limits that may harm the organisms themselves, and hence any elevation in tissue concentrations can provide useful early warning of bioavailability of these constituents. The bioaccumulation monitoring programme serves an ecosystem protection role in addition to the human health aspect.

Local Indigenous people harvest fish and mussels from Mudginberri Billabong, 12 km downstream of the Ranger mine (Map 3). Routine monitoring of the levels of radionuclides and some metals in these food items commenced in 2000. Monitoring had not shown any issues of potential concern with regards to bioaccumulation in fish. Hence, the focus of the bioaccumulation monitoring programme has been directed at mussel tissue analysis, while the two-yearly fish sampling programme was discontinued in 2007. Up until 2008, mussels were collected annually from Mudginberri Billabong (the potentially impacted site) and Sandy Billabong (the control site in a different catchment, sampled from 2002 onwards). The results showed that radionuclide burdens in mussels from Mudginberri Billabong were generally about twice that observed in the reference Sandy Billabong. Two research projects reported in previous Supervising Scientist annual reports concluded that this difference was due to natural catchment influences and differences in water chemistry, rather than mining-related inputs to Magela Creek. Thus, the scope of the monitoring programme for mussel bioaccumulation was reduced from 2009 onwards. It now involves the annual collection and analysis of a bulk mussel sample from Mudginberri Billabong, rather than analysing separate age-classed mussels from both Mudginberri and Sandy Billabongs. This is done primarily to provide re-assurance that the consumption of mussels does not present a radiological risk to the public. Every three years, starting with the October 2011 collection (reported in the 2011–12 Supervising Scientist Annual Report), a detailed study (analysis of aged mussels from Mudginberri and Sandy Billabongs) is conducted and results compared with those from previous years.

In 2012, an Independent Surface Water Working Group (ISWWG) was convened by ERA and GAC, with findings of this review released in March 2013. One of the ISWWG recommendations was for SSD to review existing metals in bush tucker data and provide advice on a potential re-introduction of a metals in bushtucker monitoring programme. To address this recommendation, a central database for metals in biota has been developed. This database can be used to extract concentrations and investigate bioaccumulation characteristics of various metals in biota tissue, including fish and mussels. Some results for fish and mussels are presented here.

Mussel, sediment and water samples were collected in October 2013 from Mudginberri Billabong. While the routine sampling schedule required just the analysis of a bulk sample for this year, mussels were aged and individual age groups analysed for ^{226}Ra and ^{210}Pb via gamma spectrometry, uranium and other metals via ICPMS, and ^{210}Po via alpha spectrometry. Typical arsenic, cadmium and lead concentrations measured in mussel and fish tissue as part of SSD’s bioaccumulation monitoring over the past decades are given in this report as well, and are compared with the Australian/New Zealand food standards for these metals in molluscs and fish.

Uranium in freshwater mussels

Uranium concentrations in mussels (mg kg^{-1} dry weight) and water collected concurrently from Mudginberri and Sandy Billabongs over the past 14 years are shown in Figure 3.29.

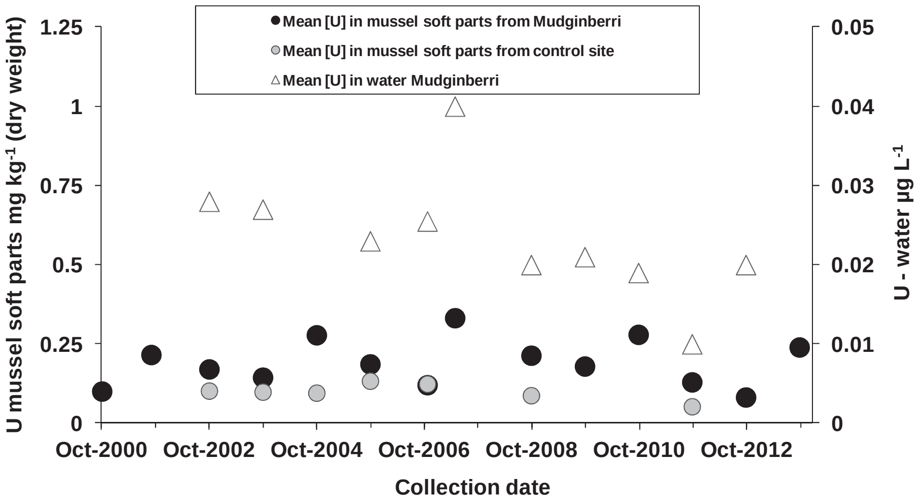


Figure 3.29 Mean concentrations of uranium (U) measured in mussel soft-parts and water samples collected from Mudginberri and Sandy Billabongs since 2000.

The average concentrations of uranium in mussels from Mudginberri Billabong are very similar from 2000 onwards, with no evidence of an increasing trend in concentration over time. Essentially constant and low levels were also observed between 1989 and 1995 (previous reports). Notwithstanding some bioaccumulation with age, uranium in mussels is reported to have a short biological half-life, a conclusion that is supported by our data. The low and constant uranium concentrations including the last sample taken in October 2013 indicate absence of any mining influence.

^{226}Ra, ^{210}Pb and ^{210}Po in mussels

^{226}Ra, ^{210}Pb and ^{210}Po activity concentrations (Bq kg^{-1} dry weight) in mussels collected from Mudginberri Billabong in 2013 are compared with the average activity concentrations measured in previous years in Figure 3.30. ^{226}Ra activity concentrations appear higher in mussels collected in 2013 compared to the average from previous collections. ^{210}Po is higher than the ^{210}Pb activity concentration, indicating higher accumulation of ^{210}Po from the water column compared to ^{210}Pb, in agreement with previous observations in the Alligator Rivers Region and elsewhere. There is no increase in ^{210}Po activity concentration with age in 1–10 year old mussels, consistent with its short physical halflife of 138 days. Average ^{210}Po activity concentration in mussels collected in 2013 (open symbols: 420 ± 60 Bq kg^{-1}) is higher than in 2012 (solid symbols: 350 ± 30 Bq kg^{-1}), in particular in three, four, five and six year old mussels. The higher ^{226}Ra and ^{210}Po activity concentrations are unlikely to be mine-related.

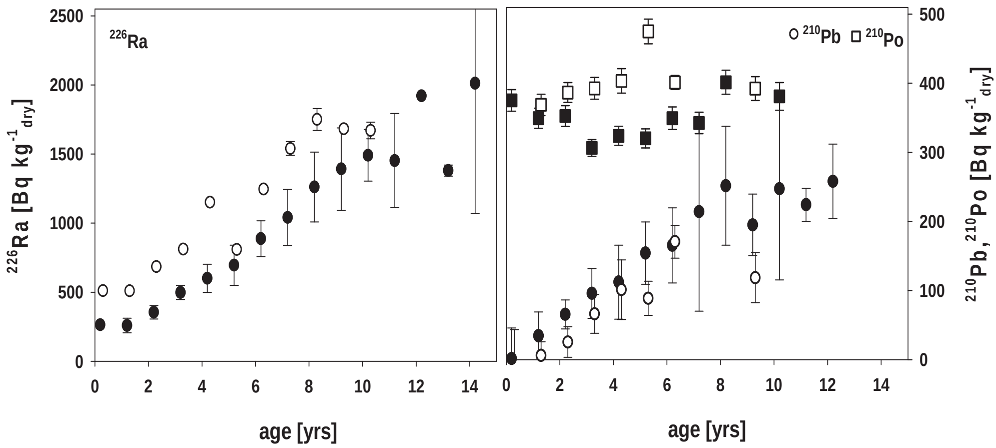


Figure 3.30 ^{226}Ra, ^{210}Pb and ^{210}Po activity concentrations measured in dry mussel flesh from Mudginberri Billabong plotted against mussel age. Averages of previous end of dry season collections (2000–12) are shown as solid symbols, open symbols show the results from the 2013 collection. The errors shown are 1 standard deviation (1sd) of the mean.

Figure 3.31 shows that ^{228}Ra activity concentrations in mussels collected in 2013 were higher on average, although the ^{228}Ra isotope is a member of the thorium decay series and unrelated to uranium mining activities. In addition, Figure 3.31 shows that, the ^{228}Ra /^{226}Ra activity ratios in aged mussels have not changed in 2013, indicating that the increase in ^{226}Ra activity concentrations are not due to any mine related increases in water ^{226}Ra activity concentrations. This is confirmed by the low water ^{226}Ra activity concentration in Mudginberri Billabong in October 2013 of only 1.46±0.14 mBq L^{-1}.

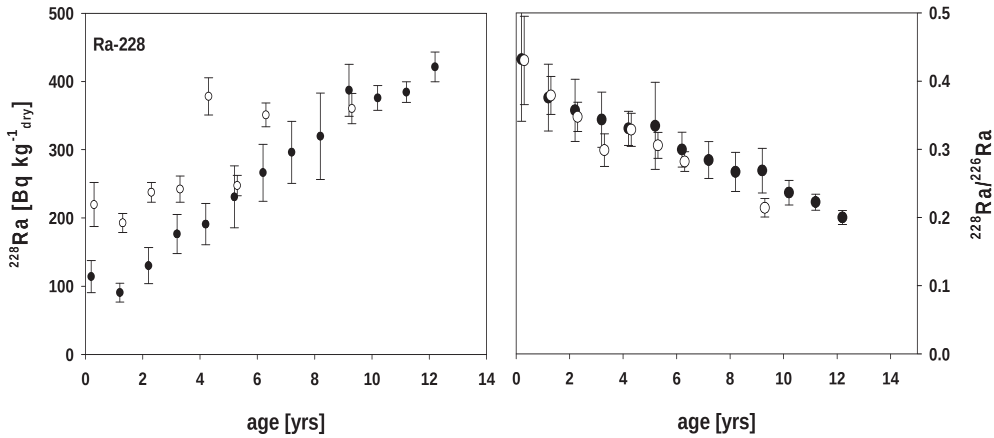


Figure 3.31 ^{228}Ra activity concentrations and ^{228}Ra/^{226}Ra activity ratios in dry mussel flesh from Mudginberri Billabong plotted against mussel age. Averages of previous end of dry season collections (2000–12) are shown as solid symbols, open symbols show the results from the 2013 collection.

Arsenic, cadmium and lead in mussel and fish tissue from Mudginberri Billabong

Table 3.9 shows the average concentrations of arsenic (As), cadmium (Cd) and lead (Pb) measured in mussel and fish tissue collected during past monitoring in Mudginberri Billabong.

The BRUCE tool, a database that has been developed by SSD to collate biota and media radionuclide data and calculate concentration ratios for various biota-radionuclide combinations (described in the 2010–11 Annual Report), has been amended in 2013 to include metal concentration data and is continually being populated. The tool has been used to extract geometric mean, or typical, concentrations on a wet tissue weight basis for As, Cd and Pb.

TABLE 3.9 MAXIMUM LEVELS FOR METAL CONTAMINANTS IN FISH AND MOLLUSCS GIVEN IN THE AUSTRALIAN/NEW ZEALAND FOOD STANDARD AND TYPICAL CONCENTRATIONS (MG KG^{-1} WET WEIGHT) MEASURED IN FISH AND FRESHWATER MUSSEL TISSUE COLLECTED FROM MUDGINBERRI AND SANDY BILLABONGS

Biota		Aus/NZ Food Standard	Mudginberri Billabong[2]		Sandy Billabong[2]	
Fish	As	2.0	0.02 ± 0.05	(*32*)	0.01 ± 0.01	(*20*)
	Cd	0.2[1]	0.01 ± 0.05	(*44*)	0.002 ± 0.002	(*20*)
	Pb	0.5	0.03 ± 0.11	(*44*)	0.01 ± 0.01	(*20*)
Molluscs	As	1.0	0.19 ± 0.08	(*73*)	0.26 ± 0.12	(*36*)
	Cd	2.0	0.06 ± 0.05	(*102*)	0.07 ± 0.04	(*47*)
	Pb	2.0	0.25 ± 0.23	(*141*)	0.09 ± 0.06	(*61*)

[1]In the absence of a cadmium standard for fish, one 10th of the standard for molluscs was assumed

[2]Values in parenthese are the number of samples used to calculate the geometric mean

Table 3.9 shows that typically As, Cd and Pb concentrations, in particular in fish tissue, are low and 5–100 times lower than the maximum levels in fish and molluscs given in the Australian/New Zealand Food Standards. Population of this database with metal concentration data for various food items is ongoing and more results will be presented in future reports.

Monitoring using macroinvertebrate community structure

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 present. The design and methodology have been refined over this period (changes are described in the 2003–04 Supervising Scientist Annual Report, section 2.2.3). The present design is a balanced one comprising upstream and downstream sites at two ‘exposed’ streams (Gulungul and Magela Creeks) and two control streams (Burdulba and Nourlangie Creeks).

Samples are collected from each site at the end of each wet season (between April and May). For each sampling occasion and for each pair of sites for a particular stream, dissimilarity indices are calculated. These indices are a measure of the extent to which macroinvertebrate communities of the two sites differ from one another. A value of ‘zero%’ indicates macroinvertebrate communities identical in structure while a value of ‘100%’ indicates totally dissimilar communities, sharing no common taxa.

Disturbed sites may be associated with significantly higher dissimilarity values compared with undisturbed sites. Compilation of the full macroinvertebrate dataset from 1988 to 2013 (2014 data for Burdulba and Nourlangie Creeks not available at the time of preparing the 2013–14 Supervising Scientist Annual Report), and data from the paired sites in the two ‘exposed’ streams, Magela and Gulungul Creeks, for 2014, have been completed with results shown in Figure 3.32. This figure plots the paired-site dissimilarity values using family-level (log-transformed) data, for the two ‘exposed’ streams and the two ‘control’ streams.

For statistical analysis, dissimilarity values for each of the five possible, randomly-paired, upstream and downstream replicates within each stream are derived. These replicate dissimilarity values may then be used to test whether macroinvertebrate community structure has altered significantly at the exposed sites for the wet season of interest. For this multi-factor ANOVA, only data gathered since 1998 have been used. (Data gathered prior to this time were based upon different and less rigorous sampling and sample processing methods, and/or absence of sampling in three of the four streams.).

Analysis for Magela and Gulungul Creeks for 2014 sampling

At the time of preparing this annual report only samples from Magela and Gulungul Creeks from the 2013–14 wet season were available for analysis. Without comparable data from the two control streams, it is not possible to run the full ANOVA testing for 2014. Instead, a modified ANOVA model was run using the factors Before/After (BA; fixed), Year (nested within BA; random) and Stream (upstream vs downstream paired dissimilarities; random) examining just the exposed creeks, Magela and Gulungul, to determine if any change in these streams has occurred. The ANOVA showed no significant change from the before (pre 2013–14) to after (2013–14) periods in the magnitude of upstream-downstream dissimilarity across both ‘exposed’ streams and this was consistent between both streams (BA and BA*Stream interaction not significant respectively).

Lack of significance in the BA and BA*Stream interaction was observed despite a sharp drop in dissimilarity for Magela Creek in 2014 (Figure 3.32). This drop indicates the upstream and downstream sites in Magela were more similar to one another at the time of sample collection than they have been historically. A marked change in dissimilarity was last reported for Gulungul Creek in 2011, but in that instance dissimilarity increased over historical values (Figure 3.32). In 2011, the BA*Stream factor was significant ($P = 0.014$) and with further data examination (including multivariate ordination) it was found that this was associated with changes at the upstream control site in Gulungul Creek (Supervising

Scientist Annual Report 2010– 2011). Hence the 2011 result was not associated with mine-related change.

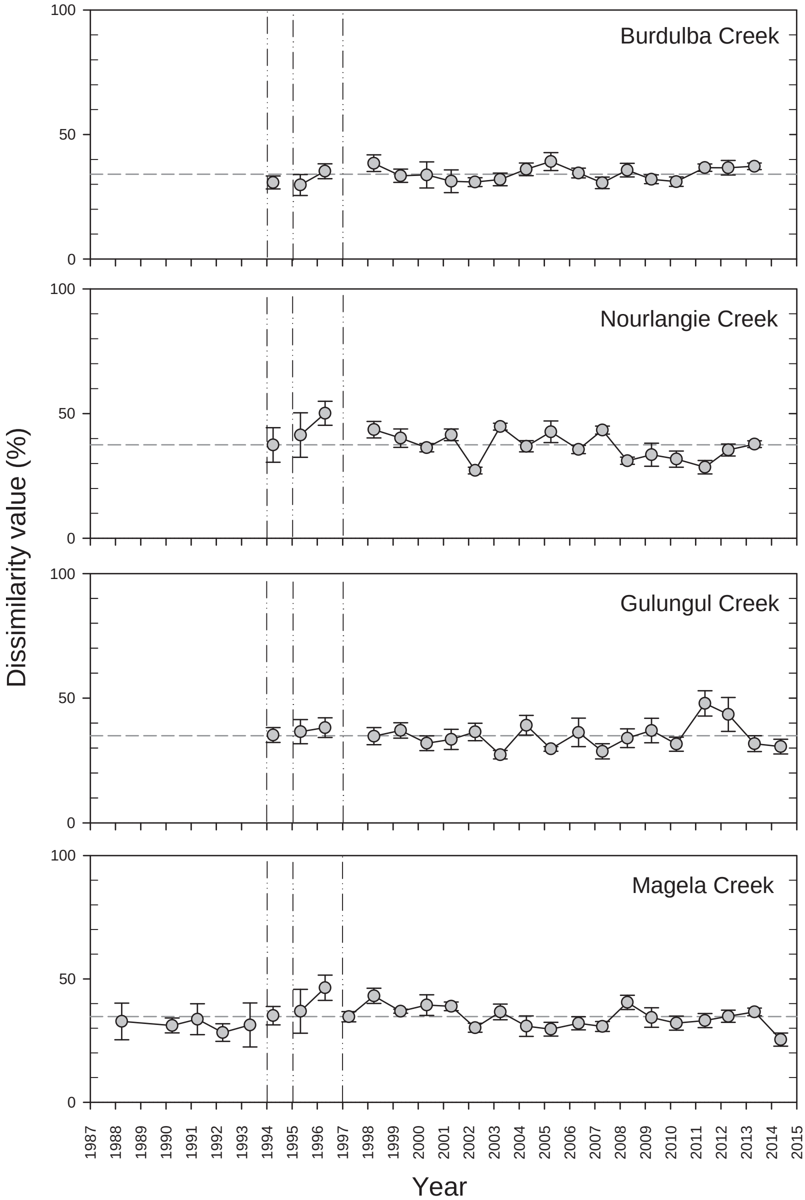


Figure 3.32 Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger mine for the period 1988 to 2014. The dashed vertical lines delineate periods for which a different sampling and/or sample processing method was used. Dashed horizontal lines indicate mean dissimilarity across years.

Dissimilarity values represent means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of upstream-downstream replicate samples within each stream.

Apart from statistical testing, graphical ordination methods can also be used to infer potential impact if points associated with exposed sites sit well outside of points representing reference sites. Figure 3.33 depicts the multivariate ordination derived using replicate within-site macroinvertebrate data. Data points are displayed in terms of the sites sampled in Magela and Gulungul Creeks downstream of Ranger for each year of study (to 2014), relative to Magela and Gulungul Creek upstream (control) sites for 2014, and all other control sites sampled up to 2013 (Magela and Gulungul upstream sites, all sites in Burdulba and Nourlangie). Samples close to one another in the ordination indicate a similar community structure.

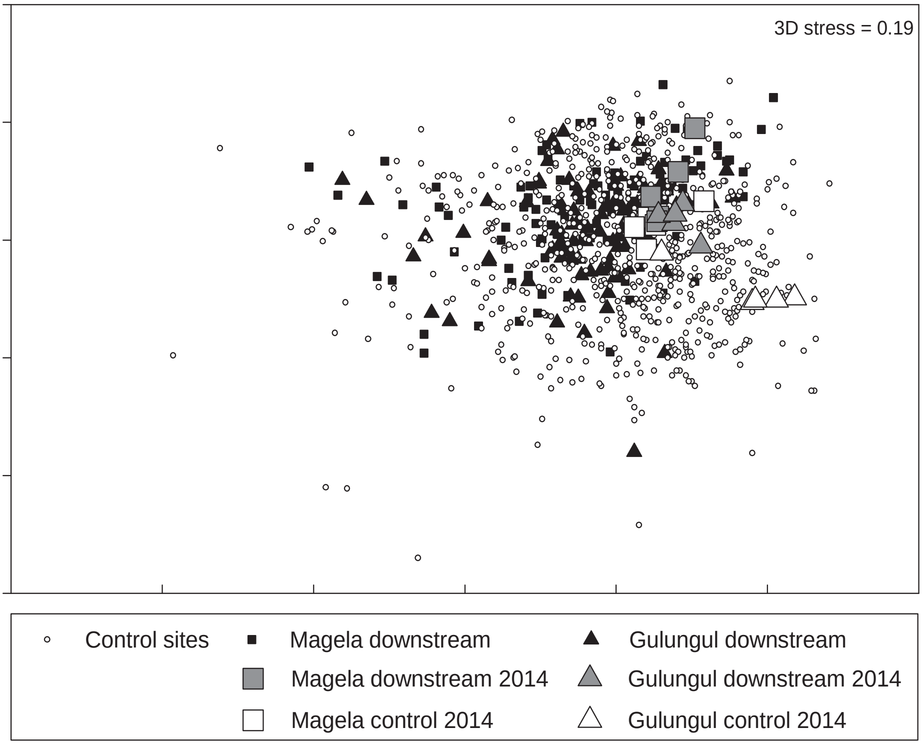


Figure 3.33 Ordination plot (axis 1 and 2) of macroinvertebrate community structure data from sites sampled in several streams in the vicinity of Ranger mine for the period 1988 to 2013. Data from Magela and Gulungul Creeks for 2013 are indicated by the enlarged symbols.

Data points associated with the 2014 Gulungul and Magela downstream sites are generally interspersed among the points representing the control sites, indicating that these ‘exposed’ sites have macroinvertebrate communities that are similar to those occurring at control sites. This was confirmed by PERMANOVA (PERmutational Multivariate ANalysis Of Variance) testing on the individual sites (cf paired site dissimilarity for the ANOVA above) of the exposed streams (Magela and Gulungul) which showed no significant difference between the downstream data from 2014 with downstream data from previous years, and no significant difference between the upstream data from 2014 with upstream data from previous years. (By comparison, the higher dissimilarity in Gulungul Creek observed in

2011 (see above), was associated with separation of upstream Gulungul Creek sites in ordination space and significant separation of these same sites from comparable upstream data from previous years in the PERMANOVA testing).

The lower paired upstream-downstream dissimilarity values observed in Magela Creek in 2014 may be associated with a combination of the generally lower flow in the creek at the time of sampling compared to previous years, and a change in sampling location at the upstream site required because of unsuitable habitat in the usual sampling location. Lower creek flows can confer more similar macroinvertebrate communities between creek sites (i.e. lower dissimilarity; see Supervising Scientist Annual Report, 2012–13, Figure 4.10). The new sampling site in 2014 was also located in the main channel of the creek (unlike the side channel sampled in previous years), more closely resembling the main-channel site downstream. Collectively, these graphical and statistical results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2014 have not adversely affected macroinvertebrate communities.

Analysis for all creeks for 2013 sampling

As noted above, 2013 data for Burdulba and Nourlangie Creeks were not available at the time of preparing the 2012–13 Supervising Scientist Annual Report. Compilation of the full macroinvertebrate dataset from 1988 to 2013 enables a complete statistical analysis of 2013 macroinvertebrate data.

A four-factor ANOVA model based on replicate, paired-site dissimilarity values, was run using the factors Before/After (BA; fixed), Control/Impact (CI or 'Exposure'; fixed), Year (nested within BA; random) and Stream (nested within CI; random) to determine if any change has occurred. The ANOVA showed no significant change from the before (pre 2013) to after (2013) periods in the magnitude of upstream-downstream dissimilarity between the control and exposed streams ($p = 0.777$ and $p = 0.529$ for BA and BA*Exposure interaction respectively).

These results confirm that the dissimilarity values for 2013 do not differ from previous years. While the Year*Stream interaction is significant in the same analysis ($p < 0.001$), this simply indicates that dissimilarity values for the streams show natural differences through time, including fluctuations in control streams. This variation over time is evident in Figure 3.32, particularly for recent years (2011 and 2012) in Gulungul Creek (see section 3.2.3.2 of the Supervising Scientist Annual Report for 2012–2013). Additional graphical and statistical testing of the full 2013 dataset are provided in an eriss Annual Research Summary paper published in 2014[2] . Those collective results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2013 have not adversely affected macroinvertebrate communities.

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[2] Humphrey CL, Hanley J, Chandler L & Camilleri C 2014. Monitoring using macroinvertebrate community structure. In ***eriss*** research summary 2012–2013. Supervising Scientist report 205, Supervising Scientist, Darwin NT, pp 72–75.

Monitoring using fish community structure

Assessment of fish communities in billabongs is conducted between late April and July each sampling year using non-destructive sampling methods applied in 'exposed' and 'control' locations. Two billabong types are sampled: deep channel billabongs studied every year, and shallow lowland billabongs, dominated by aquatic plants, which are studied every two years.

Deep channel billabongs

The exposed location for the channel billabong study is Mudginberri Billabong. For the 2014 monitoring period, access to Mudginberri Billabong was not possible due to an important time of mourning for the local Indigenous community. The next assessment will be undertaken in 2015 and will be reported in the Supervising Scientist annual report for 2014–15.

Shallow lowland billabongs

Monitoring of fish communities in shallow lowland billabongs has previously been conducted every two years, with the exception of a break in sampling between 2009 and 2012. The last assessment of fish communities in these billabongs occurred in June 2012 with results reported in the Supervising Scientist annual report for 2011–12 (section 2.2.3). Results from sampling conducted in June 2014 are described below.

The monitoring programme for fish communities in shallow billabongs is conducted in six billabongs, comprising three 'control' versus 'exposed' billabong pairs. In a similar manner to fish communities in channel billabongs (see Supervising Scientist annual report 2011–12, section 2.2.3), the similarity of fish communities in the directly exposed sites downstream of Ranger on Magela Creek (Georgetown, Coonjimba and Gulungul billabongs) to those of the control sites (Sandy Shallow and Buba billabongs on Nourlangie Creek and Wirnmuyurr Billabong – a Magela floodplain tributary) (see Map 3) is determined using multivariate dissimilarity indices calculated for each sampling occasion. A plot of the dissimilarity values of the control-exposed site pairings – Coonjimba-Buba, Georgetown-Sandy Shallow and Gulungul-Wirnmuyurr Billabongs – from 1994 to 2014, is shown in Figure 3.34.

The three sets of paired-billabong dissimilarity values measured since 1998 (when sampling of all three site-pairs commenced) have been analysed using a three-factor ANOVA with Before/After (BA; fixed), Year (nested within BA; random) and Site-pair (Fixed) as factors. In this analysis, the BA factor tests whether values for the year of interest (2014) are consistent with the range of values reported in previous years (1998 to 2012), the factor 'Year' tests for differences amongst years within the before or after periods and the 'Site-pair' factor tests for differences amongst the three paired-billabong dissimilarities.

The ANOVA results showed that across all three site-pairs there was no significant change from 2014 to other years (BA factor, $p = 0.763$) and that the change between 2014 and previous years within the individual site-pairs was consistent (BA*Site-pair interaction, $p = 0.953$). These results confirm that dissimilarity values for 2014 for all three site-pairs do not differ from those values from previous years. Significant differences do occur over time within site-pairs (Year*Site-pair interaction, $p = 0.000$), which reflects (natural) changes through time. This variation over time is evident in Figure 3.34 and is further considered below. The paired-site dissimilarities shown in Figure 3.34 average between 40 and 60%, indicating fish communities in each of the billabongs comprising a site-pair are quite different from one another. The dissimilarity values appear to reflect differences in aquatic plant communities of the site-pair billabongs, with particularly high dissimilarity values (i.e. Coonjimba-Buba pairing for 2002 and 2007, Gulungul-Wirnmuyurr site pairing for 2002, Figure 3.34) attributable to high densities of particular aquatic plant types in one or both billabongs in a billabong pair (see Supervising Scientist annual report 2006–07, section 2.2.3).

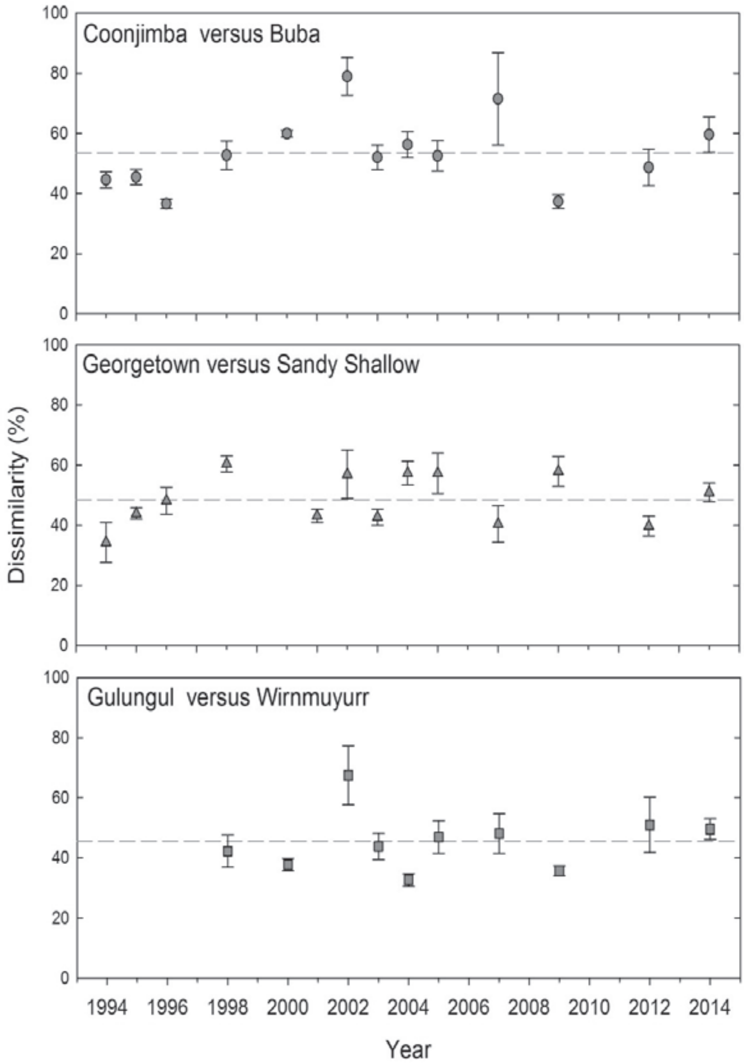

Figure 3.34 Paired control-exposed site dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in 'exposed' Magela and 'control' Nourlangie and Magela Billabongs in the vicinity of Ranger mine over time. Values are means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of average trap enclosure data between the pairwise billabong comparisons, Coonjimba-Buba, Gulungul-Wirnmuyurr and Georgetown-Sandy Shallow billabongs.

Excessive plant densities are unfavourable for fish communities as fish movement, and hence residency, is physically prevented. Collectively, the graphical and statistical results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2014 have not adversely affected fish communities in shallow billabongs.

3.3 Jabiluka

3.3.1 Developments

The site continues to be maintained under a long-term care and maintenance regime of management. In October 2013 work on the removal of the Interim Water Management Pond (IWMP) was completed and the area contoured and prepared for revegetation. As of February 2014, 3600 individual tube stock had been planted within the Jabiluka mine site footprint with survival rates of 48% noted during the June 2014 RPI.

As a result of the IWMP removal there was an increase in the statutory monitoring programme undertaken by ERA in Swift Creek (Ngarradj) during the reporting period. SSD continues to monitor downstream water quality.

3.3.2 On-site environmental management

3.3.2.1 Water Management

The site continues to be maintained as a passive discharge site. On 5 December 2012 ERA submitted an application to discharge Interim Water Management Pond (IWMP) water to Swift Creek (Ngarradj) for the purpose of emptying the IWMP prior to rehabilitation. Due to the below average rainfall during the 2012–13 wet season creek flow was insufficient to enable all the IWMP water to be discharged. ERA submitted a subsequent application on 14 June 2013 to enable land irrigation of the remaining IWMP water. Stakeholders approved this application on 27 June 2013 and viewed the dewatering operation during an inspection on 2 July 2013 (Table 3.10).

3.3.2.2 Audit and Routine Periodic Inspections (RPIs)

Six inspections were undertaken at Jabiluka during 2013–14 (Table 3.9). An environmental audit was held in May 2014 and RPIs were held in July, September, October and December 2013, February and June 2014.

TABLE 3.10 RPI FOCUS DURING THE REPORTING PERIOD

Date	Inspection type	Foci
2 July 2013	RPI	IWMP removal project and IWMP dewatering operations.
16 September 2013	RPI	IWMP removal project.
17 October 2013	RPI	IWMP removal project.
12 December 2013	RPI	Rehabilitation works within the Jabiluka footprint.
20 February 2014	RPI	Wet season impacts on the rehabilitation works.
12–15 May 2014	Audit	MTC application for IWMP removal and rehabilitation; One Year Weed Management Plan 2013.
19 June 2014	RPI	Revegetation success of the rehabilitation works.

Audit outcomes

Closeout of findings from the May 2013 environmental audit

The conditional finding from the 2013 audit relates to the ongoing works to finalise rehabilitation of redundant bore holes in Mine Valley. ERA reported at the 40th meeting of ARRAC on 5 September 2013 that 35 boreholes had been rehabilitated within Mine Valley. Further surveys identified additional clean up opportunities for 2014 onwards.

May 2014 environmental audit

Thirty two commitments taken from the MTC application for IWMP removal and rehabilitation and the One Year Weed Management Plan 2013 were assesed. These commitments and communications were audited against the grading system shown in Table 3.5. The following significant findings were determined:

- One category two non-conformances
    - no formal process for recording visual erosion inspections
- Five conditional findings
- Two observations.

3.3.2.3 Minesite Technical Committee

The Jabiluka MTC met six times during 2013–14. Dates of meetings and significant issues discussed are shown in Table 3.11.

TABLE 3.11 JABILUKA MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items
6 September 2013	IWMP rehabilitation, Mine Valley groundwater bores
15 November 2013	IWMP rehabilitation, Mine Valley groundwater bores
17 February 2014	Post-rehabilitation track maintenance, Mine Valley groundwater bores, Jabiluka Wet Season Report and Interpretative Report.
28 March 2014	Mine Valley groundwater bores, requirement for Authorisation amendment.
9 May 2014	Rehabilitation, Mine Valley groundwater bores, Jabiluka Annual Plan of Rehabilitation.

3.3.2.4 Authorisations and approvals

No applications to alter Jabiluka Authorisation 0140-5 were received during the reporting period.

3.3.2.5 Incidents

During the 2013–14 reporting period, a total of three environmental incidents occurred during the reporting period, none of which were of a serious enough nature to warrant a separate independent investigation.

3.3.3 Off-site environmental protection

3.3.3.1 Surface water quality

Flow was first recorded at the Ngarradj (Swift Creek) monitoring station on 27 November 2013 and was very low at the start of the wet season with the multiprobes only submerged for short periods of time when the water level was sufficiently high. Increased flow from 9 January 2014 resulted in the multiprobes being fully submerged. EC decreased and remained below 20 $\mu S\ cm^{-1}$ (Figure 3.35).

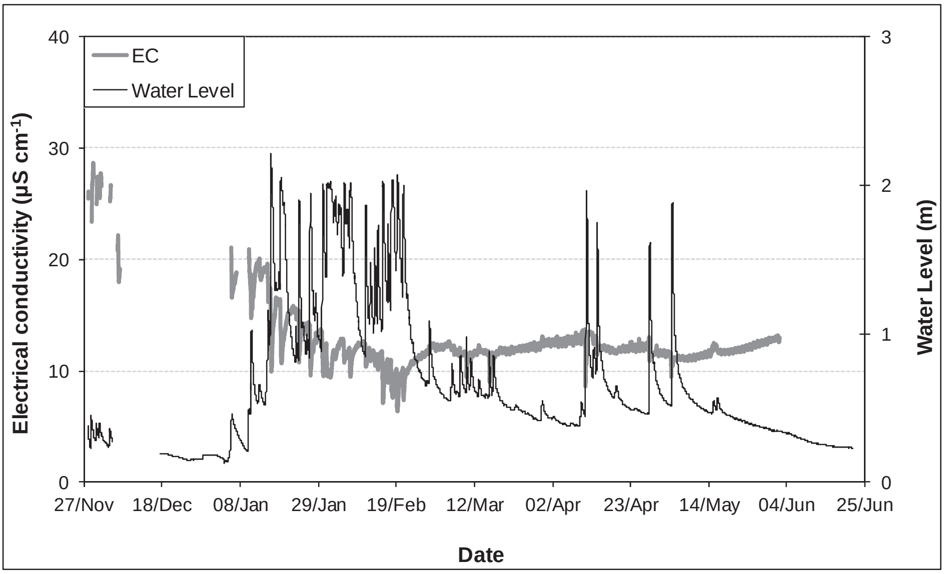

Figure 3.35 Ngarradj (Swift Creek) continuous EC monitoring data during the 2013–14 wet season.

On 26 January 2014 a turbidity event of occurred during a 90 mm rainfall event at the site (Figure 3.36). Trigger values for turbidity within Ngarradj (Swift Creek) were not included within the Water Quality Objectives as determined by the Jabiluka Minesite Technical Committee on 21 September 2001. However, baseline values for the physical and chemical characteristics of streams within the Jabiluka lease were established by Cusbert et al. in 1998[1] including 'low risk trigger value' ranges for ecosystem protection. The trigger value range proposed for turbidity was 4.0–105, with non-compliance being turbidity events due to mining activity < 4.0 NTU or > 105 NTU. Thus, the turbidity event of 26 January 2014 of 56.5 NTU falls in the middle of this 'acceptable' range. There have previously been 20 turbidity events > 50 NTU at Ngarradj since continuous monitoring of turbidity began in the 2003–04 wet season.

Another turbidity event occurred on 10 April 2014 during a 90 mm rainfall event at the site and peaked at 112 NTU. This peak was above the upper guideline level for the 'acceptable' range (105 NTU) for less than 10 minutes. There have previously been 3 turbidity events > 105 NTU at Ngarradj since continuous monitoring of turbidity began in the 2003–04 wet season.

[1] Cusbert P, Klessa D, leGras C, Moliere D & Rusten K 1998. Baseline values for physical and chemical indicators in streams of the Jabiluka lease area. Part 1. Interim findings. Internal Report 300. September, Supervising Scientist, Darwin.

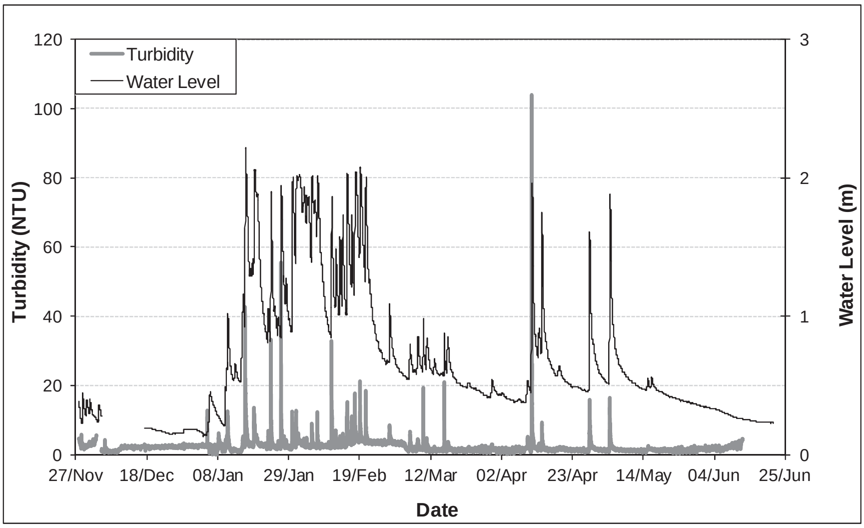

Figure 3.36 Ngarradj (Swift Creek) continuous turbidity monitoring data during the 2013–14 wet season.

During late February and March 2014 the water levels within Ngarradj decreased leading to gradually increasing EC levels, fluctuating with each rainfall event. Conductivity stabilised in Ngarradj through April and May with the creek entering its recessional flow period.

Continuous monitoring of Ngarradj continued until 12 June 2014 when the multiprobes were out of the water and could not be lowered any further. Cease to flow was agreed by stakeholders on 13 June 2014.

Overall, once flow commenced in the creek, the water quality measured in Ngarradj for the 2013–14 wet season was comparable with previous wet seasons (Figure 3.37).

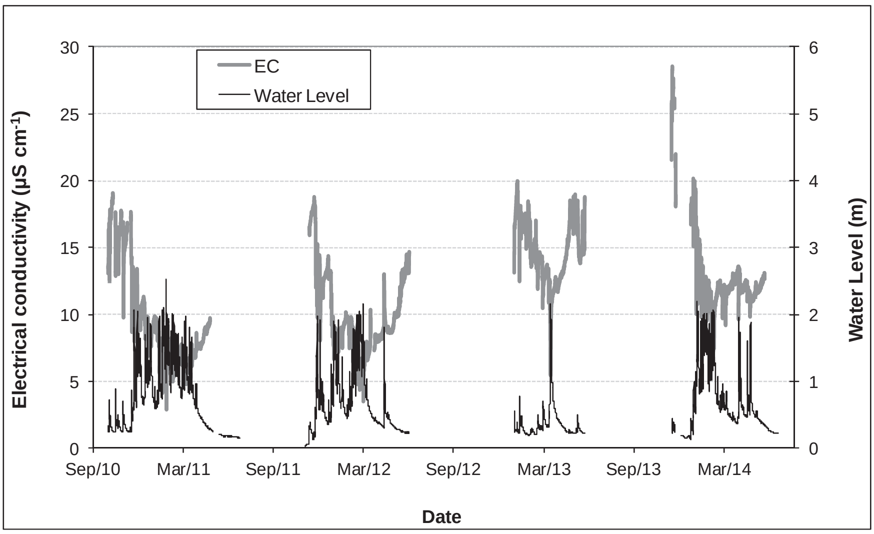

Figure 3.37 Continuous electrical conductivity and water level (lower trace) in Ngarradj (Swift Creek) for each wet season between September 2010 and June 2014 (values averaged over a 90 minute period of measurement).

3.4 Nabarlek

3.4.1 Developments

In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd, thereby acquiring the Nabarlek lease (MLN 962). UEL has since developed plans to further explore the lease, clean up the site and continue revegetation and rehabilitation works. Authorisation 0435-01 was granted to UEL on the 28 May 2008 allowing exploration and rehabilitation works at Nabarlek to proceed. Since this time UEL has undertaken significant works to clean up several areas of the site including the old Nabarlek Village and re-contouring of the waste rock dump runoff pond. A Mining Management Plan (MMP) for the 2013 dry season exploration works was submitted to DME in April 2014 and was approved on 10 June 2014.

3.4.1.1 Minesite Technical Committee

The Nabarlek MTC met once during the reporting period. The following items were discussed at a meeting held on 22 July 2013:

- Rehabilitation
- Exploration
- Monitoring
- Radiological Anomalous Area (RAA)
- Development of closure criteria.

3.4.1.2 Authorisations and approvals

There was no change to the Nabarlek Authorisation during 2013–14.

3.4.1.3 Incidents

There were no environmental incidents reported at Nabarlek during 2013–14.

3.4.2 On-site conditions

The site is generally subject to two inspections from ***oss*** staff during the year. In addition, ***oss*** may carry out opportunistic site visits if in the area on other business (e.g. exploration inspections).

The formal site inspections carried out at Nabarlek each year are:

- Post-wet season inspection – the intent of this inspection is to check site stability and erosion following the wet season and to plan works for the coming dry season.
- Annual audit (pre-wet season) of compliance with the Nabarlek MMP.

3.4.2.1 Annual audit

A formal audit was not held during 2013–14 as UEL did not undertake an active exploration drilling programme during the 2013 dry season.

3.4.2.2 Inspections

The post wet-season inspection of the Nabarlek site was held on 19 July 2013.

Areas inspected included:

- Nabarlek Village area
- Sewage treatment ponds area
- Landfill
- Plant area and plant run-off pond
- Backfilled pit
- Waste rock dump area and waste rock dump runoff pond
- Radiologically anomalous area (RAA)
- Evaporation ponds.

3.4.2.3 Radiologically anomalous area (RAA)

The area of the RAA is approximately 0.4 ha and is located immediately south-west of the former pit area. The RAA exhibits elevated levels of radioactivity and has been identified to contribute about one-quarter of the total radon flux from the rehabilitated minesite and three-quarters of the radionuclide flux from the site via the erosion pathway (more detail is provided in Supervising Scientist Annual Report 2004–05).

The issue remains a standing item on the Nabarlek MTC agenda. No works on the RAA were undertaken during this reporting period.

3.4.3 Off-site environmental protection

Statutory monitoring of the site is conducted by DME and the operator, UEL. DME carries out surface and groundwater monitoring on and off site, including surface water monitoring downstream of the mine in Kadjirrikamarnda and Cooper creeks, and reports the results of this monitoring in the six-monthly Northern Territory Supervising Authorities Environmental Surveillance Monitoring in the Alligator Rivers Region reports to the Alligator Rivers Region Advisory Committee (ARRAC).

3.5 Other activities in the Alligator Rivers Region

3.5.1 Rehabilitation of the South Alligator Valley uranium mines

Background on the remediation of historic uranium mining sites in the South Alligator Valley has been provided in Supervising Scientist Annual Report 2008–09.

Construction of a new containment facility at the location of the old El Sherana airstrip for the final disposal of historic uranium mining waste was completed during the 2009 dry season by Parks Australia.

oss staff carried out the annual inspection of the containment facility on 10 October 2013 following completion of erosion repair works. Revegetation is progressing well over the old containment areas and previous erosion gullies in parts of the cap had been repaired. An inspection report was provided to Parks Australia.

3.5.2 Exploration

oss undertakes a programme of site inspections and audits at exploration sites in western Arnhem Land. During the reporting period SSD lead audits of the following exploration sites in Western Arnhem Land:

- Cameco King River Camp and exploration activities
- Alligator Energy Myra Camp and exploration activities
- UXA Resources Limited Nabarlek Project
- Each operation was audited against commitments from their approved MMP and criteria tested were graded in accordance with the classifications presented in Table 3.5.

3.5.2.1 Cameco King River Camp

SSD, DME and NLC audited Cameco's West Arnhem operations on 18–19 September 2013. The audit tested Cameco's compliance with 42 commitments from their approved 2013 MMP. Auditors inspected the King River camp and current and rehabilitated drill holes at Angularli prospect. Two category two non-conformances and one conditional finding were identified during the audit:

- Two category two non-conformances
    - Six uncapped drill holes located on EL 10176 at the U40 prospect.
    - A vehicle check/wash down was not requested of an audit team vehicle when it was known it had travelled from Nabarlek/Myra Camp, an area with identified weeds.
- One conditional finding relating to incorrect bunding of a pump.

3.5.2.2 Alligator Energy Myra Camp

SSD and DME audited Alligator Energy's exploration activities based at Myra Camp on 17 September 2013. The audit tested Alligator Energy's compliance with 22 commitments from their approved 2013 MMP. The auditors inspected Myra Camp, the Two Rocks prospect and Caramel prospect. The audit resulted in three observations. The audit team was pleased to note the minimal environmental disturbance made during the creation of the new NE Myra track.

3.5.2.3 UXA Nabarlek Project

UXA Resources Ltd went into receivership in November 2013. An inspection of the extent of exploration activities and rehabilitation at the Nabarlek Group Project on EL24868 was held on 19 September 2013. The inspection team was made up of representatives from SSD, DME and NLC. A traditional owner accompanied the team on the inspection. All drill pads and drill holes observed had rehabilitation activities completed with no evidence of erosion. Most of the tracks were in the progress of self-vegetation, which impedes future access. A constructed creek crossing between Area 1 and 2 prospects still had a tall pile of extracted material adjacent to the crossing with 'whoa-boys' constructed on either side of the creek crossing. The creek crossing and associated 'whoa-boys' were the only aspects observed during the inspection which may require further rehabilitation.

3.6 Radiological issues

3.6.1 Background

3.6.1.1 Applicable standards

The radiation dose limit for workers recommended by the International Commission on Radiological Protection (ICRP) and adopted in Australia by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is 100 millisievert (mSv) in a five-year period with a maximum of 50 mSv in any one year. In practice this is considered to be an average of 20 mSv per year. The radiation dose limit to the public from a practice such as uranium mining recommended by the ICRP is 1 mSv per year. This limit applies to the sum of all sources and exposure pathways. As outlined in the 'Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing' (2005)[2], it is the operator's and employer's responsibility to 'ensure that the workplace and work procedures are designed, constructed, and operated so as to keep exposures to ionising radiation as low as reasonably achievable'.

The Safety Guide further recommends to separate radiation workers into designated and non-designated cohorts for monitoring and reporting purposes, where designated workers are those who may be expected to receive a significant occupational radiation dose, nominally above 5 mSv per year. These workers are monitored more intensely than the non-designated workers.

Consequently, there are three levels of radiation dose from other-than-natural sources to distinguish:

- Limit to a member of the public (1 mSv)
- Non-designated workers (5 mSv)
- Limit to workers (100 mSv over 5 years with a maximum of 50 mSv in any one year).

[2] ARPANSA (2005) Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing. Radiation Protection Series No. 9, Australian Radiation Protection and Nuclear Safety Agency, Yallambie.

In addition, the ICRP (2006[3]) recommends the use of dose constraints for the optimisation of radiation protection:

> The principle of optimisation is defined by the Commission as the source related process to keep the magnitude of individual doses, the number of people exposed, and the likelihood of potential exposure as low as reasonably achievable below the appropriate dose constraints, with economic and social factors being taken into account. According to the Commission's revised recommendations, this process of optimisation below constraint should be applied whatever the exposure situation; i.e. planned, emergency, or existing.

3.6.1.2 Monitoring and research programmes

ERA conducts statutory and operational monitoring of external gamma exposure to employees (through the use of gamma dose badges), radon decay products and long lived alpha activity (dust) in the air, and surface contamination levels. The statutory aspects of the programme are prescribed in Annex B of the Ranger Authorisation with results reported to MTC members on a quarterly basis.

SSD conducts routine monitoring of the atmospheric pathways of radiation dispersion from Ranger and a number of radiation research projects for human and environmental protection.

An application to optimise the Radiation and Atmospheric Monitoring Plan (originally submitted to the MTC in November 2008) was approved with the issue of Authorisation 0108-13 on 29 November 2011. Approval of this application resulted in a change to the quarterly reporting requirements for ERA and instead of a quarterly report, SSD and other stakeholders are now provided with summary data that are then discussed during a meeting with ERA. This change first came into effect for the Q1/2012 reporting period. All quarterly reports and summary data due during the reporting period were received and reviewed by SSD.

Dose constraints for the Ranger operation are revised annually and detailed in the *Annual Radiation and Atmospheric Monitoring Report*. The current dose constraints for Ranger mine are listed in Table 3.12.

TABLE 3.12 ANNUAL RADIATION DOSE CONSTRAINTS FOR RANGER MINE (mSv)

Mine	2.4
Plant	5.5
Exploration Decline	5
Non-designated workers	2
Workers under the age of 18	2
Members of the public	0.3

[3] ICRP 2006. Assessing dose of the representative person for the purpose of radiation protection of the public and the optimisation of radiological protection: broadening the process. ICRP Publication 101, Elsevier Ltd.

3.6.2 On-site and off-site radiation exposure at Ranger

3.6.2.1 Radiological exposure of employees

The three primary pathways of radiation exposure to workers at Ranger are:

- inhalation of radioactive dust
- exposure to external gamma radiation
- inhalation of radon decay products (RDP).

Table 3.13 shows the annual doses received by designated and non-designated workers in 2013, and a comparison with the average doses from the year before as reported by ERA. The average and maximum radiation doses received by designated workers in the 2013 calendar year were approximately 7% and 33% respectively of the recommended ICRP (2007[4]) annual dose limits.

TABLE 3.13 ANNUAL RADIATION DOSES RECEIVED BY WORKERS AT RANGER MINE

	Annual dose in 2012		Annual dose in 2013	
	Average mSv	Maximum mSv	Average mSv	Maximum mSv
Non-designated worker	Not calculated[1]	1.0	Not calculated[1]	1.9
Designated worker	1.2	4.5	1.4	6.5

1 A hypothetical maximum radiation dose to non-designated employees is calculated using the gamma exposure results of employees of the Emergency Services Group, and dust and radon results measured at the Acid Plant. Consequently, the dose is conservative and would exceed actual doses received by non-designated employees, and are hence considered maximum doses.

All work groups received their greatest dose from the external gamma pathway. As a result of higher gamma contribution, the average doses across Ranger mine were elevated in 2013 but remain very low compared to the limit of 20 mSv per annum. The average dose for the year was 1.4 mSv. This is an increase over 2012 but remains consistent with doses since 2004. Doses prior to 2004 were in the range of 1.5 mSv to 5.2 mSv. An investigation into the doses indicate that a change in the model of TLD reader and associated systems was the reason behind this apparent increase in gamma contribution.

The maximum dose in 2013 was 6.5 mSv and is higher than that observed in 2012. It belonged to a Processing Production Operator; 6.2 mSv was from gamma exposure, 0.17 mSv from RDP exposure and 0.14 mSv from dust exposure.

3.6.2.2 Radiological exposure of the public

National radiation protection standards require that the annual radiation dose received by a member of the public from practices such as uranium mining and milling must not exceed

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[4] The 2007 recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Elsevier Ltd

1 mSv. This dose is on top of the radiation dose received naturally, which averages approximately 1.5 mSv per year in Australia, but which ranges from 1–10 mSv per year, depending on location.

Ranger uranium mine is the main potential source of above background radiation dose to members of the public in the ARR. The two main pathways of potential radiation exposure to the public during the operational phase of Ranger mine are inhalation and ingestion. The inhalation pathway results from radionuclides released to the air from the minesite, while the ingestion pathway is caused by the uptake of radionuclides into bush foods from the Magela Creek system downstream of the mine.

Inhalation pathway

SSD measures concentrations of radon progeny and dust-bound long-lived alpha activity (LLAA) radionuclides in air at Jabiru town and near the Mudginberri community at Four Gates Road radon station. Jabiru town and Mudginberri community are the main areas of permanent habitation in the vicinity of the Ranger mine and Jabiluka.

Figures 3.38 and 3.39 show hourly and quarterly average radon progeny potential alpha energy concentration (PAEC) monitoring data from Jabiru town and near Mudginberri community, respectively, for the 2013 calendar year. Gaps in the data are due to instrument maintenance and data quality issues.

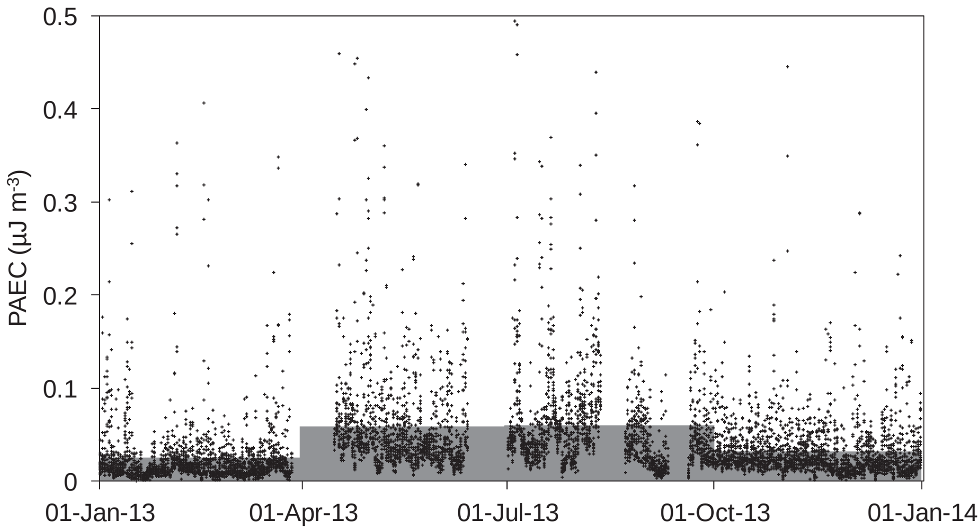

Figure 3.38 Hourly (black crosses) and quarterly average (grey columns) radon progeny PAEC in air at Jabiru town in 2013.

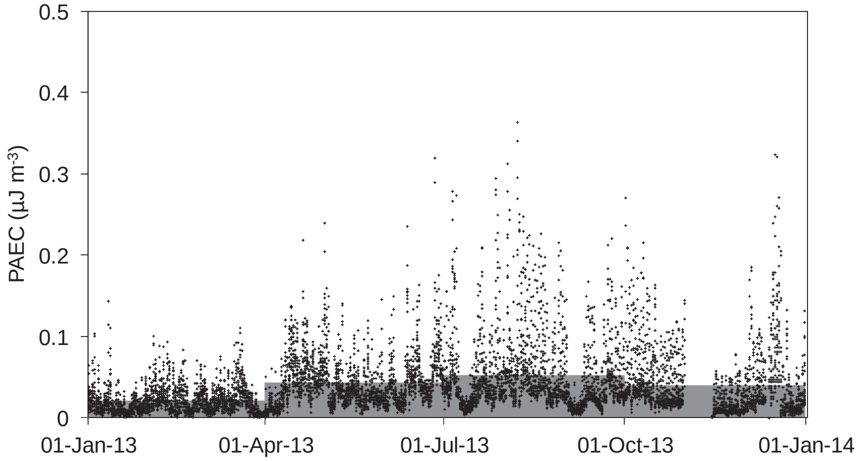

Figure 3.39 Hourly (black crosses) and quarterly average (grey columns) radon progeny PAEC in air at Four Gates Road radon station near Mudginberri community in 2013.

The spikiness in the hourly PAEC data reflects the normal diurnal pattern in radon progeny concentrations in surface air. Higher concentrations typically occur in the early morning around sunrise when atmospheric conditions tend to be most stable. Thereafter, the surface air becomes mixed by convection (solar heating) and advection (wind), which disperses the radon progeny into a larger atmospheric volume.

The quarterly average PAEC results show the typical wet-dry seasonal trend, with higher concentrations occurring in the second and third quarter of the year (dry season) and lower concentrations occurring in the first and fourth quarter of the year (wet season). The effect of rainfall is to suppress radon exhalation from the soil surface and thus decrease the radon progeny PAEC in air.

Table 3.14 provides a summary of annual average radon progeny PAEC in air and estimated doses to the public, as well as comparison with values reported by ERA for Jabiru town. The total annual effective dose from radon progeny in air, which includes contribution from natural background, has been estimated to be 0.405 mSv at Jabiru town and 0.382 mSv at Mudginberri.

TABLE 3.14 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI DURING 2013*

	Jabiru town	Mudginberri
Annual average PAEC [µJ m^{-3}]	0.042 (0.045)	0.040
Total annual dose [mSv]	0.405 (0.530)	0.382
Mine-derived dose** [mSv]	0.055 (0.031)	0.002

* Values in brackets refer to data from the ERA Radiation Protection and Atmospheric Monitoring Program Report for the Year Ending 31 December 2013.

** The radon progeny PAEC difference used in the SSD mine-derived dose calculation was 0.024 µJ/m^3 for Jabiru town and 0.009 µJ m^{-3} for Mudginberri.

This total annual dose has been estimated from the product of the annual average radon progeny PAEC in air, the radon progeny dose conversion factor of 0.0011 mSv per µJ·h m^{-3} recommended by the ICRP and the assumed full year occupancy of 8 760 hours.

The mine-derived annual dose from radon progeny in air has been estimated to be 0.055 mSv at Jabiru town and 0.002 mSv at Mudginberri. This dose is dependent on wind direction and has been estimated from the difference in average radon progeny PAEC in air when the wind was from the direction of the mine and when the wind was from directions other than the mine. Hourly wind direction data for 2013 were obtained from the Bureau of Meteorology (BoM) weather station at Jabiru Airport. Analysis of these data suggests that the wind was from the direction of the mine for 2 029 hours during the year at Jabiru town (90–110 degree sector) and 210 hours during the year at Mudginberri (140–160 degree sector).

Differences between the SSD and ERA radon progeny PAEC results and public dose estimates for Jabiru town are most likely due to differences in monitoring regime. Whereas SSD aims to monitor continuous hourly radon progeny PAEC in air over the full year, the ERA regime is based on a minimum requirement of one week per month continuous monitoring.

Figures 3.40 and 3.41 show measured and quarterly average concentrations of dust-bound LLAA radionuclides in air at Jabiru town and near Mudginberri community, respectively, for 2013. Gaps in the data are due to instrument maintenance and data quality issues.

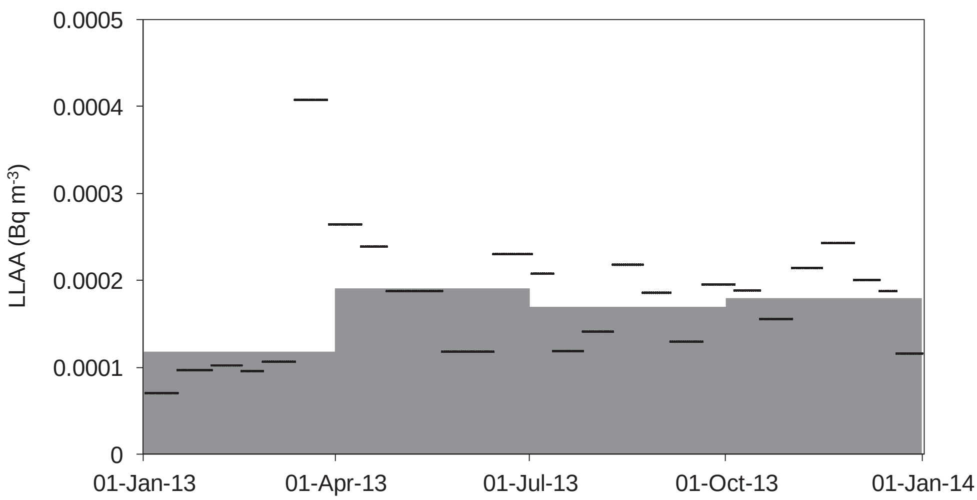

Figure 3.40 Measured (black lines) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Jabiru town in 2013.

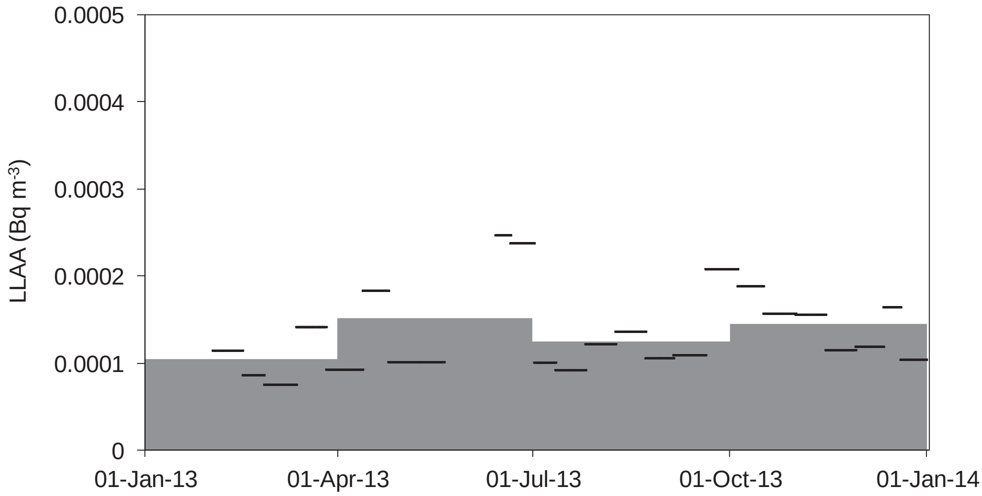

Figure 3.41 Measured (black lines) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Four Gates Road radon station near the Mudginberri community in 2013.

Table 3.15 provides a summary of annual average LLAA radionuclide concentration and estimated total and mine-related doses to the public. The total annual effective dose from dust-bound LLAA radionuclides, which includes contribution from natural background, has been estimated to be 0.007 mSv at Jabiru town and 0.005 mSv at Mudginberri. This total annual dose has been estimated by calculating the time weighted annual average LLAA concentration from the individual samples and then multiplying with a dose conversion factor of 0.0061 mSv Bqα^{-1}, breathing rate of 0.75 m^3 h^{-1} and assumed full year occupancy of 8 760 hours.

TABLE 3.15 LLAA RADIONUCLIDE CONCENTRATIONS IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI IN 2013

	Jabiru town	Mudginberri
Annual average PAEC [μJ m^{-3}]	1.7×10^{-4}	1.3×10^{-4}
Total annual dose [mSv]	0.007	0.005
Mine-related dose* [mSv]	1×10^{-3}	3×10^{-5}

* Calculated from the assumption that the ratio of mine-related to total annual dose from dust is the same as that for radon progeny.

The mine-related dose from dust-bound LLAA radionuclides has been estimated by assuming that the ratio of mine-related to total annual dose from dust is the same as that for radon progeny. This assumption is likely to result in an overestimate of the mine-related dose via the dust inhalation pathway. This is because dust in air should settle out much quicker as a function of distance from the mine compared with gaseous radon, meaning that the mine-related to total dose ratio for dust should be less than that for radon progeny.

Ingestion pathway

SSD routinely monitors the aquatic aspects of the ingestion pathway and collects and analyses mussels for both radionuclides and heavy metals each year at Mudginberri Billabong and every three years at Sandy Billabong (control site in the Nourlangie catchment). Local indigenous people have historically expressed concern about radionuclides in mussels from Mudginberri Billabong as these are a regularly consumed bush food item. The SSD's monitoring focuses on ^{226}Ra as it has been shown that ^{226}Ra in mussels is the biggest potential contributor to mine-related ingestion dose. The ^{226}Ra activity concentration in Magela Creek waters is routinely monitored by both ERA and the Supervising Scientist and its limit is based on potential dietary uptake of ^{226}Ra by the Indigenous people downstream of the mine. To this end, no increase of ^{226}Ra activity concentrations in Magela Creek downstream of the mine has been observed (see section 3.2.3.1).

Based upon the measured activity concentrations of ^{226}Ra and ^{210}Pb in mussel flesh and the age distribution of the mussels collected in 2013 (see Section 3.2.3.2), an average annual committed effective dose from ingestion of these isotopes can be calculated for a 10-year old child who eats 2 kg (wet weight) of mussel flesh from Mudginberri Billabong. This dose amounted to 0.15 mSv in 2013. Figure 3.42 shows the doses from ^{226}Ra and ^{210}Pb ingestion estimated for individual years, and the median, 80 and 95 percentiles for all collections.

The difference between ^{226}Ra activity concentrations measured in Magela Creek upstream and downstream of the Ranger mine is only very small (see section 3.2.3.1), and findings from previously reported research show that mussel ^{226}Ra activity loads in Mudginberri Billabong are currently due to natural catchment rather than mining influences. Consequently, the ingestion dose reported here is almost exclusively from natural background contributions and would be received irrespective of the operation of the Ranger mine.

With the rehabilitation of Ranger there will be radiological protection issues associated with the use of the land by local Indigenous people and a shift towards terrestrial food sources. These foodstuffs include both terrestrial animals and plants. Data on activity concentrations in bushfoods and environmental media from the ARR sampled by ***eriss*** and other organisations over the past 30 years have now been consolidated into a consistent, quality controlled database (described in the 2010–11 Supervising Scientist Annual Report). This database (the BRUCE tool) provides a central data repository and facilitates calculation of radionuclide concentration ratios for bushfoods and calculation of ingestion doses for members of the public from consumption of these bushfoods. Chapter 4.6 summarises the concentration ratios and shows how they are used to determine post-rehabilitation doses from the ingestion of traditional terrestrial bushfoods. The database is also continuously populated with metal concentration data for various bushfoods collected in the ARR. Some typical metal concentration data for fish and freshwater mussels from Mudginberri Billabong are shown in section 3.2.3.2 of this report.

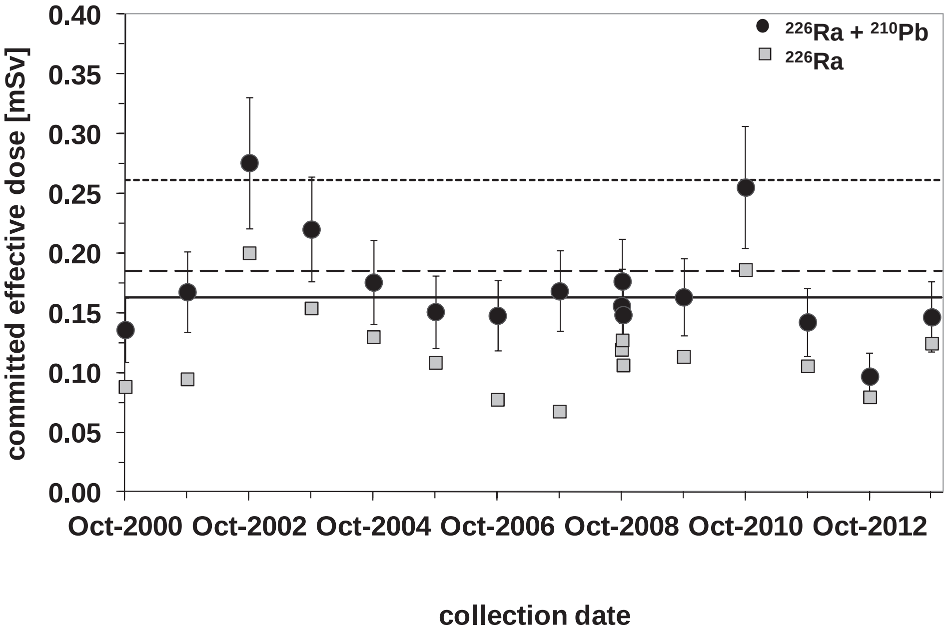

Figure 3.42 Annual committed effective doses (point data) from ^{226}Ra and ^{210}Pb for a 10 year old child eating 2 kg of mussels from Mudginberri Billabong. The median for ^{226}Ra + ^{210}Pb for all the data (solid line), the 80th percentile (dashed line) and 95th percentile (dotted line) are shown for reference.

3.6.3 Jabiluka

3.6.3.1 Radiological exposure of employees

The Jabiluka Authorisation was revised in July 2003 and the statutory requirement of quarterly reporting of radiological monitoring data for Jabiluka was removed. The current Authorisation requires reporting of radiation monitoring data only if any ground-disturbing activities involving radioactive mineralisation occur on site. No ground-disturbing activities took place during this reporting period.

3.6.3.2 Radiological exposure of the public

The population group that may, in theory, receive a radiation dose due to activities at Jabiluka is a small community approximately 10 km south of Jabiluka at Mudginberri.

SSD has a permanent atmospheric monitoring station at Four Gates Road radon station, which is located a few kilometres west of Mudginberri. Radon progeny and dust-bound LLAA radionuclide concentrations are measured at the station.

Figures 3.39 and 3.41 show radon progeny PAEC and dust-bound LLAA radionuclide concentrations measured in air at Four Gates Road radon station during 2013. Tables 3.14 and 3.15 provide public dose estimates for these exposure pathways for a person living at Mudginberri in 2013.

3.7 EPBC assessment advice

SSD continues to provide advice to the Environment Assessment and Compliance Division of DoE on referrals submitted in accordance with the EPBC Act for new and expanding uranium mines.

During the reporting period SSD provided coordinated responses from SSD on the following assessment activities:

- Kintyre Uranium Project, Environmental Review Management Programme (ERMP)
- Olympic Dam, Mine Closure and Rehabilitation Plan (2013)
- Referral of a proposed action for the extension to the Wiluna Uranium Project
- Ranger 3 Deeps underground mine Environmental Impact Statement guidelines.

A representative from SSD visited the Kintyre Uranium Project in April 2014 as part of a site visit involving representatives from Cameco, the Western Australian Environmental Protection Authority (EPA), Office of the EPA and Department of Mines and Petroleum. The purpose of this visit was to provide on-ground context and assist in clarification on matters raised during the ERMP assessment process.

4 ENVIRONMENTAL RESEARCH

4.1 Introduction

The *Environment Protection (Alligator Rivers Region) Act 1978* established the Alligator Rivers Region Research Institute (ARRRI) to undertake research into the environmental effects of uranium mining in the Alligator Rivers Region (see Map 1). The scope of the research programme was widened in 1994 following amendments to the Act. The Alligator Rivers Region Research Institute was subsequently renamed the Environmental Research Institute of the Supervising Scientist (***eriss***).

The core work of ***eriss*** comprises developing and refining monitoring procedures and standards for the protection of people and the environment from the effects of uranium mining in the Alligator Rivers Region (ARR). The details and outcomes of the monitoring programmes are reported in chapter 3. The expertise of the Institute is also applied to conducting research on the environmental protection of tropical rivers and their associated wetlands, and to providing advice to the Department and other government organisations on other relevant environmental issues as requested (see chapter 5). ***eriss*** also provides (on a commercial basis) consultancy services that assist the management of water quality issues at other types of mines in the northern tropics. This consultancy work is limited to activities that are strategically aligned to our core statutory responsibilities, and is subject to assessment to ensure that it does not constitute any conflict-of-interest with other work of the Department.

The content and outcomes of the ***eriss*** research programme are assessed annually by ARRTC against identified Key Knowledge Needs (KKNs). These KKNs define the key research needs within each of the geographic domains in the ARR relating to monitoring, closure and rehabilitation for current (Ranger and Jabiluka), rehabilitated (Nabarlek) and legacy (South Alligator River Valley) sites. The charter and activities of ARRTC are described in chapter 2 of this annual report and the current list of KKNs is provided for reference in Appendix 1.

eriss contributes to the addressing of each of the KKNs by applying a broad range of scientific expertise across the research fields of:

- ecotoxicology
- environmental radioactivity
- hydrologic, geomorphic and chemical processes
- aquatic ecology and ecosystem protection
- revegetation and landscape ecology.

Highlights from the 2013–14 ***eriss*** research programs are presented in this chapter. Specifically, eight projects that cover all the above-listed research fields are discussed. They represent a snapshot of the broader research programme within ***eriss***, which covered almost 40 projects. Of these, six were completed, 13 were commenced and the remainder were continuing projects. The full research project suite is listed in Appendix 4. The majority (~95%) of these projects were addressing issues associated with the current operational phase and/or proposed rehabilitation and post-rehabilitation phases of Ranger mine. More comprehensive descriptions of ***eriss*** research are published in journal and conference papers and in the Supervising Scientist and Internal Report series. Publications by SSD staff in 2012–13 are listed in Appendix 2, while presentations given during the year are listed in Appendix 3. More information on the Division's publications, including the full list of staff publications from 1978 to the end of June 2013, is available on the SSD website at www.environment.gov.au/ssd/publications.

4.2 *Hydra viridissima* (Green hydra) rapidly recovers from exposure to multiple magnesium pulses

4.2.1 Background

Magnesium (Mg) is more toxic to aquatic organisms inhabiting low ionic strength waters, such as those found in the sandy braided streams of northern Australia. Given this, a significant research effort has focussed on ensuring that discharges of Mg from Ranger uranium mine to adjacent creeks are well understood. This has resulted in the development and implementation of a site-specific water quality guideline trigger value (TV) framework for Mg. A long-term continuous electrical conductivity (EC) monitoring programme has provided a high resolution temporal record of Mg concentrations in Magela Creek, as Mg concentrations can be reliably inferred from EC (Turner & Jones 2010[7]). This record has been used to understand the potential exposure patterns of Mg to organisms in the environment. Generally, increases in Mg concentration occur as 'pulses' lasting minutes to hours. In contrast, the data used to derive the site-specific Mg TV was derived from continuous exposure toxicity tests where organisms were exposed for periods of three to six days (van Dam et al. 2010[8]). To address this disparity, a duration-based TV for Mg in Magela Creek was developed based on empirical pulse exposure data (Hogan et al. 2013[9]). The use of this TV in a regulatory framework was described by Sinclair et al. (2013)[10].

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[7] Turner K & Jones D 2010. Surface water transport of mine-related solutes in the Magela Creek catchment using continuous monitoring techniques. In: Jones D, Webb A (eds.). ***eriss*** *research summary 2008–2009.* Supervising Scientist, Commonwealth of Australia, Canberra.

[8] van Dam RA, Hogan AC, McCullough CD, Houston MA, Humphrey CL & Harford AJ 2010. Aquatic toxicity of magnesium sulfate, and the influence of calcium, in very low ionic concentration water. *Environmental Toxicology & Chemistry* 29: 410–421.

[9] Hogan AC, Trenfield MA, Harford AJ & van Dam, RA 2013. Toxicity of magnesium pulses to tropical freshwater species and the development of a duration-based water quality guideline. *Environmental Toxicology & Chemistry* 32, 1969–1980.

[10] Sinclair A, Tayler K, van Dam R & Hogan A 2013. Site-specific water quality guidelines: 2. development of a water quality regulation framework for pulse exposures of mine water discharges at a uranium mine in northern Australia. *Environmental Science & Pollution Research* 21, 131–140.

A recognised limitation of the duration-based TV method was that it is based on single pulse toxicity data. Hence, it was unknown if the organisms had fully recovered from a pulse exposure or if they carried damage, resulting in higher sensitivity to subsequent pulses. Multiple pulses were observed in the creek over short time-frames and, if organism recovery was slow or incomplete, then the TV could potentially be under-protective.

The present study assessed organism recovery time and the potential for carry-over toxicity for one species, the Green hydra (*Hydra viridissima*). This species was chosen as a model organism as it was the second most sensitive of the local species to Mg and the test protocol allows for a simple assessment of recovery through a comparison of population growth rates after 96 h. *Hydra viridissima* was exposed to a range of multiple pulse scenarios relevant to the Ranger mine discharge, allowing a comparison of biological responses between combinations of single and multiple Mg pulses with varying pulse and inter-pulse durations. The broader aim of the study was to generate data that informed the use of the site-specific Mg TV framework when assessing multiple, closely-spaced pulses of Mg in Magela Creek.

4.2.2 Methods

4.2.2.1 Characterisation of Mg pulses in Magela Creek

An analysis of the continuous monitoring EC/Mg data was conducted to determine the frequency, magnitude and duration of pulses and inter-pulse periods observed in Magela Creek between 2005–2012. This information enabled environmentally relevant recovery periods to be tested.

4.2.2.2 Toxicity testing

All toxicity tests were conducted according to the standard ***eriss*** protocol for the 96-h *H. viridissima* population growth rate test.

Apparent recovery

Apparent recovery is an assessment of when organisms appear to have recovered (in terms of growth rate) and does not indicate the potential for organisms to carry over damage that may cause them to be more sensitive to subsequent pulses. An estimate of apparent recovery was needed for the present study to provide guidance on the recovery periods to be tested in the true recovery experiments (see below). It was also used to determine if apparent recovery provided an accurate indication of true recovery having occurred.

Apparent recovery data already existed for single 4-h Mg pulses as the growth rates of exposed hydra returned to that of controls within the standard 96-h test duration. As recovery from longer pulse exposures is usually more prolonged, a 24-h pulse test was conducted and the duration extended until apparent recovery was observed (192–240 h depending on treatment).

Data from both the 4- and 24-h pulse recovery experiments were incorporated into a control chart, which was used to calculate the time taken for the Mg-pulsed treatments to return to growth rates similar to controls.

True recovery

True recovery was considered to have occurred when the hydra exhibited similar sensitivity to a second pulse compared to a single pulse. That is, their ability to withstand a subsequent pulse was equal to their original sensitivity. In order to determine when true recovery occurred, the hydra were exposed to double Mg pulses that were separated by different recovery periods. Specifically, *H. viridissima* were exposed to 4-h Mg pulses of 790 and 1100 mg L^{-1} separated by 2, 10, 18, 24, 48 and 72-h recovery periods. Twenty four-hour pulses of 570, 910 and 940 mg L^{-1} were separated by 24, 48 and 168-h recovery periods.

Multiple pulse scenarios

This test aimed to compare treatments that could be considered equivalent in terms of total exposure duration and magnitude, but different in terms of the actual pulse and inter-pulse durations. The growth rates of the hydra were compared across six treatments. The first four treatments exposed the hydra to 850 mg L^{-1} Mg for an overall exposure of 24-h but under different pulse scenarios (i.e. 1 × 24 h pulse, 6 × 4 h pulses, 3 × 8 h pulses and 4 × 6 h pulses). The 68-h continuous exposure to 300 mg L^{-1} Mg was a time-weighted average comparison to the 6 × 4-h pulse exposure scenario. Alternatively, the 68-h pulse exposure to 850 mg L^{-1} mimicked a potential conservative application of the TV, where the duration of a series of Mg pulse-events is considered one long event.

4.2.3 Results

4.2.3.1 Characterisation of Mg pulses in Magela Creek

Seventy one Mg pulses were identified from the 2005–2006 wet season through to the 2011–2012 wet season, with 95% of the pulse durations being < 24 h and only 2 pulses with durations considered as chronic (> 96 h). A large proportion of the pulses (60%) were within the 4–24-h duration range assessed in this study. Thirty six percent of pulses were shorter than 4 h and the remaining 4% were greater than 24 h in duration.

Inter-pulse periods were often short with the shortest lasting only 1.3 h. Multiple pulses often occurred within a short timeframe, with 30% of inter-pulse periods being < 24 h duration, 50% < 48 h duration and 60% < 96 h duration. This further emphasised the need for this study and provided guidance on the recovery periods to be tested.

4.2.3.2 Toxicity testing

Apparent recovery

Recovery from 4-h Mg exposures appeared to have occurred prior to the first observation at 24 h for all but the highest survivable concentration tested (Figure 4.1). Time to apparent recovery for the highest survivable 4-h Mg exposure of 1300 mg L^{-1} was estimated to be between 72 and 96 h. The estimated times to apparent recovery after a single 24-h pulse were between 24 h and 48 h for 210, 420 and 630 mg L^{-1} Mg; between 72 h and 96 h for 860 mg L^{-1} Mg; and greater than 120 h for 1100 mgL^{-1} Mg. These results guided the recovery periods tested in the true recovery experiments.

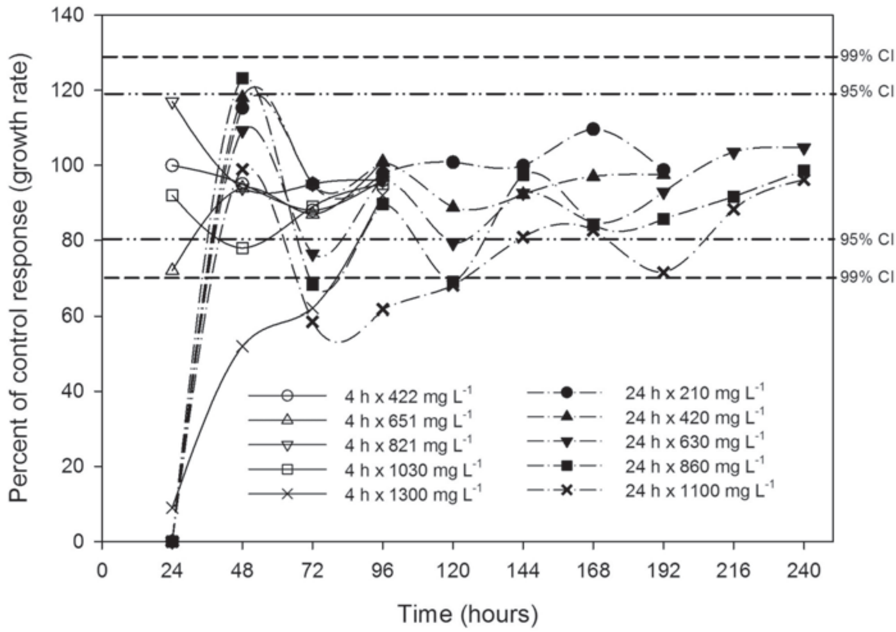

Figure 4.1 The time taken for *Hydra viridissima* to show apparent recovery. The 99% CI (71 & 129%) represent the expected range for the percentage of mean control growth. When the treatment growth was within this range apparent recovery was considered to have occurred. Data was smoothed using a moving three day average.

True recovery

All organisms showed a statistically similar or reduced sensitivity to the second pulse when compared to the single pulse sensitivity (Figures 4.2 and 4.3). An asterix in the following figures denotes significant differences ($P < 0.05$) between double and single pulse treatments, detected by Dunnett's test.

This indicated that full recovery occurred prior to the exposure of the second pulse for the recovery periods tested. Where the result was unclear, a repeat test was conducted (Figures 4.2 b and 4.3b) to confirm the response.

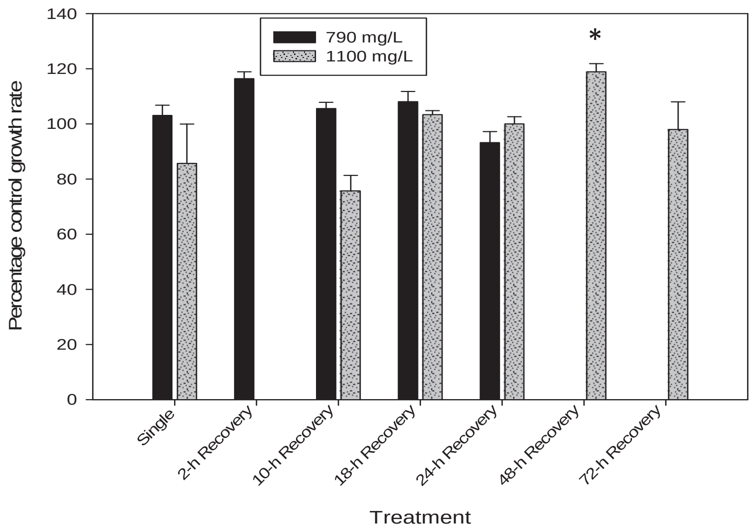

Figure 4.2 a) Mean percentage of control growth rates of *Hydra viridissima* after a single 4-h Mg pulse and a second 4-h Mg pulse after the nominated recovery periods. Error bars represent the standard error of the mean. Pulse magnitudes were 790 and 1100 mg L^{-1}.

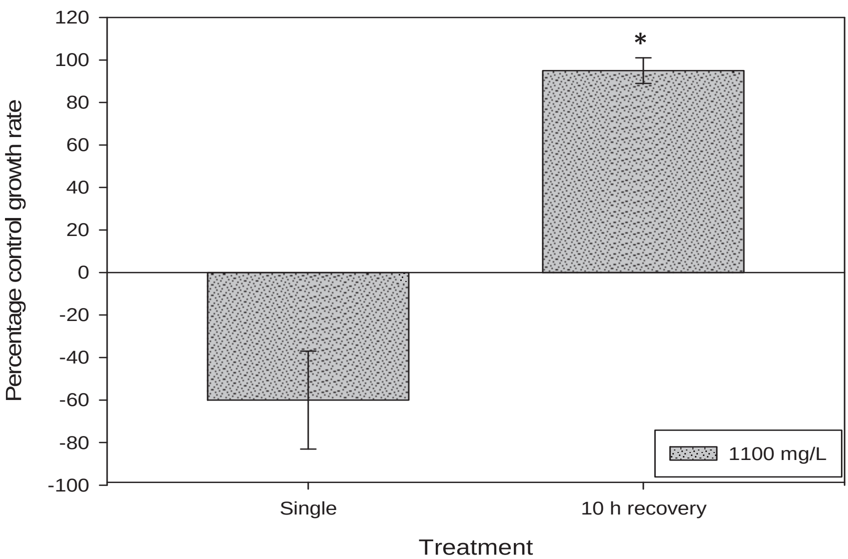

Figure 4.2 b) result of repeat experiment for 1100 mg L^{-1} Mg treatment.

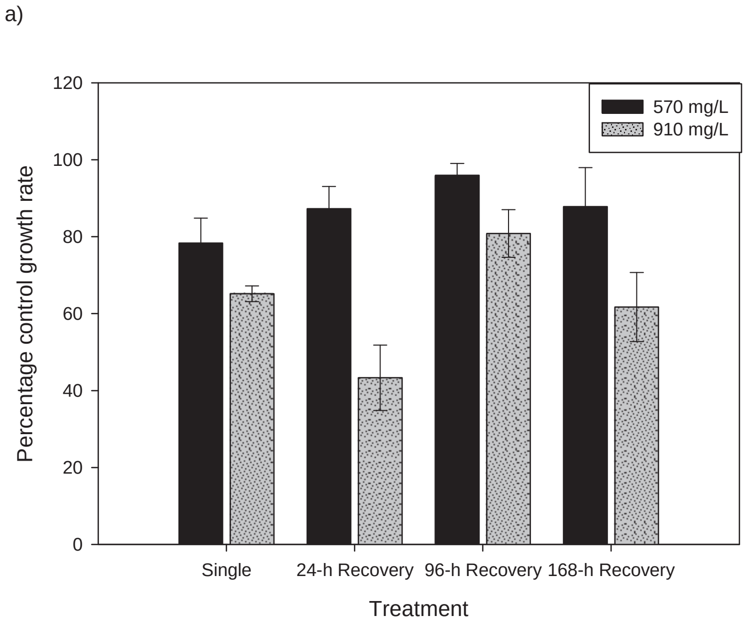

Figure 4.3 a) Mean percentage of control growth rates of *Hydra viridissima* after a single 24-h magnesium pulse and a second 24-h magnesium pulse after the nominated recovery periods. Error bars represent the standard error of the mean. Pulse magnitudes were 570 and 910 mg L^{-1}.

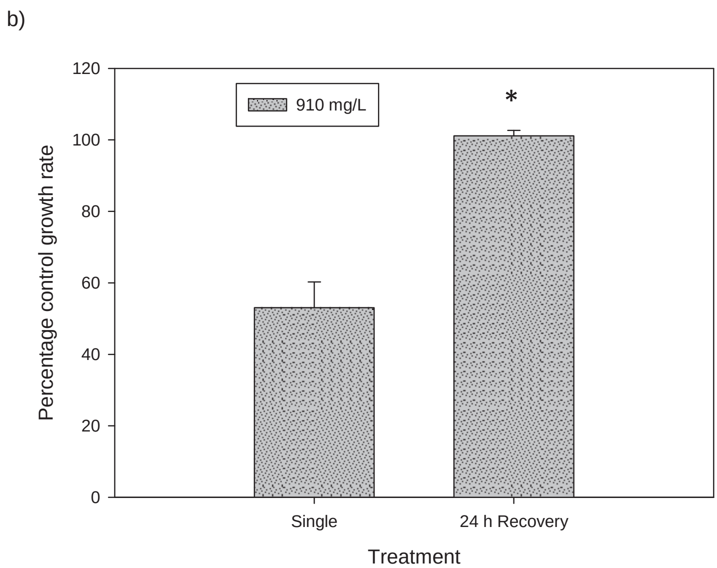

Figure 4.3 b) result of repeat experiment for 910 mg L^{-1} treatment (measured Mg = 940 mg L^{-1}).

Multiple pulse scenarios

Five variations of equivalent time-weighted average concentrations were used to compare sensitivity of organisms after multiple pulses within a standard 96-h toxicity test. The sensitivity of the organisms to the multiple pulses generally corresponded with the time-weighted average response, although the hydra's growth was statistically higher in two multiple pulse scenarios indicating that this species benefited from recovery periods (Figure 4.4).

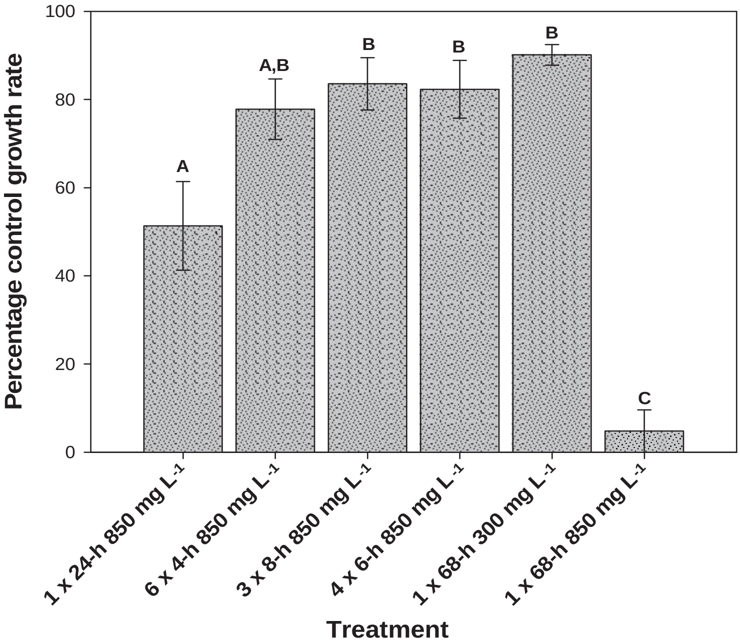

Figure 4.4 *Hydra viridissima* mean 96-h percentage of control growth rate after a 1 x 24 h, 6 x 4 h, 3 x 8 h and 4 x 6 h at 850 mg L^{-1} Mg pulses, a 1 x 68 h pulse at 300 mg L^{-1} Mg and 1 x 68 h at 850 mg L^{-1} Mg pulse. Significant differences between treatments are shown by differing letters, Tukey's post-hoc test $P < 0.001$.

The potential regulatory approach of applying a total additive time, or the 68 h exposure to 850 mg L^{-1}, showed statistically lower percentage control growth at 5 ± 5% than all other treatments indicating that, based on the response of *H. viridissima* alone, this would be an overly-conservative approach.

4.2.4 Conclusions

Complete recovery of *H. viridissima* was observed for all Mg concentrations, pulse durations and recovery periods tested. This indicates that this species truly recovers from Mg pulses and does not carry over any toxicity to subsequent pulses.

True recovery occurred more rapidly than expected based on observations of apparent recovery from single Mg pulse tests, demonstrating that apparent recovery is a conservative indicator of true recovery for this species. While additional organisms should be tested, the double pulse experiments suggest that Mg pulses more than 24 h apart (i.e. the shortest recovery period tested for both pulse durations) may be considered as independent events when applying the TV in a regulatory framework.

Hydra viridissima appear to be slightly less sensitive to multiple short pulses than one longer pulse of equivalent exposure. This indicates that for this species, time weighted averaging may be a suitable approach when assessing the risk of multiple Mg pulses with inter-pulse periods < 24 h apart.

4.2.5 Further work

This study focussed on one organism, and further toxicity testing on several species would be needed if changes to the application of the site-specific TV framework were to be recommended. Given the high sensitivity and slow apparent recovery from single pulse experiments using *Moinodaphnia macleayi*, this species is considered a priority test organism.

4.3 Derivation of a water quality trigger value for manganese

4.3.1 Background

Manganese (Mn) occurs at elevated concentrations in the mine waters of the Ranger uranium mine. Although, Mn is reported to be lower in toxicity compared to many other metals, the very soft-water of Magela Creek increases the risk of Mn being toxic to local organisms. Hence, site-specific water quality Trigger Values (TV) for Mn are needed for the mine's current operations as well as for closure criteria for its rehabilitation targets. An assessment of the toxicity of Mn to local species has been ongoing since a preliminary study in 2008. Further context and past progress of this project have been previously reported in Supervising Scientist's annual research summaries and annual reports (Supervising Scientist 2014[11]).

The Mn TV project had the following aims:

- Assess the toxicity of manganese (Mn) in natural Magela Creek water (NMCW; pH ~6 6.5) to tropical freshwater species, and
- Derive a site-specific water quality TV for Mn based on the toxicity data.

4.3.2 Methods

The toxicity of Mn was assessed using six local freshwater species. Toxicity testing methods used have been previously described and preliminary toxicity estimates previously provided (Supervising Scientist 2014). The final toxicity estimates were used to derive a site-specific 99% species protection TV using the species sensitivity distribution method. Three toxicity estimates (Peters et al. 2011[12]) from international studies with physico-chemical conditions closely related to Magela Creek were identified in the literature. These were added to the local species dataset to increase the sample size and statistical rigour of the method.

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[11] Supervising Scientist 2014. *Annual Report 2012–2013*. Canberra.

[12] Peters A, Lofts S, Merrington G, Brown B, Stubblefield W & Harlow K 2011. Development of biotic ligand models for chronic manganese toxicity to fish, invertebrates, and algae. *Environmental Toxicology and Chemistry* 30(11) 2407–2415.

4.3.3 Toxicity

Manganese toxicity estimates varied markedly between the six local tropical freshwater species (see Table 4.1 for final toxicity estimates). *Hydra viridissima* was the second most sensitive species reported in the literature after the freshwater amphipod, *Hyalella azteca* (IC10 = 100 µg L^{-1}). The order of sensitivity of the six species to Mn was:

H. viridissima > *A. cumingi* >*M. macleayi* >> *L. aequinoctialis* > *Chlorella* sp. >> *M. mogurnda.*

TABLE 4.1 FINAL MANGANESE TOXICITY ESTIMATES FOR THE SIX TROPICAL FRESHWATER SPECIES.

	Manganese (µg L^{-1})	
Species	**IC10[a]**	**IC50[a]**
Chlorella sp.	12000 (10000 – 14000)	60000 (55000 – 70000)
Lemna aequinoctialis	2200 (910 – 3400)	11000 (9000 - 10000
Hydra viridissima	140 (100 - 180)	1380 (1200 - 1560)
Moinodaphnia macleayi	610 (500 - 690)	1100 (1030 - 1170)
Amerianna cumingi	340 (830 - 920)	5660 (2830 - 12660)
	LC05[b]	**LC50[b]**
Mogurnda mogurnda	80000 (40000 – 110000)	240000 (200000 – 320000)

[a] IC10 and IC50: concentration resulting in 10% and 50% effect relative to the control response, respectively

[b] LC05 and LC50: concentration resulting in 5% and 50% mortality relative to the control response, respectively.

4.3.4 Manganese water quality trigger value derivation

The toxicity estimates from the natural Magela Creek water study (Table 4.1), along with international data (Peters et al. 2011) from toxicity tests conducted in a natural water (Pinelands, New Jersey, USA) with a similar physico-chemistry to NMCW (i.e. temperature = 24–25°C, pH = 6.7, alkalinity = 8 mg L^{-1}, hardness = 12 mg L^{-1} and DOC = 12 mg L^{-1}) were used to construct a Species Sensitivity Distribution (SSD). Inclusion of the international data in the method improved the fit of the distribution and the confidence intervals of the TV. Both the European Commission and Australia recommend that a minimum of eight toxicity estimates are needed for a "high reliability" TV (European Commission 2011[13]; Batley et al. 2014[14]). These data result in a 99% species protection TV

[13] European Comission 2011. Technical guidance for deriving environmental quality standards. Guidance Document No 27, Common Implementation Strategy for the Water Framework Directive, European Commission, Brussels.

[14] Batley GE, Chapman JC, Fox DR, Hickey CW, Stauber JL, van Dam RA & Warne MStJ 2014. Revision of the method for deriving water quality guideline trigger values for toxicants. Prepared for the Council of Australian Governments Standing Council on Environment and Water (SCEW), Canberra.

of 73 µg L^{-1} with lower 95% and 80% confidence intervals around the TV of 33 and 46 µg L^{-1}, respectively (Figure 4.5). Hence, it was recommended that a 99% protection TV of 75 µg L^{-1} Mn be applied as the Limit at MG009, with accompanying Focus and Action levels of 35 and 45 µg L^{-1}, respectively.

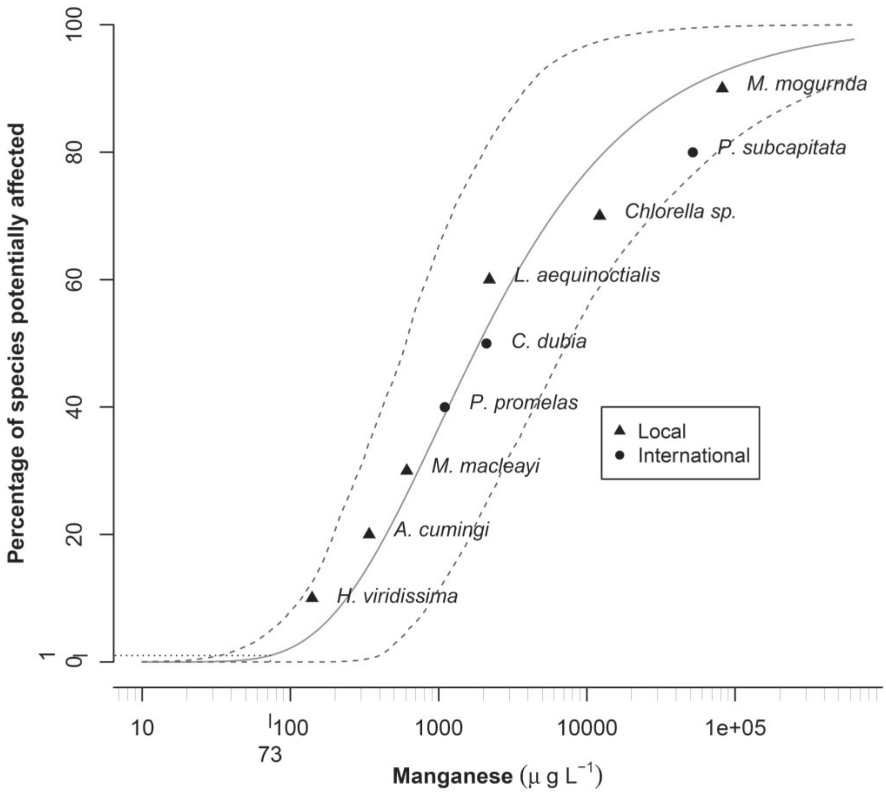


Figure 4.5 Species Sensitivity Distribution of manganese toxicity estimates for the six local species, and including 3 toxicity estimates from international datasets (*P. subcapitata*, *C. dubia* and *P. promelas*).

4.3.5 Conclusions

The Mn trigger framework (Focus, Action, Limit) recommended above was formally implemented into the Ranger regulatory framework prior to the wet season of 2013–14. The Mn toxicity and trigger value study will be externally published in 2014–15.

4.4 Environmental factors associated with toxicity monitoring in Magela and Gulungul Creeks

4.4.1 Influences of different snail culturing conditions on the snail egg production response

Background

The influence of culturing conditions under which snails are reared, is a potential source of variability in egg production during wet season test exposures in the creeks. This was described in last year's Supervising Scientist Annual Report (2012–2013). Since the 2011–12 wet season, snail stocks for test exposures have been sourced from both shallow static shallow water containers and deep (~1.1 m) containers with a non-static Recirculating Aquaculture System (RAS). For the 2012–13 wet season testing, egg production was compared under routine creek testing conditions between snails cultured under the two culture-water regimes. 'Age' of the snail cohort, as measured by length of time from initial container seeding with egg masses to use of the snails in a toxicity monitoring test, was also examined. However continuous growth and recruitment of snails from the progeny of ensuing generations of snails held in each container was not strictly controlled and so this aspect could not be properly assessed.

Container type (shallow/deep) was found to be a highly significant source of variation in snail egg counts in the tests: snails sourced from shallow static containers produced more eggs than those from the deep (RAS) containers ($P = 0.0001$). No ready explanation for this difference was provided at the time However the more frequent dilution of RAS waters with reverse osmosis-filtered and tap (bore) waters may be removing nutrients and potential for algal food production in these containers.

It was not always possible to attribute an egg count from each snail pair to a specific treatment type in the 2012–13 data analyses. This is because snails were not necessarily sourced from the same culture-water regime when setting up replicate pairs of snails placed in each egg-laying chamber.

Methods

With improvements to the design used in the previous wet season, the effect of snail culturing treatments was further examined in the 2013–14 wet. Two broad treatment classes were adopted:

(i) Deep recirculating aquaculture systems (RAS) (2500 L) versus shallow static containers (1000 L), as used in previous years; and

(ii) Snail stocks established at the start of the wet season and self-replenishing throughout the ensuing wet season ('established') versus stocks re-established as new 'cohorts' at regular intervals. Established stocks developed mixed age classes over time, the oldest snails of which could span the entire wet season (230 days), while 'cohort' stocks contained snails between 53 and 112 days of age at the time of testing (Figure 4.6). Thus cohort snails were of known, and on average younger, age compared to established snails. Four consecutive cohorts were established for wet season testing. Upper numeric values in the 2nd horizontal axis of Figure 4.6 delineate, and indicate age of, cohorts used for testing.

It was possible to further compare egg production for snails held in shallow containers by positioning these either under a broad open awning (‘outside’) or inside a walled-in portion of the same facility (‘inside’). Shallow containers held ‘inside’ were subject to darker day-time conditions (albeit unquantified) while the water temperature outside reached slightly higher day-time but slightly lower night-time water temperatures (± 0.5°C) (data not shown). Differences in egg production between these treatments could thereby indicate light and/or water temperature effects upon egg production.

A total of six treatments were tested over the 2013–14 wet season:

1.	RAS - Deep	Outside	Established at start
2.	RAS - Deep	Outside	Cohorts
3.	Static shallow	Outside	Established at start
4.	Static shallow	Outside	Cohorts
5.	Static shallow	Inside	Established at start
6.	Static shallow	Inside	Cohorts

For each toxicity monitoring test and each creek and site (upstream/downstream), replicate snail pairs were selected for testing in equal numbers from across the six treatments described above (i.e. 3 snail pairs per treatment, per site). Thus, and unlike the 2012–13 wet season, each snail pair was sourced from the *same* treatment. The total egg count arising from each replicate snail pair was determined, with mean values for all replicate pairs from each of the six treatments plotted for each test in Figure 4.6.

Analysis of variance (ANOVA) testing was used to examine egg number differences amongst the six treatments (see above) for creeks combined and for separate creeks (from Figure 4.6). Container age varied with each test and so this factor was unevenly distributed amongst container types and could only be nested within this factor. In the previous year’s analysis (Supervising Scientist Annual Report for 2012–2013; Section 4.4), snail size, snail weight, site (up/downstream) and test order were additional covariates or factors included in the analysis. For reasons outlined in the previous Annual Report these covariates and factors were not considered in the current ANOVA.

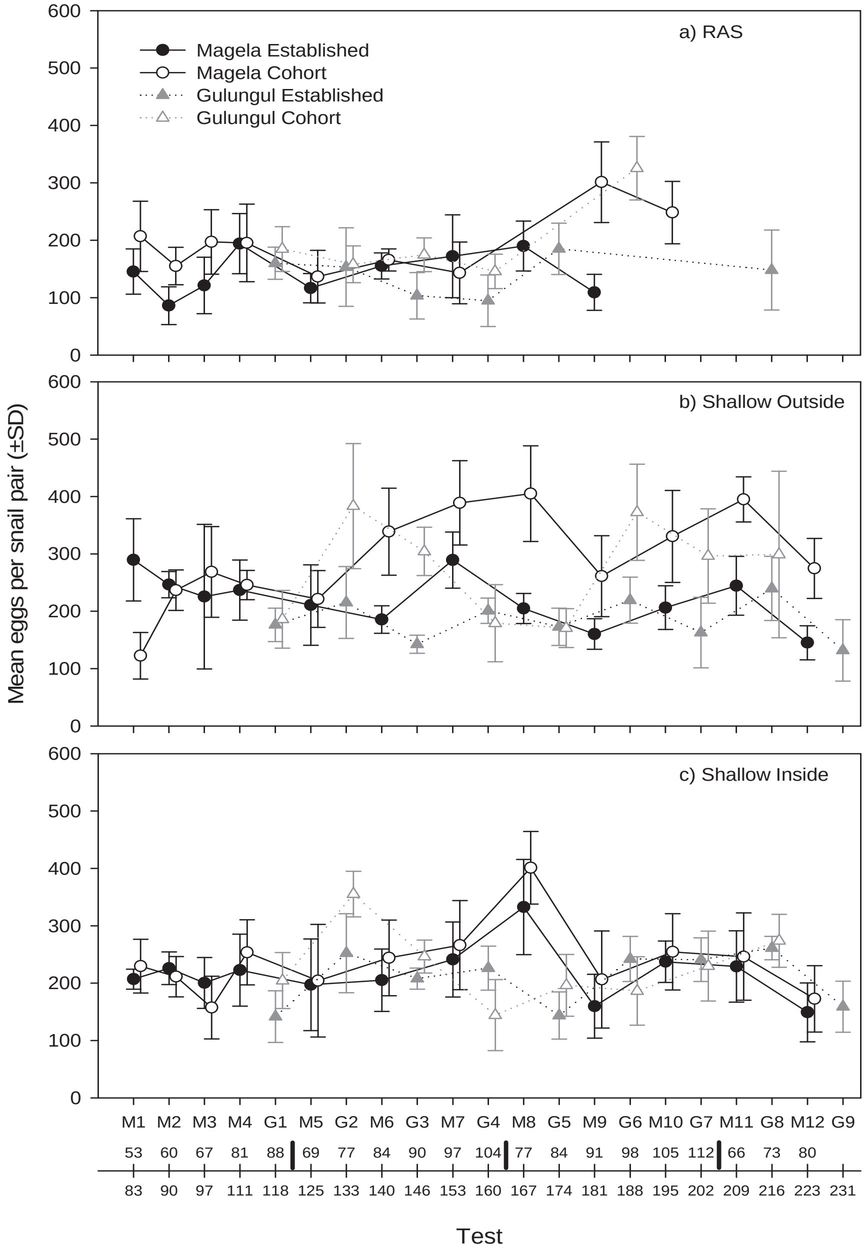


Figure 4.6 Mean egg count for replicate snail pairs (*n*=3) sourced from shallow static and deep RAS culture container types, and according to culture age (established and cohorts), for Magela and Gulungul toxicity monitoring tests conducted in the 2013–14 wet season. Horizontal axis shows the test order over the wet season, with M and G referring to Magela and Gulungul Creeks, respectively. Upper and lower numeric values in the 2nd horizonal axis indicate age of cohorts and time since establishment, for 'culture age' treatments, respectively.

Results

ANOVA testing showed:

1. Snail egg number differed significantly amongst the three container-type treatments for creeks combined and creeks separate ($P = 0.001$). All (three) pairwise comparisons (including shallow inside versus shallow outside) showed highly significant differences for creeks combined and creeks separate ($P = 0.001$). Greater egg production followed the order shallow outside > shallow inside > deep (RAS), evident in the plotted data shown in Figure 4.6. This result supported the 2012–13 wet season analysis (Supervising Scientist Annual Report for 2012–2013; Section 4.4) which showed, similarly, greater egg production for snail pairs reared in shallow static containers compared to deep RAS containers.
2. Egg number differed significantly between established and cohort treatments for creeks combined and creeks separate ($P < 0.01$). Cohort snails produced significantly greater numbers of eggs compared to established snails and this was most evident in the shallow outside treatment (Figure 4.6).
3. Actual container age (or maximum age for ‘established’ treatment), nested within the container age factor, was significant for each creek examined separately ($P = 0.001$). When the ‘established’ treatment was removed from analysis, with container age for just the ‘cohort’ treatment now nested within container type, the factor held a similar significance for each creek ($P = 0.001$). Examining Figure 4.6, it is evident that the egg production for cohort snail age 77 days in both the 2nd and 3rd cohorts, was particularly high, probably explaining the significance of this factor. While fecundity increases generally with snail size (Supervising Scientist Annual Report for 2012–2013; Section 4.4), it is also possible that fecundity has an interaction with snail age with greatest egg production observed at an intermediate age of snails (~77 days). This requires further investigation.

The results of the 2013–14 husbandry investigation have practical implications that guide future snail culturing for routine toxicity monitoring in Magela and Gulungul creeks. Firstly, culturing snails in regular cohorts of known snail age appears to result in greater reproductive vigour. Moreover, the more resource-intensive recirculating aquaculture systems is not providing obvious benefit in terms of snail egg production and could be re-considered in terms of future application. Finally, the results highlight the importance of allocating snails from a particular culturing treatment evenly to each of the paired sites in a toxicity monitoring test. If this is not done, the upstream-downstream difference value for the test may reflect an artefact of culture type, as opposed to its proper representation of detecting changes in water quality.

4.4.2 Influences of ambient water quality on the snail egg production response

As reported above (Section 3.2.3.2, Biological monitoring in Magela Creek), water temperature and electrical conductivity (EC) influence the snail egg laying response in Magela and Gulungul creeks. Continuous water quality data gathered from sondes at each of the monitoring sites since the 2006–07 wet season has enabled accurate and effective integration of water quality exposure conditions for each of the four-day toxicity monitoring tests. Measures of water temperature and EC used in data analyses represent the median of 10 minute continuous readings taken across the four-day exposure period at each of the creek sites. The collective water quality and egg production data gathered since the 2006–07 wet season are shown in Figure 4.7. As described in Section 3.2.3.2 of this report, an interacting effect between water temperature and EC has been observed. As EC increases (generally across the range ~7-30 µS cm^{-1}), snail egg production:

- increases at lower water temperature ranges (27–30°C), and
- decreases (i.e. negative effect) at higher water temperatures (> 30°C) (see Figure 4.7).

The increase in egg production with increasing EC at lower water temperature ranges (< 30°C) is highly significant and this relationship has generally strengthened in the past several years (cumulative results not provided). The decrease in egg production with increasing EC at higher water temperature ranges (30°C) is a weaker relationship that has fluctuated between significance ($P < 0.05$) and non-significance after each wet season of accruing data gathered since 2011 (data also not provided).

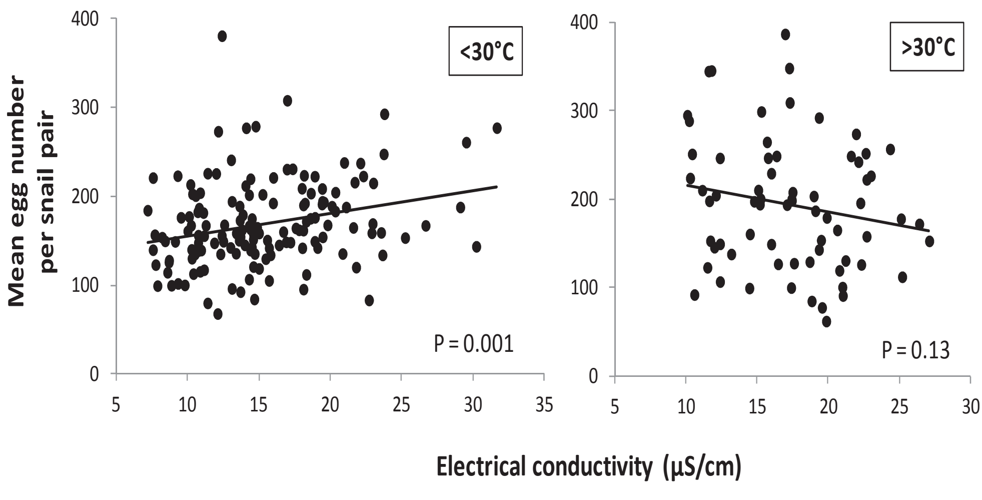


Figure 4.7 Relationships between mean snail egg number for each site in Magela and Gulungul Creeks, and ambient electrical conductivity and water temperature over the four-day exposure test periods for wet seasons between 2006–07 and 2013–14.

As discussed in Section 3.2.3.2, these water quality/egg production relationships as depicted in Figure 4.7, can usefully be applied to interpreting annual toxicity monitoring results in Magela and Gulungul creeks. The relationships have limited use in explaining the *magnitude* of egg production at a site, but can generally explain the *difference*s in egg production between the paired upstream and downstream sites.

Of the 100 tests conducted from 2006–07 to the present, the difference in egg number between upstream and downstream sites can be successfully predicted in more than 75% of tests for median water temperature <30°C and in more than 65% of tests for median water temperature >30°C. As noted in Section 3.2.3.2 above, a (4-day) downstream median EC in Magela and Gulungul creeks greater than 20 µS cm^{-1}, represents a value typically associated with mine waste water discharges. Of the 100 tests conducted since 2006–07 to the present:

- Higher downstream egg production was observed in 15% of the (over 100) tests where median water temperature <30ºC and downstream EC values > 20µS cm^{-1} were observed, and
- Lower downstream egg production was observed in 9% of the (over 100) tests where median water temperature > 30ºC and downstream EC values > 20µS cm^{-1} were observed. Seventy-five percent of these (high water temperature) tests were conducted in Magela Creek.

As noted in Section 3.2.3.2, at this stage these mine-related ‘effects’, representing enhancement in snail reproductive activity in most cases, are not regarded as constituting environmental concern.

4.4.3 Conclusions

Toxicity monitoring results for the 2013–14 wet season supported the findings from the 2012–13 wet season that snail culturing conditions have a significant influence upon the egg laying response in ensuing toxicity monitoring tests. In the previous Supervising Scientist Annual Report for 2012–2013 (Section 4.4), it was suggested that variation in snail egg counts observed in toxicity monitoring tests for 2012–2013 was mostly ambient water quality-related compared to culture-related. This was based upon the proportion of the variation associated with treatments/factors from the ANOVA testing (described above). For the 2012–13 wet season, variation in snail egg counts accounted for by culture conditions was attributed to the factor container type and ambient creek water quality to test order. For these, variation associated with ambient water quality was about 2.5 times greater than culture-type variation.

For the 2013–14 wet season, factors associated with culture conditions included container type and container age. When variation within the ANOVA for these factors is combined and this value is compared to the variation associated with test order (data not provided here), variation associated with ‘ambient water quality’ is about 2 times greater than culture-type variation for Gulungul Creek, but is the same order of variation and contribution as ambient water quality for Magela Creek.

Such comparative assessments (culturing versus water quality) need to be considered carefully, because egg production measured and associated with the different culturing treatments is itself, a reflection of creek water exposures. Hence, culturing responses are not independent of the effects of exposure to creek water quality. The best evidence that creek water quality is the more important contributor to the egg laying response is the fact that the pattern of response in Magela and Gulungul creeks is each relatively independent of one another over the wet season for each of the culturing treatments (Figure 4.6). An improved understanding of the relative influences of culturing versus water quality upon egg production would arise from a laboratory control, where water quality is held constant amongst consecutive tests, run in parallel with the toxicity monitoring tests.

If culturing conditions are contributing to the overall magnitude of egg production in the creeks over the wet season, then snails sourced from the ‘outside’ static shallow containers in both the 2012–13 wet season (Supervising Scientist annual report for 2012–2013, Figure 4.13) and 2013–14 wet season (Figure 4.6) may be responsible for the high egg production observed in both seasons (Figure 3.28 current report). Lower overall egg production in the 2013–14 wet season compared to the previous wet season may be a consequence of the comparatively lower egg production in snails sourced from the deep RAS containers in this wet season (Figure 4.6) compared to the previous wet season (Figure 4.13 from the 2012–2013 Annual Report).

4.5 Radon exhalation from a rehabilitated landform

4.5.1 Introduction

The inhalation of radon decay products is to be included as an exposure pathway in the development of a radiological dose model to estimate above background doses to the public from the rehabilitated Ranger mine site. At Jabiru or Mudginberri, inhalation doses are unlikely to be of concern given that annual mine-derived doses received via the inhalation pathway for the operating mine site at present are less than 0.1 mSv (see chapter 3.6.2). However, people roaming the site after rehabilitation for hunting and gathering activities and camping on site, or in areas nearby, may be exposed to higher radon decay product concentrations. Knowledge of the radon exhalation fluxes from the surface of the substrate used to shape the landform is the first step to predict potential post-rehabilitation doses received via the inhalation of radon decay products.

Radon(^{222}Rn) is part of the natural uranium decay chain and is produced by the decay of radium (^{226}Ra) in soil particles. It is a noble gas and some of the radon emanates from the particles, migrates through the soil pore space and eventually exhales from the soil surface. Radon exhalation depends on soil ^{226}Ra activity concentration and the ^{222}Rn diffusion length, which in turn is influenced by soil porosity, moisture and particle size. Radon in air decays with a half life of 3.82 days to short-lived isotopes of the metals polonium (^{218}Po, ^{214}Po), lead (^{214}Pb) and bismuth (^{214}Bi). It is these radon decay products, rather than the radon gas, that can deposit in the lungs and deliver a radiation dose upon inhalation.

Previous work has focussed on the Ranger trial landform to determine the seasonal and temporal changes in radon exhalation fluxes from different substrates (waste rock only and waste rock-laterite mix). Results were reported in the 2011–12 Supervising Scientist Annual Report and various ***eriss*** Research Summaries. In 2013–14, the focus was on the measurement of radon flux densities from various height radon columns, which were established at the Jabiru Field Station to experimentally determine the radon diffusion length for waste rock used to rehabilitate Ranger uranium mine.

4.5.2 Methods

Two sets of six 240 mm diameter PVC tube columns (Figure 4.8) were set up at the Jabiru Field Station in April 2013, in collaboration with Energy Resources of Australia Ltd and Safe Radiation, Brisbane. The columns were filled with waste rock from Ranger mine consisting of a 4:1 mix of rocks with a diameter of ~70 mm and rocks and gravel less than 40 mm, believed to reasonably represent the substrate that will be used as a cover material for the site. The six columns in each set covered a rock depth from 0.5 m to 3.0 m in 0.5 m intervals, with a 0.2 m deep head space left at the top of the columns. The open end of each column has a machined flange to attach a lid and connect to the *Durridge Rad7* radon detectors that measure the ^{222}Rn exhaling from the surface of the waste rock in the columns. ^{222}Rn activity flux density measurements were conducted in May 2013 and one year later, in April 2014, to investigate whether there is a change in diffusion length with time due to compaction effects of the material in the columns. In addition, the ^{226}Ra activity concentration of the material used to fill each column was measured using scintillation detectors and gamma spectrometry.

Figure 4.8 Set up of the radon columns at the Jabiru Field Station (photo: *Safe Radiation* 2013)

The constant replenishment of ^{222}Rn through the decay of ^{226}Ra in the waste rock leads to the establishment of a ^{222}Rn concentration gradient in the pore space of the waste rock columns. Measurements show ^{222}Rn activity concentrations in the pore space in the order ~10^5 Bq·m^{-3} at two metres below the surface and about 200 Bq·m^{-3} at the surface. Radon diffuses along this concentration gradient and the ^{222}Rn activity flux density from the surface of each of the columns is determined from the increase of the ^{222}Rn activity concentration measured in air within the head space, after closing the column with the lid attached to the *Rad7* instrument.

Assuming that diffusion is the main process governing ^{222}Rn migration though the pore space, the following equation can be used to determine the diffusion length L in the material:

$$\text{Equation 1: } E(h) = E_\infty \cdot \tanh(h/L) = E_\infty \cdot [(1-e^{-2h/L})/(1+e^{-2h/L})]$$

where $E(h)$ and E_∞ are the ^{222}Rn activity flux densities in $Bq{\cdot}m^{-2}{\cdot}s^{-1}$ from a layer of thickness h (in m) or an infinitely thick layer of a particular material, and L is the diffusion length, or effective relaxation length, in meters.

4.5.3 Results and Discussion

The ^{222}Rn activity concentration measured in the head space of a column is humidity corrected, as the relative humidity was generally above 30% during the measurements and the *Rad7* gives low values for a relative humidity above 10%. Figure 4.9 shows a plot of the ^{222}Rn activity flux densities from the various height columns, calculated from the increase of the ^{222}Rn activity concentrations measured in the head space of the columns over time, plotted versus the column height. A curve of the form given in Equation 1 has been fitted to the calculated ^{222}Rn activity flux densities from the various height columns. The coefficients L and E_∞ were obtained through a Levenberg-Marquardt non-linear least square curve fit and the covariant matrix generated was used to determine the variance and coefficient of determination, R^2.

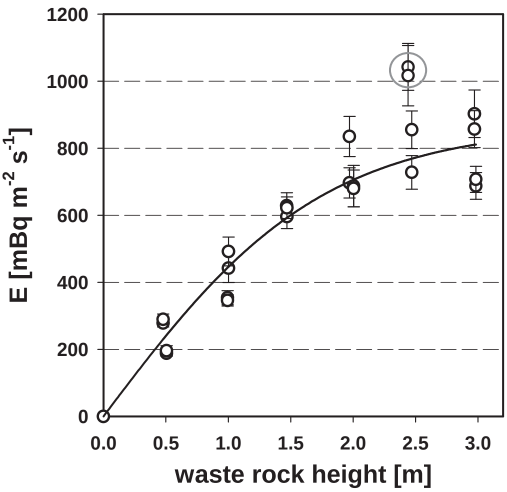


Figure 4.9 ^{222}Rn activity flux density E versus the height of waste rock in the columns from the April 2014 measurements. The circled data belong to column 2.5M2 and have been treated as outliers for the fit. A possible explanation for the higher ^{222}Rn activity flux density could be a higher than estimated activity concentration of the material used to fill the column, due to heterogeneities in the waste rock. The solid line is a curve fit to the data of the form given in equation 1.

From the fit to the experimentally derived data, a ^{222}Rn diffusion length L of 1.8±0.2 m and a ^{222}Rn activity flux density $E\infty$ of 0.87±0.04 $Bq{\cdot}m^{-2}{\cdot}s^{-1}$ were obtained for waste rock with a ^{226}Ra activity concentration of 1860±220 $Bq{\cdot}kg^{-1}$ (average of waste rock ^{226}Ra activity concentration in the columns). The diffusion length is a little higher than typical diffusion lengths in natural soils most likely due to the more porous nature of the material compared to aged natural soils.

Figure 4.10 shows the percentage values of E/E_∞ plotted against h/L. This plot has been used to estimate changes in the ^{222}Rn activity flux from the cover material with height of the material. Assuming a diffusion length of 1.8 m, there will be a less than 5% increase in the ^{222}Rn activity flux from the material layers exceeding 3.3 m in thickness. Two metres of the material will exhale ^{222}Rn at an activity flux density of ~80% of the maximum value.

Effectiveness of waste rock as a cover material

The obtained diffusion length also allows to determine the effectiveness of the waste rock as a substrate to reduce the ^{222}Rn exhalation from a source underneath. Equation 2 can be used to determine the reduction of the ^{222}Rn activity flux density from a source (such as buried tailings) over which the waste rock is laid for capping. If a material with surface activity flux *E0s* is covered with a thickness *h* of a capping material, then the flux will reduce to a value *Ehs* as:

$$\text{Equation 2: } E_{hs} = E_{0s} \cdot e^{-h/L}$$

where E_{0s} and E_{hs} are the ^{222}Rn activity flux densities from the surface of the uncovered material and after a waste rock capping of height *h* has been applied, respectively.

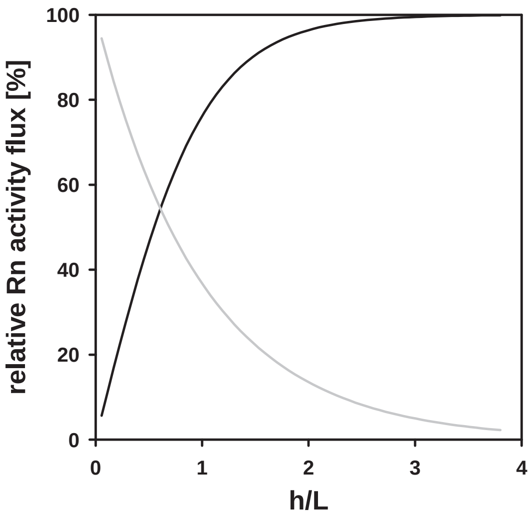


Figure 4.10 Relative ^{222}Rn activity flux density plotted versus the ratio of waste rock height and diffusion length. The black line shows the increase of the ^{222}Rn activity flux density from the waste rock itself with increasing height of the material (equation 1), the grey line shows the reduction of the ^{222}Rn activity flux density from a capped ^{222}Rn source with increasing height of the capping material (equation 2).

Figure 4.10 shows the reduction of the ^{222}Rn exhalation by applying a waste rock cover of height *h* as cover material, plotted against *h/L*.

It is obvious from Figure 4.10 that, while waste rock is suitable as a capping material to lower ^{222}Rn exhalation from buried ^{226}Ra rich material, it will also be a source of ^{222}Rn due to its generally above natural background ^{226}Ra activity concentration. For example, a capping of about three times the diffusion length will reduce the source ^{222}Rn exhalation to less than 5% but, at the same time, the ^{222}Rn exhalation from the capping material itself will effectively be E_∞. The value E_∞ for the radon activity flux density depends on the ^{226}Ra activity concentration of the capping material and, consequently, the lowest grade waste rock should be used for the surface of the rehabilitated landform.

4.5.4 Conclusions

We have determined the radon diffusion length one year after set-up of the radon exhalation columns to be 1.8±0.2 m. The diffusion length has decreased little, if at all, compared to initial measurements conducted in May 2013. The diffusion length has been used to examine the effectiveness of waste rock as a cover material and also the ^{222}Rn exhalation from the waste rock itself. The ratio $R_{E\text{-}R}$ of E_∞ to the average ^{226}Ra activity concentration in the waste rock, determined in this experimental set up, is (0.47±0.05) $Bq{\cdot}m^{-2}{\cdot}s^{-1}$ per $Bq{\cdot}g^{-1}$, which is similar to the ratio determined through measurements on the trial landform.

A further set of ^{222}Rn exhalation measurements will be conducted in the dry season of 2015. This is to determine whether there is a statistically significant decrease in the ^{222}Rn diffusion length with time. Future work will include the modeling of above baseline ^{222}Rn exhalation fluxes from the rehabilitated landform, using pre-mining fluxes reported in previous Supervising Scientist annual reports and various rehabilitation scenarios. Ultimately, these above background fluxes will be used to determine above background doses from the inhalation of radon decay products.

4.6 Post-rehabilitation radiation exposure due to Indigenous bush foods from terrestrial ecosystems

4.6.1 Introduction

The current authorisation for Ranger mine requires that all mining and processing activities must cease by 2021, and that site rehabilitation must be completed by 2026. Rehabilitation of the mine will result in the re-establishment of terrestrial ecosystem and eventual return of the land to traditional owners. Traditional owners using the rehabilitated site and adjacent areas of Kakadu National Park for cultural activities may incur a radiation dose from the site. This dose must not exceed the public dose limit of 1 mSv in a year above the pre-mining background.

A radiological dose model is currently being developed to estimate above background doses to Indigenous people from the rehabilitated Ranger mine site. The ingestion of radionuclides accumulated in bush foods is to be included as an exposure pathway within the dose model to account for traditional living scenarios. A common approach used in dose models to estimate radionuclide accumulation in food items is to use concentration ratios (CRs). These can be expressed as the ratio of the radionuclide activity concentration in the food item (plant or animal tissue) to that in the relevant environmental medium (soil for terrestrial ecosystems).

eriss has substantial data on the radionuclide activity concentrations in terrestrial wild plants and animals and in soils collected from the ARR. These data have amassed from radioactivity measurements of field samples collected over several decades. The data have recently been collated and CRs calculated for plant- and animal-based bush foods from terrestrial ecosystems. The CRs may be used in combination with other parameters to estimate above background ingestion doses due to the rehabilitated Ranger mine site.

4.6.2 Data and analysis

Radionuclide data were collated from ***eriss*** publications and a large set of unpublished analysis results. These data receive quality assurance checks before reporting. Data of ERA and others were also included to produce a comprehensive dataset from which CRs could be derived. The data of ERA were largely from statutory environmental monitoring reports and assumed to be of good quality. Data collation focussed on retrieval of individual sample results rather than summary statistics. In total, data for 164 terrestrial plant samples, 165 terrestrial animal samples and more than 1500 soil samples were collated.

The collated data were organised around a number of biota groups considered representative of common bush food types. These biota groups included bandicoot, buffalo, goanna, pig, wallaby, fruit and yam. The BRUCE tool (described in the 2010–11 Annual Report) was then used to calculate CRs from the data on a wet mass biota tissue to dry mass soil basis. For a small number of biota-tissue-radionuclide combinations the only tissue activity concentration data available were less than detection limit values. A weighting factor of 0.5 was applied to the tissue activity concentration to calculate CRs for these combinations.

4.6.3 Results and discussion

4.6.3.1 CR results

CR results for more than 100 biota-tissue-radionuclide combinations were determined. Figure 4.11 shows the CR geometric mean and standard deviation for each combination. The sample count was low for most combinations and precluded rigorous statistical treatment of the results. Nevertheless, the following general trends were observed:

1. *CRs for yam higher than fruit*. Yams are root vegetables and uptake radionuclides directly from the soil. Fruits on the other hand sequester radionuclides translocated from the root of the plant following uptake from the soil. Hence, the transfer pathway to fruits is effectively longer than for yams and so there is greater possibility of immobilisation of the radionuclide along this pathway by physical and chemical processes.
2. *CRs for ^{210}Po in animal tissue higher, and for U and Th lower, than other radionuclides*. The higher CRs for ^{210}Po may be from elevated ^{210}Po concentrations in the above-ground parts of plants and grasses consumed by foraging animals due to atmospheric deposition and foliar adsorption of this radionuclide. ^{210}Po is present in the atmosphere from the decay of ^{222}Rn, a natural radioactive gas released to the atmosphere by soils and rocks. The lower CRs for U and Th were potentially due to low gastrointestinal fractional absorption by animals. Gastrointestinal fractional absorption follows the order Th < U < Ra < Pb < Po. This may also contribute to the higher CRs for ^{210}Po.
3. *CRs for ^{210}Pb and ^{210}Po in liver and kidney higher than flesh*. Comparative results for bandicoot, buffalo, goanna and wallaby showed that CRs for ^{210}Pb and ^{210}Po in liver and kidney were higher than flesh by approximately one order of magnitude. The liver and kidneys act as filters for substances passing through the body of an animal and are known to accumulate various metals and pollutants, including radionuclides.
4. *CRs for ^{226}Ra in bone much higher than flesh*. The bone ^{226}Ra CR was greater than the flesh ^{226}Ra CR in buffalo and pig by two orders of magnitude and in wallaby by four orders of magnitude. The similar chemical properties of group 2 elements means that radium essentially follows the same metabolism as calcium, and so is preferentially

incorporated in bone and other calcified tissue. This may also explain the higher observed ^{226}Ra CR for goanna egg, which was two orders of magnitude higher than that for goanna flesh.

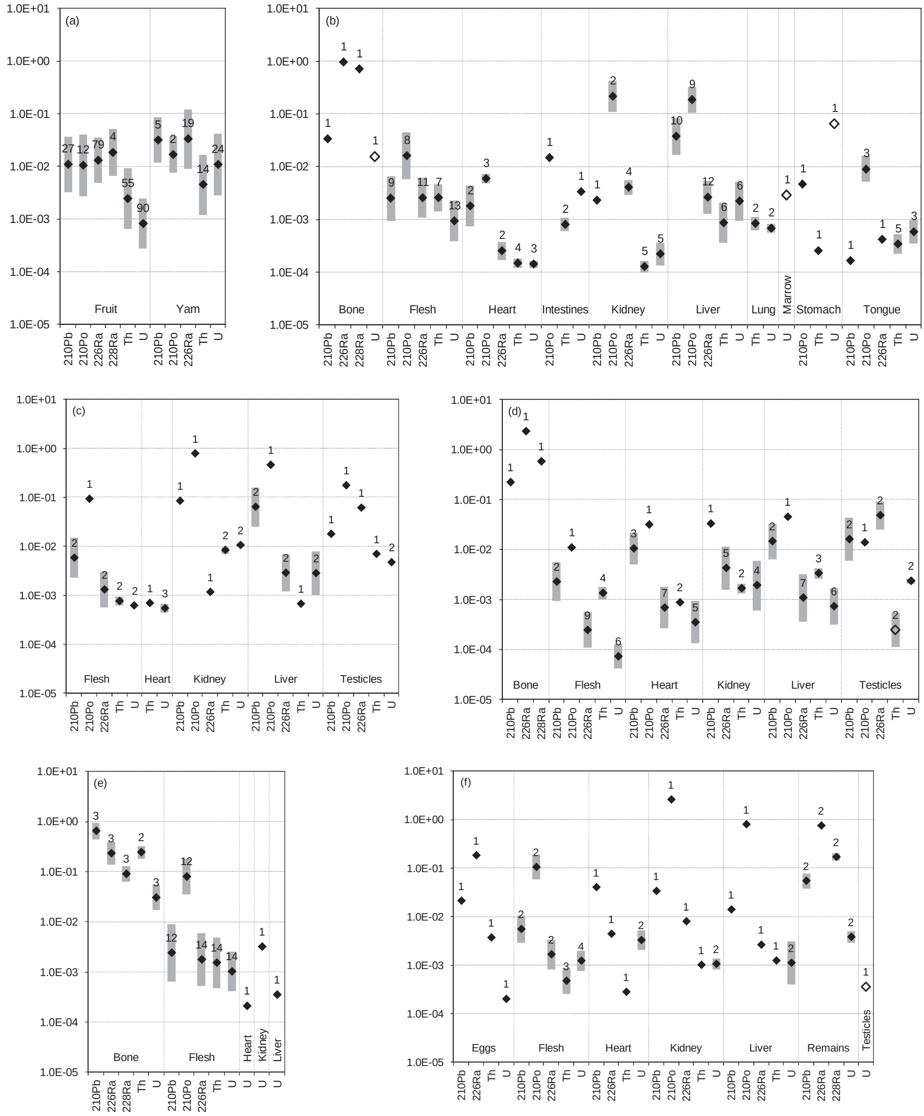


Figure 4.11 CR geometric means and standard deviations (Bq kg^{-1} wet mass biota tissue per Bq kg^{-1} dry mass soil) for (a) fruit and yam; (b) buffalo; (c) bandicoot; (d) wallaby; (e) pig; and (f) goanna. The number above each diamond indicates the number of results on which values are based. Values plotted with an open diamond indicate that a less than weighting factor of 0.5 was applied to the tissue radionuclide activity concentration to calculate the geometric mean.

4.6.3.2 Dose assessment context

Terrestrial plants and animals may accumulate radionuclides above background levels if they are exposed to the rehabilitated Ranger mine site. This applies to plants growing on the site and animals having a home range that overlaps in whole or part with the site. Indigenous people may receive an above background ingestion dose if they consume the tissues of these exposed plants or animals as part of a traditional diet. The goal in calculating CRs is to estimate the annual above background ingestion dose that an Indigenous person could potentially receive from the accumulation of radionuclides in terrestrial bush foods due to the rehabilitated site. This dose can be estimated for each bush food as:

$$Dose\ (mSv) = S \times \sum (CR \times DC) \times M \times F_E \times F_H$$

where:

- S is the above background soil activity concentration (Bq kg^{-1}) of ^{238}U in secular equilibrium with its progeny on the surface of the rehabilitated Ranger mine site.
- $\Sigma(CR \times DC)$ is the sum of the products of the CR and the corresponding radionuclide ingestion dose coefficient (DC, mSv Bq^{-1}) for ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po.
- M is the wet mass (kg) of the bush food consumed in a year.
- FE is the average fraction that an animal is exposed to the rehabilitated site; and
- FH is the average fraction spent hunting in the zone from within which animals may be exposed to the rehabilitated site.

The parameters S, $\Sigma(CR \times DC)$ and F_E determine the above background radionuclide activity concentrations in plants and animals exposed to the rehabilitated Ranger mine site. Values for these parameters are now relatively well known: above background soil activity concentrations of ^{238}U series radionuclides on the surface of the rehabilitated site can be reasonably estimated from the preferred rehabilitation strategy and work done by ***eriss*** to determine the pre-mining radiological conditions (described in the 2010–11 Annual Report); CRs for terrestrial bush foods have been calculated (Figure 4.11); ingestion dose coefficients have been determined by the International Commission on Radiological Protection; and F_E can be estimated from size of the rehabilitated site and animal home ranges. The parameters M and F_H determine the fraction of contaminated diet. Their values are less well known because they depend on post-rehabilitation land use for hunting and gathering and future dietary habits. Agreed land use scenarios and reference diet for rehabilitation planning of the Ranger mine do not yet exist, but are being developed through a Cultural Closure Criteria Working Group that consults with Indigenous advocacy groups on cultural issues important to rehabilitation.

Table 4.2 gives an example ingestion dose calculation for the consumption of selected bush foods by an Indigenous adult for an assumed traditional living scenario and set of circumstances for the rehabilitated Ranger mine site. This example calculation has been provided to illustrate the logistics and mechanics of estimating the above background dose from terrestrial bush foods; parameter values and results shown in Table 4.2 are indicative only and do not necessarily represent final dose estimates. The assumptions made in the example calculation were:

1. Rehabilitated site general characteristics. The area of the rehabilitated Ranger mine site is assumed to be 8 km^2. This is the approximate size of the mine disturbed area requiring rehabilitation. The surface of the rehabilitated site is assumed to be covered

with mine waste rock and shaped as near as practicable to resemble the pre-mining landscape. This is currently the preferred rehabilitation strategy for mine disturbed areas. The rehabilitated site is assumed to be revegetated using local native plant species to broadly match adjacent areas of Kakadu National Park. The site is assumed to be used as habitat by terrestrial animals similar to other parts of Kakadu National Park and to equally support the growth of plant species included in traditional diet.

2. *Rehabilitated site soil radionuclide activity concentrations*. Ranger waste rock has a maximum ore grade equivalent to approximately 2100 Bq kg^{-1} ^{238}U. Average ^{238}U activity concentration in waste rock used to cover the rehabilitated site is assumed to be half this maximum ore grade and ^{238}U series radionuclides in the waste rock cover are assumed to be in secular equilibrium. The average pre-mining soil ^{238}U activity concentration of the site has been determined from previous ***eriss*** work to be approximately 360 Bq kg^{-1}. This implies an average above background activity concentration of ^{238}U in secular equilibrium with its progeny of 690 Bq kg^{-1} on the surface of the rehabilitated site.

3. *Diet*. In lieu of an agreed reference diet for rehabilitation of the Ranger mine site, a diet previously developed by ***eriss*** from consultation with Indigenous people and general observations of traditional dietary habits was used. Bandicoot was not included in the ***eriss*** diet, and so it was assumed that the annual consumption of bandicoot flesh was one quarter that of wallaby flesh.

4. *Post-rehabilitation land use for hunting and gathering*. Indigenous people leading a traditional lifestyle in the vicinity of the rehabilitated Ranger mine site are assumed to hunt over an area of approximately 300 km^2. This is half the nomadic range observed for a group of Indigenous people leading a traditional lifestyle near Momega outstation, approximately 85 km east of the Ranger mine. Anecdotal evidence suggests the nomadic range in the vicinity of the rehabilitated Ranger mine site will probably be less than for the area around Momega outstation due to greater abundance of bush food resources in the Magela Creek corridor.

5. *Animal exposed and hunting fractions*. The animal exposed and hunting fractions were calculated by assuming the rehabilitated site is a circle of radius 1.6 km, the home range of an animal is a circle of radius typical of the particular species and the hunting range is a circle of radius 10 km. The animal exposed fraction represents the portion of the animal home range overlapping with the rehabilitated site and the hunting fraction represents the portion of the hunting range overlapping with the zone from within which an animal may be exposed to the rehabilitated site.

From these assumptions, the annual above background dose from animal-based terrestrial bush foods would be of the order of 0.1 mSv and come largely from buffalo flesh and organs. The annual above background dose from plant-based terrestrial bush foods would be of the order of 0.01 mSv and come almost exclusively from yams. However, buffalo have been significantly eradicated from Kakadu National Park in recent decades, making them potentially less available as a bush food resource in the Magela Creek corridor. The implication is that the dietary intake of wild buffalo sourced from around the rehabilitated Ranger mine site may be less than assumed, and so the dose from buffalo may be lower than estimated. Similar consideration of the 'real-world' availability of other terrestrial bush foods in the Magela Creek corridor should be applied when interpreting assessment results in the context of dose limits.

TABLE 4.2 EXAMPLE INGESTION DOSE CALCULATION: ESTIMATED ANNUAL AVERAGE ABOVE BACKGROUND DOSE TO AN INDIGENOUS ADULT

Biota	Tissue	S ($Bq\ kg^{-1}$)	Σ(CR×DC) ($mSv\ Bq^{-1}$)	M (kg)	F_E	F_H	Dose (mSv)
Bandicoot	Flesh	690	1.2×10^{-4}	5	6.9×10^{-1}	2.5×10^{-2}	6.9×10^{-3}
Buffalo	Flesh	690	2.2×10^{-5}	146	7.4×10^{-2}	1.1×10^{-1}	1.8×10^{-2}
Buffalo	Kidney	690	2.6×10^{-4}	18	7.4×10^{-2}	1.1×10^{-1}	2.6×10^{-2}
Buffalo	Liver	690	2.5×10^{-4}	18	7.4×10^{-2}	1.1×10^{-1}	2.5×10^{-2}
Goanna	Flesh	690	1.3×10^{-4}	2	6.9×10^{-1}	2.5×10^{-2}	3.1×10^{-3}
Pig	Flesh	690	9.8×10^{-5}	25	1.0×10^{-1}	8.7×10^{-2}	1.5×10^{-2}
Wallaby	Flesh	690	1.5×10^{-5}	20	6.9×10^{-1}	2.5×10^{-2}	3.6×10^{-3}
Fruit	Flesh	690	2.4×10^{-5}	3	1.0×10^{0}	1.9×10^{-2}	9.3×10^{-4}
Yam	Tuber	690	5.3×10^{-5}	20	1.0×10^{0}	1.9×10^{-2}	1.4×10^{-2}

4.6.4 Conclusions

Terrestrial wild plants and animals are an important part of traditional Indigenous diet in the ARR. They are also a potential vector for above background public radiation exposure following rehabilitation of the Ranger mine. CRs have been determined for radionuclides significant to uranium mining for terrestrial wild plants and animals important to traditional Aboriginal diet of the ARR. These CRs have been used in combination with other parameters in an example of an ingestion dose calculation to illustrate the dose assessment process for the terrestrial bush food exposure pathway. Lack of agreed land use scenarios and reference diet currently impedes the final estimation of above background dose due to bush foods sourced from terrestrial ecosystems.

4.7 Unmanned aerial system (UAS) demonstration project

4.7.1 Introduction

Remote sensing has been used widely to study spatial and temporal variations in ecological phenomena. Data from satellite remote sensing (such as the Landsat series) enable regional- to global-scale observations of ecological indicators over time. The main limitation associated with satellite remote sensing is the mismatch between the pixel resolution of such imagery (30 m for Landsat), the revisit period (18 days for Landsat) and the scale of ecological processes. This is particularly the case when using remote sensing for monitoring mine site rehabilitation where objects of interest on the ground (such as small trees and shrubs) can be sub-metre in size. Satellite remote sensing data at high spatial resolution (such as 2 m WorldView-2 imagery) is costly and not available at the appropriate temporal scale. Airborne remote sensing data is also costly, with deployment from interstate limiting its application for temporal analysis. Therefore, the monitoring of vegetation condition (i.e. phenology and seasonal water stress) via remote sensing requires scales of data capture that are difficult to provide using satellite or manned aircraft. Consequently, a niche exists for a remote sensing platform that can provide high spatial and temporal resolution imagery in a cost-effective manner.

A relatively new method to obtain data at a spatial and temporal scale relevant to the monitoring of mine site rehabilitation is the use of unmanned aerial systems (UAS). UAS use a lightweight aircraft platform controlled by a pilot on the ground that can carry an imaging payload (usually a camera) to fly and photograph areas of interest. Recent technological advances have led to UAS technology having lower costs and increased reliability. Advances in photogrammetric image processing have also meant that low cost lightweight cameras can now produce products as good as traditional aerial photography. Imaging sensors within UAS are able to capture very high spatial resolution data that not only includes imagery of sub-decimetre resolution but also are the bases for very high resolution photogrametrically derived products, including 3D point cloud data and digital surface models. Some of the advantages over satellite imagery and traditional aerial photography include the higher spatial resolution, lower costs for high temporal resolution sensing, ability to operate below cloud and rapid response time to events. UAS are capable of capturing data with spatial and temporal scales relevant to the monitoring of minesite rehabilitation (with particular emphasis on monitoring surface conditions, landform changes and vegetation growth).

A typical UAS consists of two main components (Figure 4.12): the aircraft, also known as an unmanned aerial vehicle (UAV), and a ground control station (GCS). The UAV contains a flight management unit (commonly referred to as an autopilot) which takes information from a number of sensors including GPS, airspeed indicator, compass and barometer to adjust the planes direction, height and attitude. This information is sent to the GCS via a radio link. The GCS station is typically a laptop with flight planning and control software and a radio transceiver. The pilot uses the GCS to monitor the state of the UAV and send information to the UAV about where to go and when to take photos.

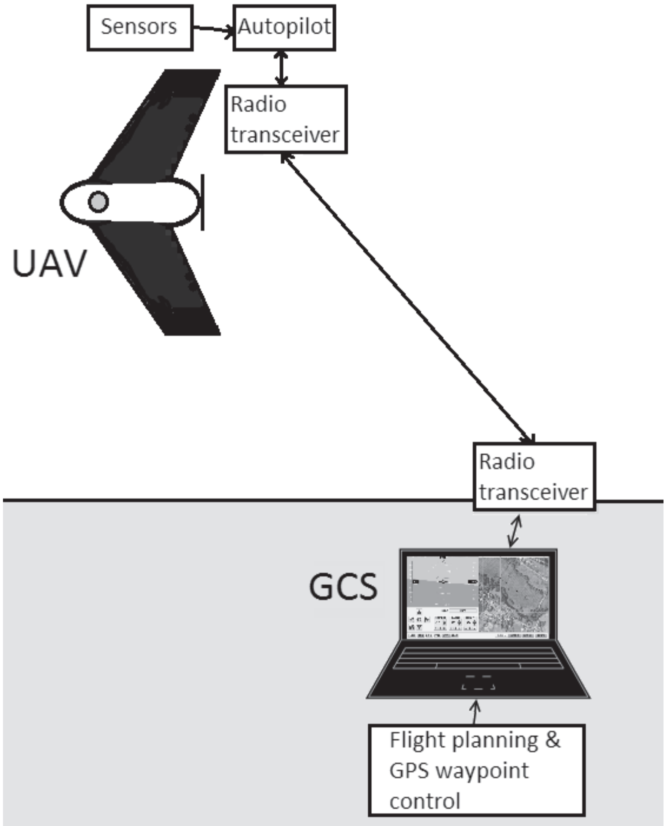
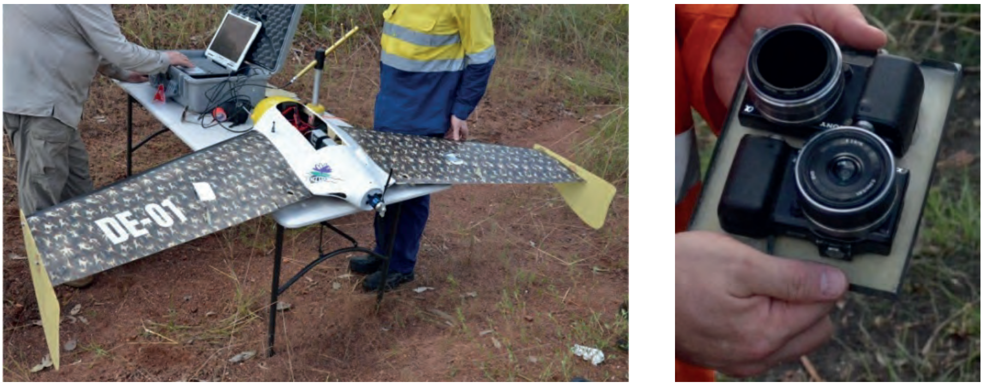


Figure 4.12 The two main components of an UAS: The aircraft or UAV and the ground control station (GCS).

4.7.2 UAS at *eriss*

eriss has acquired a Skycam Swampfox UAV, a fixed-wing aircraft that is propelled by a battery powered electric motor (Figure 4.13a), primarily as a means to monitor the rehabilitation efforts at both Ranger and Jabiluka mine sites. The Revegetation and Landscape Ecology (RLE) group at ***eriss*** are now preparing documentation to submit to Civil Aviation Safety Authority (CASA) to obtain their UAS Operator's Certificate. All researchers in the RLE group have undertaken training to become CASA certified remote pilots and have each undertaken over five hours flying of the Swampfox under the tutelage of Skycam's Lew Woods.

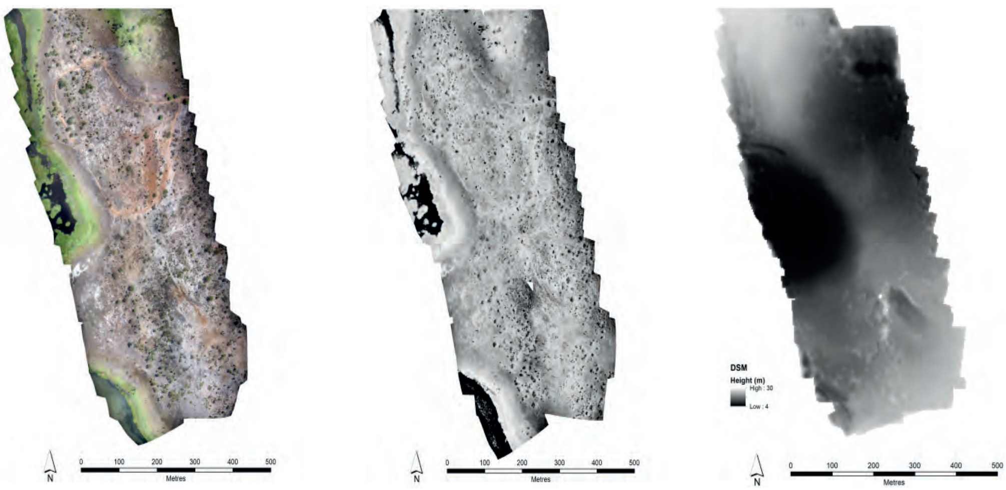
The main payload for the Swampfox is a dual DSLR camera setup: one camera is standard while the other is converted to capture near infrared imagery (Figure 4.13b). The Swampfox also has a secondary payload that includes a video camera that can stream live video back to the GCS. We have conducted a number of flights to trial the UAS for use as a monitoring tool. The first flights were undertaken in October 2013 as part of a trial in collaboration with colleagues from University of Queensland's Centre for Mined Land Rehabilitation mapping a range of environments. Since then flights have been conducted in April–May and June 2014 focussing on the rehabilitation efforts at Jabiluka.



(a) (b)

Figure 4.13 The Swampfox UAS (a) and dual camera payload (b).

The hundreds of images captured each flight are processed using photogrammetry software developed specifically for use with images collected by a UAS. Using the GPS data from the UAV flight log and the overlapping photos, the outputs include georeferenced orthomosaics in true colour RGB and NIR, 3D point clouds and digital surface models. The NIR imagery is important for assisting with monitoring of plant vigour. Figure 4.14 shows true colour and near infrared orthomosaics produced from a selection of photographs captured at the Djarr Djarr camp rehabilitation site adjacent to the Magela Creek floodplain in October 2013.



(a) (b) (c)

Figure 4.14 UAV orthomosaics over Djarr Djarr camp rehabilitation site captured in October 2013: True colour mosaic (a), near infrared mosaic (b) and digital surface model (c).

The mosaics have a pixel resolution of 3 cm. Also shown is the digital surface model indicating heights of the surface. Analysis of the data can provide an indication of the condition of the area of interest.

4.7.3 Conclusions and future work

The main aim of the project is to establish a robust UAS-based monitoring programme to evaluate the ongoing success of the rehabilitation of Ranger uranium mine at spatial and temporal scales aligning to the ecological features that are to be observed. Data collected from the flights conducted so far will be used as baselines to further develop image processing and analysis methods. Further work will include the collection of multi-temporal UAS image data to describe the seasonality of plant growth phases and changes in the landscape over time. There will also be further analysis of structural, spectral and textural information within the imagery to discriminate tree, ground cover and aquatic species.

4.8 A multi-year assessment of landform evolution model predictions for a trial rehabilitated landform.

4.8.1 Introduction

The Environmental Research Institute of the Supervising Scientist, in collaboration with research partners at the University of Hull (Professor T. Coulthard) and the University of Newcastle (Associate Professor G. Hancock), has carried out a multi-year assessment of the geomorphic stability of the trial rehabilitated landform of the Ranger mine using the *CAESAR-Lisflood* landscape evolution model (LEM). The LEMs can provide information on landform stability at decadal or centennial scales over large spatial extents, and evaluate the sensitivity of these processes to environmental changes. An important issue associated with the use of models is the ability to assess the reliability and accuracy of the model. In this study, the *CAESAR-Lisflood* LEM is tested for its ability to predict bedload and suspended sediment loads from specially constructed erosion plots on the Ranger trial landform (Figure 4.15).

These were compared with field measured observations collected over four wet seasons from 2009. Once calibrated for the specific site hydrological conditions, the predicted bedload demonstrated an excellent correspondence with the field data. However, longer-term simulations of 10 years identified an exhaustion effect in sediment yield from the landform. This latter result indicated that the incorporation of a weathering function into the *CAESAR-Lisflood* LEM will improve the model's ability to correctly predict the long term evolution of a rehabilitated landform once it has been constructed.

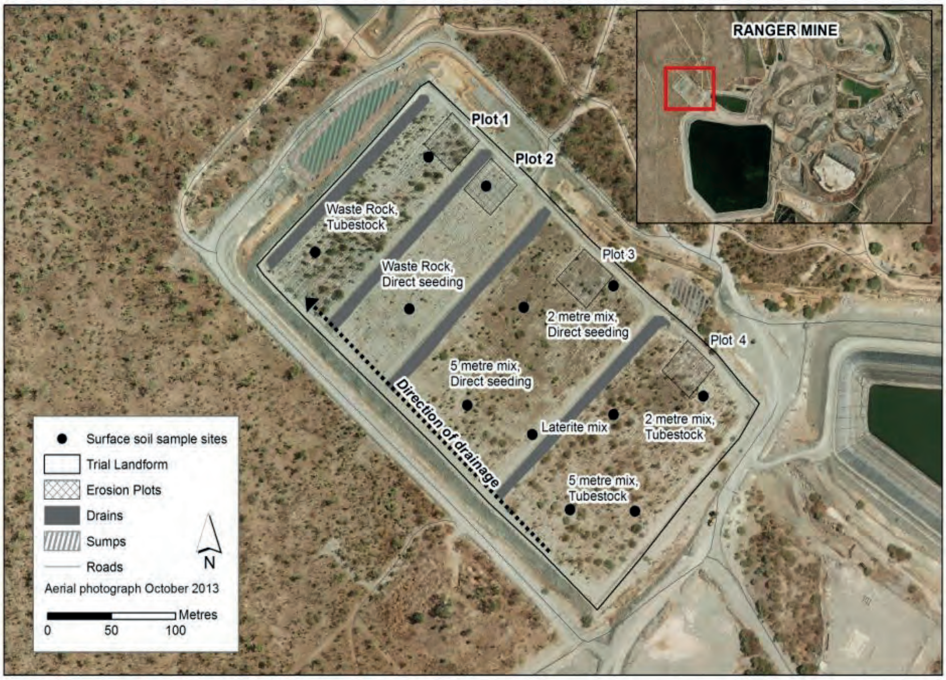


Figure 4.15 Aerial photograph of the trial landform at Ranger mine showing the size and location of plots 1 and 2.

4.8.2 Methodology

The application of the *CAESAR-Lisflood* LEM to the trial landform required the collation and integration of data from a range of different sources. The key data inputs used by the model were a digital elevation model (DEM) of each erosion plot; rainfall data and surface particle size data.

A DEM of the trial landform was produced from data collected by a Terrestrial Laser Scanner in June 2010. For the purposes of this study, the data for the erosion plots were interpolated to produce a surface grid with a horizontal resolution of 20 cm. The DEMs were processed using ArcGIS software to ensure that the DEMs were pit-filled and hydrologically corrected. This pit filling was important in order to remove data artefacts, which included remnants of vegetation (peaks) as well as artificial depressions, or sinks that existed in the data but were not on the ground.

For the purposes of this study, the *CAESAR-Lisflood* model utilised rainfall data collected on the trial landform at a 1-minute interval. The data were aggregated into 10-minute intervals for use in the LEM. Rainfall data collected during the 2009–10, 2010–11, 2011–12 and 2012–13 rainfall years from the trial landform surface are used in the simulations reported here.

Grain size data for *CAESAR-Lisflood* were obtained from size fractionated bulk samples of surface material collected at eight points on the waste rock surface of the Ranger trial landform. Grain size analysis was completed on these samples and the results averaged into nine grain size classes ranging from 63 µm to 64 mm.

The *CAESAR-Lisflood* model currently does not have a weathering function. Consequently, when running simulations for periods of four years, it was necessary to manually simulate a weathering effect. This was done by stopping the simulation after two years, modifying the proportions of the grain size classes used (reducing the proportion of the largest grain size) and restarting the simulation to run for the remaining two years of the simulation period.

The comparison of *CAESAR-Lisflood* modelled results and field measurements focussed on Plots 1 and 2 as they had the most complete sets of validated hydrological and measured bedload data, and corrected DEMs at the time of writing. Consequently, only these two plots have been used in this study.

Five sets of simulations have been conducted for each plot:

1. A 4-year simulation using rainfall data collected on the landform for the period 2009–13 at intervals of 10 minutes.
2. A 10-year simulation using the 2009–13 rainfall data looped 2.5 times.
3. A 10-year simulation using the 2009–13 rainfall data looped 2.5 times with the inclusion of measured data from an extreme rain event, in which 785 mm fell over 72 h between 17:00 h on 27 February and 17:00 h on 2 March 2007 at Jabiru Airport, inserted in the first year of the simulation.
4. A 10-year simulation using the 2009–13 rainfall data looped 2.5 times with the inclusion of the 2007 extreme event inserted in the third year of the simulation.
5. A 10-year simulation using the 2009–13 rainfall data looped 2.5 times with the inclusion of the 2007 extreme event inserted in the eighth year of the simulation.

4.8.3 Results

The four-year simulation results for measured and modelled bedload yields are shown in Figures 4.16 (Plot 1) and 4.17 (Plot 2). These indicate that after a period of four years, the modelled and measured bedload figures for both plots are within a range of 10% of each other and thus very similar. Longer term 10 year simulations of Plots 1 and 2 were run utilising the rainfall scenarios described earlier in the methodology section. Both plots returned the same trends in denudation and sediment yield under the different scenarios (Table 4.3). These show that the addition of an extreme rainfall event after three years produces the greatest increase in sediment yield, whilst the addition of an extreme rainfall event after eight years does not appear to have an impact on the sediment yield or denudation rate.

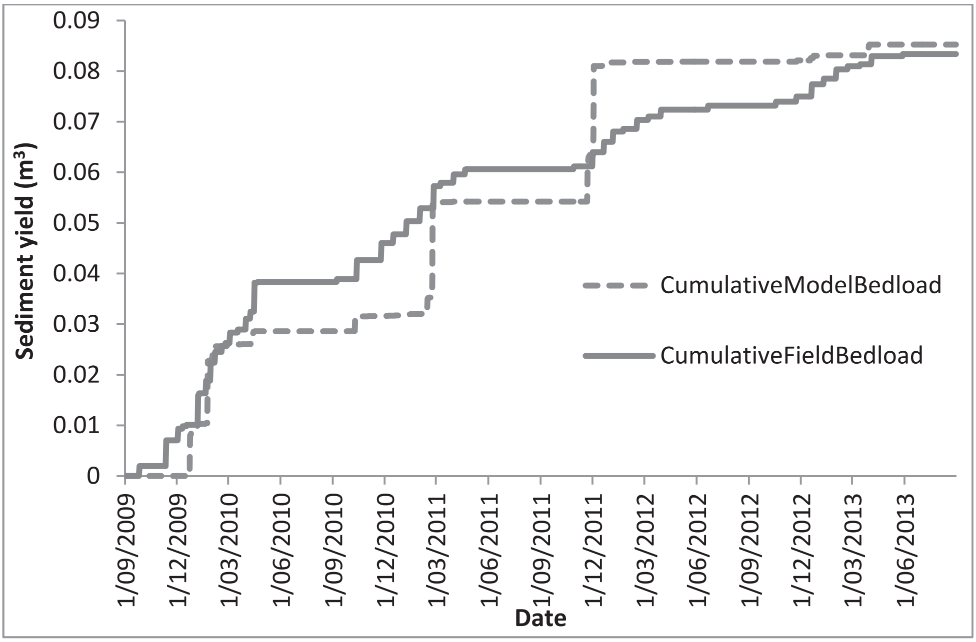


Figure 4.16 Comparison of modelled cumulative bedload (blue broken line) and field-measured cumulative bedload (red solid line) yield for Plot 1.

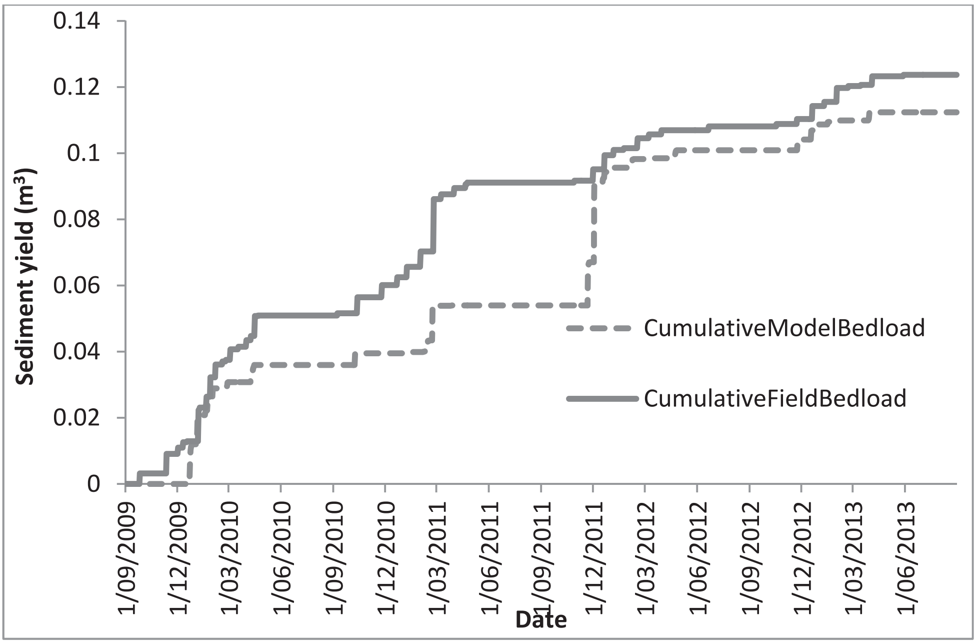


Figure 4.17 Comparison of modelled cumulative bedload (blue broken line) and field-measured cumulative bedload (red solid line) yield for Plot 2.

TABLE 4.3 PREDICTED TOTAL LOADS AND DENUDATION RATES AFTER 10 YEARS FOR PLOTS 1 AND 2

	Plot 1		Plot 2	
	Total Load (m^3)	Denudation rate (mm yr^{-1})	Total Load (m^3)	Denudation rate (mm yr^{-1})
10 years	0.38	0.04	0.24	0.02
10 years – extreme event in year 1	0.44	0.05	0.37	0.04
10 years – extreme event in year 3	0.54	0.06	0.41	0.05
10 years – extreme event in year 8	0.38	0.04	0.24	0.02

The introduction of an extreme event (utilising the rainfall from February 2007) at the beginning of year 3 and toward the end of the simulation period is shown in Figures 4.18 and 4.19 respectively. All simulations for both plots show a sediment exhaustion effect well before the end of the 10 years, regardless of the presence or timing of the extreme event.

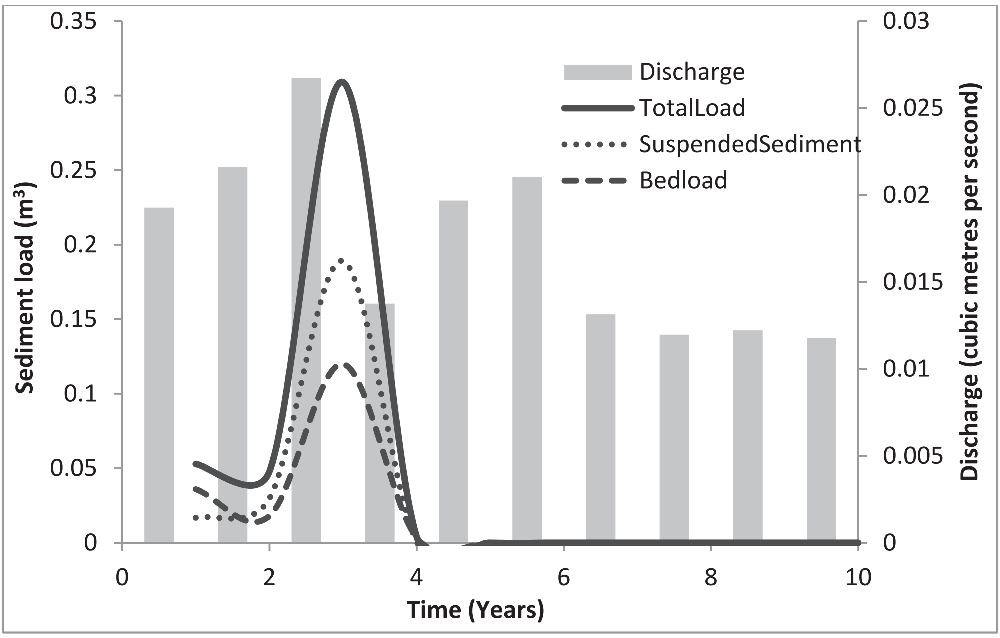


Figure 4.18 10 year simulation for Plot 2 with the extreme rain event after 3 years.

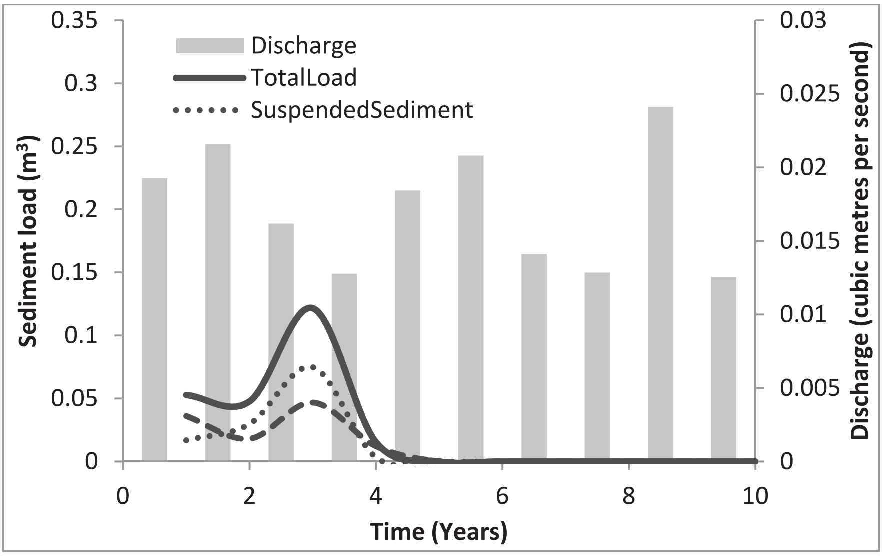


Figure 4.19 10 year simulation for Plot 2 with the extreme rain event after 8 years.

4.8.4 Conclusions and future work

The predicted bedload yields from the *CAESAR-Lisflood* simulation for the period 2009-2013 demonstrate an excellent correspondence with the field measurements for the same period for both Plots 1 and 2. For the first two years (2009–2011), measured cumulative bedload from Plot 1 (Figure 4.16) was slightly higher than the predicted cumulative bedload. However, at the start of the 2011–12 water year, a spike in predicted bedload yield occurred, which exceeds the measured bedload. This is attributed to a manual (as opposed to automatic) modification in the proportion of the larger particle sizes used in the simulation. This represented an attempt to manually introduce a weathering function into the *CAESAR-Lisflood* model. The effect of this was to produce a final predicted bedload yield which is approximately 3% greater than the final measured bedload yield. The similarity between the final predicted and measured bedload yields provides encouragement that the model is able to predict bedload from a rehabilitated surface. For Plot 2 (Figure 4.17), the predicted bedload generally compares well with the measured bedload. Compared to Plot 1, the predicted bedload is less than the measured throughout the simulated period. However, at the end of the simulation period, the total bedload yield of both the predicted and measured datasets are very similar – within 7% of each other.

The denudation rates for Plots 1 and 2 are 0.07 mm yr^{-1} and 0.06 mm yr^{-1}, respectively, over a simulated period of four years. These are higher than the published rates (0.01 – 0.04 mm yr^{-1}) of natural denudation for the region. However, it must be noted that the latter were determined from a range of catchments of different size. In this study, each plot represented a closed catchment of approximately 900 m^2 with little initial vegetation cover and freshly exposed unweathered waste rock. When extended to a simulated period of 10 years, the predicted denudation rates for both plots matched the published rates.

Several caveats need to be placed on the results produced to date. Foremost is recognition that the simulations have modelled an 'idealised' environment. Specifically, the erosion plots are located on a uniformly gently sloping (2%) surface that represents only a component, albeit a substantial fraction, of the total area of the proposed rehabilitated landform. In addition, the roles of vegetation or fire were not considered in the simulations. Similarly, the study plots are closed catchments, with no capacity to recharge or replenish the material within the plot.

Previous studies have focussed on collecting field data to enable the parameterisation of specific LEM applications (i.e. SIBERIA). Currently, field data are being collected on a stand-alone basis and can be used to support a range of model applications. In this case, field measurements closely match predicted outputs of the CAESAR model, thereby validating model results over the period of field collection. The development of a weathering module to incorporate into the *CAESAR-Lisflood* model will provide increased confidence in the ability of *CAESAR-Lisflood* to predict the long-term stability of a rehabilitated landform.

4.9 Rehabilitation and closure ecological risk assessment for Ranger uranium mine

4.9.1 Background

ERA is required to rehabilitate Ranger uranium mine by January 2026 and, thus, a large number of research and assessment projects are underway by both SSD and ERA to ensure the necessary knowledge is available to inform the rehabilitation and closure strategy. SSD and ERA are collaborating on an ecological risk assessment for the rehabilitation and closure of Ranger uranium mine. The rehabilitation risk assessment provides a structured and comprehensive framework for confirming that all the key issues related to ensuring the protection of the off-site environment and successful rehabilitation of the on-site environment are identified.

The risk assessment has been broken into the following three phases: (1) problem formulation; (2) risk analysis; and (3) interpretation of results. The causal models produced during the problem formulation phase and reported in the 2012–13 Annual Report were finalised in late 2013 and have been published as Internal Report 624, available on SSD's website. The paper presented here summarises work undertaken to (i) define the importance of ecological processes for aquatic ecosystems for the causal models and further risk analysis, and (ii) screen the ecological risks identified during the problem formulation phase to prioritise them for further (quantitative) analysis.

4.9.2 The importance of ecological processes

The Environmental Requirements (ERs) for Ranger uranium mine set out the Australian Government's environmental protection conditions with which ERA must comply. The ERs highlight the importance of ecological processes, and the maintenance of ecological processes is specifically mentioned as an environmental objective for protection of the environment. Ecological processes and functions were identified in the causal models for aquatic ecosystems during the initial workshop to develop these models. However, ecological processes and functions were not included in the final causal models given the complexity required to define them for use in a rehabilitation context. For the models, assessment endpoints to capture ecological processes and function proposed for both off-site and on-site aquatic ecosystems, were: biodiversity (structure and function) of off-site aquatic ecosystems are similar to the agreed reference condition; and biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria. In order to incorporate ecological processes and measurement endpoints in the causal models, further work has focused on identifying and understanding the importance of ecological processes for the on-site and off-site environment. The aim of this work is to determine whether the existing causal models address ecological processes, or whether further detail on ecological processes is still required and revision of the models is needed to incorporate this level of detail.

A list of relevant ecological processes was identified from the literature. Abiotic and biotic processes were identified for the on-site and off-site environment as shown in Table 4.4. Once these processes were listed, their importance for each habitat received an overall ranking as well as a ranking for the dry and wet seasons. The habitats that were identified are: sandy channel (those billabongs in the main creek channels with a sandy substrate); shallow lowland billabongs (seasonally inundated billabongs which may or may not dry out each year and include backflow and channel backflow billabongs); permanent waterbody (channel and floodplain billabongs that contain water all year); floodplain (which can be further delineated into upper and lower floodplain; riparian (fringing vegetation along creek lines and inherent within sandy channel and shallow lowland billabongs); lowland woodlands; stone country. The overall ranking of importance was assigned as follows:

1 – the process has low activity in the habitat

2 – the process is active in the habitat but is neither high nor low

3 – the process is highly active in the habitat.

TABLE 4.4 ABIOTIC AND BIOTIC PROCESSES FOR THE ON-SITE AND OFF-SITE ENVIRONMENT

Abiotic	Biotic
Formation of habitat	Movement of organisms: Recruitment, regeneration and dispersal
Chemical processes	Primary Productivity: Phytoplankton and Macrophytes
Hydrological processes	Predation, herbivory, competition, parasitism, mutualism
Natural disturbance – Fire, cyclone, drought and flood	
Geomorphic processes	

Table 4.5 shows the ranking results for the wet season. The ranking process has enabled us

to visualise the key habitats within the system in relation to ecological processes. For example, the riparian habitat has the highest ranking (3, most active) for almost all ecological processes in the wet season.

TABLE 4.5 IMPORTANCE RANKING OF ECOLOGICAL PROCESSES ACROSS HABITATS DURING THE WET SEASON

	Sandy channel	Shallow lowland billabong	Permanent waterbody (channel)	Permanent waterbody (floodplain)	Floodplain-upper	Floodplain-lower	Lowland woodlands	Riparian	Stone country
Abiotic ecological processes									
Formation of habitat	3	2	2	2	3	3	3	3	3
Chemical processes	1	1	1	1	2	2	1	3	1
Hydrological processes	3	3	2	2	3	3	1	3	1
Natural disturbance – Fire	1	1	1	1	1	1	2	3	2
Natural disturbance – Cyclone	3	2	1	1	1	1	3	3	1
Natural disturbance – Drought	1	1	1	1	3	3	1	3	1
Natural disturbance – Flood	3	1	3	1	1	1	1	3	3
Geomorphic processes	3	2	3	1	1	1	1	2	2
Biotic ecological processes									
Movement of organisms: Recruitment & regeneration dispersal	3	3	3	3	3	3	3	3	3
Movement of organisms: Dispersal	3	3	3	3	3	3	3	3	3
Primary Productivity: Phytoplankton and macrophytes	3	3	3	3	3	3	2	3	2
Predation, herbivory, competition, parasitism, mutualism	3	3	3	3	3	3	3	3	3

Further work will focus on assigning the stressors across these habitats and ecological processes, and determining whether the stressors are likely to vary between the dry and wet season. Through the process of mapping the stressors into the current matrix, we will be able to assess and rank the magnitude of any associated future impact. Knowledge of the importance of the ecological process or value and the potential impact of the stressor will be essential when we assign ‘likelihood’ and ‘consequence’ to ecological risks. Currently, this process is outside the risk screening work that has been undertaken. The two components of work will be brought together prior to the risk analysis phase.

4.9.3 Risk screening

A stakeholder workshop was convened in February 2014 and facilitated by Dr Carmel Pollino from the CSIRO to complete a screening-level risk assessment. The main objective of this workshop was to undertake a scientifically defensible screening of risks identified through the causal models. The outcomes of the workshop were:

- A refined set of likelihood and consequence statements;
- An assessment of likelihoods and consequences to inform the next steps of the ecological risk assessment; and
- An understanding of the key knowledge gaps.

Prior to the workshop, a survey was sent to workshop participants that contained a total of 68 likelihood and consequence statements encompassing all of the stressors and assessment endpoints identified in the causal models. The participants were asked to score the likelihood and consequence statements based on scales developed for this exercise. Participants were also asked to identify the evidence base for each likelihood and consequence score (i.e. published literature, experimentation or observation, models, expert opinion, none), which enabled knowledge gaps to be identified and a qualitative assessment of uncertainty to be made.

During the workshop, the pre-workshop survey was reviewed by the participants in the context of assumptions and evidence, and statements that required clarification or explanation were resurveyed where deemed necessary. The post-workshop distributions of responses for the likelihood and consequence statements were then used to populate a Bayesian Belief Network (BBN), which produced a ranking for all the risks. The preliminary results indicate that the critical risks defined as stressor-effect are: feral animals-wildlife; weeds-vegetation; feral animals-vegetation; trace metals-sediment; weeds-habitat; sediment-habitat; feral animals (mammals)-habitat; and weeds-wildlife.

A further preliminary exercise was undertaken to map the risk screening results to the existing Key Knowledge Needs (KKNs) as part of an ongoing review of the KKN framework. This resulted in identifying: ‘orphan’ risks where there was no association with an existing KKN; and risks ranked as low but they are associated with a KKN that people believe is important.

4.9.4 Future work

The results of the risk screening are currently under final review. Information is being collated on those responses for likelihood and consequence statements that had high levels of uncertainty. The cultural-based ecological risks are not amenable to the process we undertook, so these will be addressed through a discussion with key stakeholders focusing on what is important, and ranking risks as high, medium or low. A review of quantitative risk analysis methods will be completed, prior to determining those risks that require a quantitative assessment.

5 OTHER SCIENCE AND TECHNICAL ACTIVITIES

5.1 Introduction

In addition to research and monitoring on the impacts of uranium mining in the ARR, SSD undertakes a significant number of activities associated with environmental protection in Australia and overseas related to uranium and other environmental issues. These activities include assisting the Department with EPBC-related approvals and other significant projects, assisting the IAEA with Best Practice Environmental Management of Uranium Mining, membership on technical committees, collaborative research with other research institutions and participating in international environmental protection activities. A summary of the key activities undertaken during 2013–14 is provided below.

5.2 National initiatives for radiation protection of the environment

Two research scientists from the ***eriss*** Environmental Radioactivity program, Dr Andreas Bollhöfer and Dr Che Doering, are involved with ARPANSA-coordinated national initiatives for radiation protection of the environment.

Dr Doering is a member of the Radiation Health Committee Working Group for development of a safety guide for radiation protection of the environment. The safety guide aims to provide nationally uniform best practice advice to industry and regulators on how to assess environmental impacts from ionising radiation associated with releases of radionuclides. The working group was established in March 2012 and comprises technical experts from both industry and government. The safety guide is currently under development, with an expected completion date in 2014.

Dr Bollhöfer was the expert scientific member of the Steering Committee for the joint ARPANSA and DoI project to review existing radionuclide activity concentration data in non-human biota inhabiting Australian uranium mining environments. The steering committee was established in November 2011 to provide guidance and strategic directions for the project and to facilitate the collection of data from published and unpublished sources. The review is now completed and results have been published in the ARPANSA Technical Report Series.

5.3 The IAEA's MODARIA program

The International Atomic Energy Agency's (IAEA) four-year Modelling and Data for Radiological Impact Assessment (MODARIA) programme was launched in November 2012, to continue some of the work of the EMRAS (Environmental Modelling for Radiation Safety) and EMRAS II programmes in the field of radioecological modelling (see 2012–13 Annual Report). Researchers from ***eriss*** have contributed to various EMRAS publications in

2012–13 and 2013–14. Three scientific papers and an IAEA Technical Report have been published, while one paper dealing with modelling radiation exposure of wildlife in contaminated wetland ecosystems was submitted in early 2014. The Supervising Scientist will continue its involvement with Working Groups 3, 4 and 8 of the MODARIA programme in 2014–2015, to remain informed on best practice developments and policy issues related to (a) the remediation of contaminated sites and recommendations on radiological impact assessment methodologies, and (b) protection of humans and the environment from the harmful effects of ionising radiation. This will also be beneficial to national initiatives supported by the Supervising Scientist such as the Radiation Health Committee and the Australian Radiation Protection and Nuclear Safety Agency sponsored Working Group to develop an Australian 'Safety Guide on Radiological Clearance/Closure Criteria and Management of Sites Contaminated as a Result of Past and Present Activities'.

5.4 The International Union of Radioecology

The International Union of Radioecology (IUR) is an independent, non-political and not for-profit organisation dedicated to the worldwide development of radioecology, with nearly 1000 members from 58 countries. The IUR initiated a process for worldwide harmonisation of R&D programmes and efforts in radioecology by inviting high-level representatives from various international networks and organisations to present relevant radioecology research activities and priorities of their organisation in Aix-en-Provence, France, in June 2014. In his role as Vice-President of the South Pacific Environmental Radioactivity Association (SPERA) and Program Leader of the Environmental Radioactivity program of the Supervising Scientist, Dr Andreas Bollhöfer was invited to attend this workshop, together with 15 high-level representatives from other organisations. It was decided to launch the FORUM (FOstering Radioecology by Uniting Members) as a tool to promote an international harmonisation process for radioecology with the objectives to coordinate, integrate, communicate and maintain radioecology expertise worldwide. Further meetings are planned for 2014–15.

5.5 Revision of National Water Quality Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) and Australian Guidelines for Monitoring and Reporting (2000), constituting Guidelines 4 and 7 of the National Water Quality Management Strategy, respectively, are currently undergoing a targeted revision. These Guidelines represent key source information in Australia and New Zealand for managing natural water quality and protecting aquatic ecosystems. SSD continued to support the revision activities through the technical coordinator roles of ***eriss*** research scientists, Dr Rick van Dam and Dr Chris Humphrey, and the hosting of the revision project coordinator, Ms Kate Dixon, with the latter role ceasing in October 2013. Key activities of the ***eriss*** personnel during 2013–14 included: attendance, drafting of technical material and/or facilitation of workshops focusing on (i) finalising the water quality management framework and associated weight of evidence approach, and (ii) developing the new web site structure; finalising a revised method for deriving toxicant guideline values; providing technical input to, and oversight of, new and revised materials on (i) the water quality management framework and (ii) monitoring and assessment; scoping the requirements for (i) toxicant guideline value revisions and (ii) ecoregional water quality and ecological information and guidance; creating a terminology glossary; and participation in Project Coordination Group and Joint Steering Committee meetings.

5.6 National Environmental Research Program (NERP)

The National Environmental Research Program (NERP) being managed by DoE replaced the Commonwealth Environment Research Facilities (CERF) program and focuses more on biodiversity and improving research delivery to the Australian Government, other end-users and stakeholders. Researchers from ***eriss*** are collaborating in the NERP Northern Australia Hub.

During the reporting period, advice was provided to the NERP Northern Australia Hub as requested while a number of seminars were held at SSD where NERP researchers presented the findings of their projects to ***eriss*** staff.

5.7 Kakadu Research Advisory Committee

The leader of the Revegetation and Landscape Ecology Group, Dr Renée Bartolo, is a member of the Kakadu Research Advisory Committee (KRAC). Members of the committee are appointed by the Parks Board of Management to advise the Board and the Director of National Parks on strategic research issues and priorities required to support the socio-cultural and biophysical management objectives for the Park. During the reporting period, Dr Bartolo provided advice to Parks Australia staff through the KRAC.

5.8 EPBC compliance audits

oss staff did not participate in the conduct of any compliance audits against approval conditions issued under the *Environment Protection and Biodiversity Conservation Act 1999* in this reporting period.

5.9 Rum Jungle Technical Working Group

The Rum Jungle legacy uranium and copper mine site is located close to the town of Batchelor, approximately 80 km south of Darwin. In 2008, the Rum Jungle Technical Working Group (RJTWG) was formed to progress and implement:

- environmental maintenance activities
- continuation of appropriate environmental monitoring programmes, and
- development of contemporary site rehabilitation strategies for the site.

The group comprises representatives from DME, NRETAS, Australian Government Department of Industry (DoI), NLC and SSD. Mr Richard McAllister (Acting Supervising Scientist) and Dr Rick van Dam (Acting Director, ***eriss***) represent SSD.

An allocation of $7 million of special purpose funds was made in the 2009 Federal Budget to progress assessment of the site over a period of four years. The programme of work is being managed by DME under the terms of a National Partnership Agreement (NPA) between DME and the Australian Government Department of Resources Energy and Tourism. The ultimate objective of the work is to develop a costed rehabilitation plan consistent with contemporary best practice. The RJTWG provides technical advice and oversight of the projects commissioned to address the terms of the National Partnership Agreement (NPA). Background material and project updates have been published by DME on the website that has been created to inform members of the general public about the progress of activities carried out under the NPA: www.nt.gov.au/d/rumjungle.

In August 2013, the Commonwealth and NT Government signed a new Project Agreement for the Management of the Former Rum Jungle Mine Site (Stage 2). Under this Agreement, the Commonwealth has committed to providing an additional $11.561 million towards progressing rehabilitation at the former Rum Jungle mine site, which includes site maintenance and environmental monitoring, technical investigations, plus specifications, drawings and costings for the rehabilitation design works.

During 2013–14, SSD attended one meeting of the RJTWG.

5.10 Advice to DoE’s expert panel for major coal seam gas projects

The Australian Government plays a role in regulating coal seam gas proposals which could have a significant impact on matters protected by the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). This includes Matters of National Environmental Significance (MNES), actions involving the Commonwealth and actions taken on, or impacting on, Commonwealth land.

To help inform the Government’s role, the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Developments was established as a statutory committee in 2012, to provide the Minister with advice on projects approved under the EPBC Act. Those projects include the Queensland Curtis LNG project, the Santos Gladstone LNG project, and the Australia Pacific LNG project. The Committee provides advice on the adequacy of water management plans which the companies must submit under the conditions of approval.

The ***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford, have continued to provide specialist ecotoxicological advice to the Committee in relation to the potential for hydraulic fracturing chemicals and fluids from proposed coal seam gas operations to impact on relevant MNES. Related, in December 2013, Dr van Dam was invited to a workshop in Canberra organised by the Department’s Office of Water Science, to identify gaps in knowledge on the potential impacts of hydraulic fracturing chemicals. This advisory role is expected to continue in 2014–15.

5.11 Developing toxicity testing methods for tropical marine species

A review by ***eriss*** and Australian Institute of Marine Science (AIMS) research scientists in 2008 identified a lack of laboratory-based methods for assessing the effects of contaminants on Australian tropical marine species. In 2012–13, funding was secured from Rio Tinto alumina and aluminium operations, the Northern Territory Research and Innovation Board and the Northern Australian Marine Research Alliance to undertake a three year project to develop such methods. ***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford, are collaborators on the project in conjunction with scientists from AIMS, Charles Darwin University and Rio Tinto.

Key outcomes in the second year of the project included: (i) the development of two toxicity tests using hermit crab and a barnacle; (ii) progress with the development of a toxicity test using marine snails; and (iii) the development of a pelagic toxicity test system for larval organisms. Work involving the development of a reliable test method for the tropical unicellular alga, *Isochrysis galbana*, and subsequent assessment of the toxicity of aluminium, gallium and molybdenum was presented at the 3rd SETAC-AU conference (1–3 October 2013, Melbourne). The associated culturing of various other marine species for assessing their suitability for toxicity testing purposes is continuing. In 2014–15, the research team will proceed with further toxicity test development and subsequent assessment of the toxicity of aluminium, gallium and molybdenum.

5.12 Advice to DoI regarding the environmental hazard classification of uranium products

The Department of Industry provided funding to review the environmental hazard classification of uranium oxide (UO_4 and U_3O_8) products. These products are classified as Dangerous Goods (DG) Class 7 (radioactive) and 9 (aquatic toxicant) for transport (via road/rail and ship) under the Australian Dangerous Goods (ADG) code, International Maritime Dangerous Goods (IMDG) code and the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Due to a lack of data regarding the solubility of the UO_4 and U_3O_8 products, the DG9 classification was Chronic Category 4, which is a default safety net classification used when the data available does not allow classification under the formal criteria. This project produced the Transformation and Dissolution data that were needed to reassess the classification of the U products, although freshwater toxicity data were used for the marine assessment because marine toxicity data were not available. During the tendering process, ***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford provided technical advice and reviewed the final reports produced for the project. Technical advice to the uranium industry on the environmental hazard of U products may continue.

5.13 Other contributions

Research staff within SSD undertook other collaborations within and outside of Australia not identified in earlier chapters. Dr Wayne Erskine is collaborating with Dr Anita Chalmers, Plant Ecologist, of the School of Environmental and Life Sciences, University of Newcastle, Ourimbah, NSW on dendrochronological potential of Australian native riparian trees and on structure and function of Melaleucas on Gulungul Creek, Ranger Mine Lease.

Dr Erskine is also collaborating with Drs John Tilleard and Tony Ladson of Moroka Pty Ltd and Dr Michael Cheetham of Earth Tech Pty Ltd on a project for the Goulburn-Broken Catchment Management Authority (Victoria) on the geomorphic basis of river management problems on the Yea and Acheron Rivers and their tributaries.

6 COMMUNICATION ACTIVITIES

6.1 Introduction

In 2013–2014 SSD undertook a range of communication activities to ensure its primary stakeholders (mining companies, traditional owners, government and NGOs) remained informed about supervision, assessment and research into, and monitoring of, the environmental effects of uranium mining in the Region, through statutory committees, assessments and reporting. Open communication also provided SSD with the opportunity to understand and address the broad range of concerns that accompany the sensitive issue of uranium mining. Communication with academic and research organisations was prioritised to position SSD at the forefront of research in its relevant fields, and as a desirable research partner.

General SSD communications activities are coordinated through the Office of the Supervising Scientist's new Science Knowledge & Communication unit, which also oversees communication with Indigenous stakeholders, and the community, in partnership with the Jabiru-based Indigenous Communication Officer.

SSD engages directly with the general public through school-based apprenticeships, intermittent employment for ad-hoc/ seasonal projects, displays and exhibits at festivals, school visits (to the Jabiru Field Station) and through publications which target local communities.

SSD community engagement activities in the ARR during 2013–14 included display booths at the Mahbilil Festival, school talks, interactive informal information sessions on country with local traditional owners, and participation in World Wetlands Day. These activities assist in strengthening SSD's relationships with local Indigenous stakeholders, non-governmental environmental groups and the general public.

Other activities undertaken in the reporting period included hosting visits from interstate and international delegates and conference participation and presentations for professional development. In addition to these activities, the SSD website is an important tool in raising community awareness of the work of the Division and providing public access to the Division's scientific data and reports, including the results of SSD's research and environmental monitoring programmes.

6.2 Communication with the public including local community and Kakadu residents

SSD has a targeted strategy for communicating to the local Indigenous communities the findings from the monitoring and research projects carried out in the region as part of the Department's overarching commitment to 'Closing the Gap'. For example, the Indigenous Communication Officer and the Science Knowledge & Communications unit collaboratively developed audiovisual material that can be used whilst visiting local Indigenous communities to assist with explaining the methods and results from SSD's monitoring of the Ranger mine and the Jabiluka rehabilitation. In addition, the Indigenous Communication Officer maintains regular informal contact with the Mirarr people – the traditional owners of the land on which Ranger and Jabiluka lie. This provides effective opportunities to communicate SSD's role and function, and to keep the local communities well informed about the monitoring and research programmes undertaken at SSD. Following an incident at Ranger Uranium Mine in December 2013, direct communication with the Mirrar people was prioritised to ensure SSD was aware of their specific concerns and expectations. SSD provided accurate information regarding the incident and assured the Mirrar people of their ongoing safety in the environment.

The Indigenous Communication Officer also regularly liaises with the broader Alligator Rivers Region stakeholder group, including Energy Resources of Australia Ltd (ERA) community relations staff, Joint Management Branch (JMB) Parks Australia staff, local Indigenous corporations and the Northern Land Council to ensure there is a continuous supply of information on current and proposed SSD activities. Consultation also occurs with Kakadu residents to explain SSD projects and seek permission to carry out research on Indigenous land, and with JMB and Tourism to advise when and where SSD will be carrying out research activities within Kakadu National Park.

Employment of Indigenous people for activities such as field research provides SSD staff the opportunity to work alongside landowners on their country, sharing knowledge and gaining greater insight into traditional cultural values. It also provides an opportunity for Indigenous people to gain valuable technical skills and a greater understanding of how SSD does its work. Regular contact between SSD's Indigenous Communication Officer and the Gundjeihmi Aboriginal Corporation (GAC) facilitate this interaction.

SSD's involvement in employment and training schemes for local people provides an avenue for communicating about the work and goals of the organisation, to both Indigenous and non-Indigenous trainees. Details of the traineeships provided by SSD are in Section 7.1.3 .

The publications produced by SSD focus on research-related information, which is pitched at varying levels of scientific detail and complexity, depending on the intended audience. This approach aims to ensure that all stakeholders including traditional owners, industry stakeholders, residents of Jabiru and the general public are catered to with publications that convey relevant aspects of the Division's work in an accessible style.

The Science Knowledge & Communication unit produces and distributes several scientific report series, including the Supervising Scientist Report series, the Internal Report series, and a range of ad-hoc products, all of which showcase and record the Divisions work. The unit also co-ordinates the Division's contribution to the Department of Environment annual report and produces the Supervising Scientist's annual report. These publications are particularly useful for informing the divisions technical advisors of the results of environmental monitoring and research by SSD staff and external authors. At the May 2014 ARRAC meeting, ARRAC board members were supplied with electronic versions of ***eriss*** research summaries, providing them with a comprehensive collection of the work of the Division from 2010 to 2013.

All of the above activities served to enhance awareness and understanding of the work and role of SSD and to maintain the Division's profile within the local and wider community.

6.3 Communication with primary stakeholders

SSD staff engage with primary stakeholders, including the traditional owners of the Alligator Rivers Region, and ensure that SSD meets its obligations of fostering awareness of the research and monitoring activities of the Division. In 2013–14 SSD's Science Knowledge & Communication unit worked closely with the Indigenous Communication Officer to jointly develop a range of communications products for traditional owners, including videos with audio in the local Indigenous language and scientific posters pitched to a lay audience.

SSD's two specialised statutory committees, ARRTC and ARRAC, continued to facilitate discussion and information exchange between SSD and its primary stakeholders in 2013–14. These committees were an important means of ensuring transparency and enhancing trust between the various stakeholder organisations. Details are in Chapter 2.

SSD hosted a stall at the Mahbilil Festival on14 September 2013 (Figure 6.1), promoting the research and monitoring that is conducted by SSD. SSD uses its presence at the Mahbilil event to respond to general community concerns that might not otherwise be raised.

Figure 6.1 Jabiru staff at the SSD stall at the Mahbilil Festival.

A range of other communication activities for traditional owners were undertaken by SSD in partnership with other organisations in the region. For example, each year Parks Joint Management Branch, in conjunction with the West Arnhem College, runs a Junior Ranger Program for school children. The programme runs for the school year and the students attend weekly activities, excursions and lessons. Part of the programme involves a unit on research and monitoring. SSD's Jabiru Field Station traditionally provides the tutorial and venue, making good use of the Division's macroinvertebrates to achieve learning outcomes.

World Wetlands Day is held on 2 February each year. In 2013–14 SSD and Parks organised stalls at the Bowali Visitor Centre to celebrate the day and highlight the importance of wetlands and the significance of the Magela floodplains as a recognised wetland under the international Ramsar Convention.

6.4 Research protocols for Kakadu National Park

Details of the proposed 2014–15 SSD research and monitoring activities within Kakadu National Park were submitted to Parks Joint Management Branch and the Northern Land Council in April 2014 as required under the protocols agreed to by the Director of National Parks and the Supervising Scientist.

The protocols define working arrangements for effective and timely communication between ***eriss*** and Parks Joint Management Branch staff, the Kakadu Board of Management and traditional owners in relation to ***eriss*** research and monitoring activities within Kakadu National Park.

6.5 Internal communication

SSD actively supports open exchange of information amongst staff within the Division, and in a broader context, within the Department.

The Division maintains effective internal communication between staff of all levels through regular general staff meetings, and also team and programme meetings. Subject-specific working groups are convened as required to address strategic business issues within the Division, and SSD staff participate in a range of business-related and technical working groups across the Portfolio.

A number of IT systems were introduced during the reporting period to make internal business and scientific communication more efficient and effective These included a series of bulletin boards on the intranet which circulate corporate and other work-related messages to all staff. The bulletin boards include a Research Update forum, allowing researchers to post aspects of interest from their work, with the capacity to host videos and chat functions. The SSD intranet more generally was restructured and furnished with a range of features to assist staff to readily access important information about working in SSD. Intranet authorship training was provided to several staff with a view to creating a more flexible and responsive intranet structure and content.

The theme of enhancing communication systems with IT solutions underpinned a number of internal communication innovations in 2013–14. A system of electronic libraries was established to accommodate the scientific information resource which had previously been housed in SSDs recently decommissioned 'bricks and mortar' library.

Social media played a role in internal communication with the implementation of an emergency texting system, which enabled the quick and accurate notification of all staff, in the event of natural disasters and other emergencies which affect the work place. SSD is located in Australia's cyclone region, so this is a critical communication innovation for staff safety.

Staff awareness of SSD scientific research activities is nurtured through a monthly 'coffee break' seminar series, featuring internal and external speakers from relevant scientific fields. The seminars encourage and develop cross-pollination of ideas and innovation across the scientific programme areas of ***eriss***.

Innovative communication systems were developed and implemented to streamline project management within the organisation. A project milestone tracking database which facilitates the reporting requirements of project managers in a transparent and efficient way facilitates clear and targeted communication between line areas. Milestones are automatically reviewed every fortnight within SSD at multiple reporting levels, and are converted into a divisional project milestone report every quarter and annually. All staff have the ability to view and use the system.

6.6 Science communication

The results of research and investigations undertaken by SSD are made available to key stakeholders as well as the scientific and wider community through publications in journals and conference proceedings, and in a range of internal and publicly distributed publications. In 2013–14 SSD posted continuous, event-based and routine water monitoring results on its website for public viewing. The surface water quality monitoring data were updated regularly while the creeks were flowing. Biological and radon monitoring data were also posted online.

In-house productions include the Supervising Scientist Report and Internal Report series (for detailed reporting on scientific projects and particular issues), and other media such as posters and educational material to suit specific requirements or events.

In addition, a number of the Division's staff contribute to external scientific, technical and other professional organisations, including various editorial boards and panels.

In keeping with the drive to innovate towards greater efficiency, SSD ceased distributing hard copies of most of its academic publications, and instead instituted various forms of electronic distribution as the default. The complete Supervising Scientist Report series is available in PDF format on the SSD website and comprehensive sets of SSD's flagship publications have been made available on memory sticks to key stakeholders. The move towards electronic distribution supports the Department's policy of reducing its environmental footprint and also reduces costs and administrative burden.

A full list of papers and reports published during 2013–14 is provided in Appendix 2. Papers presented at national and international conferences are listed in Appendix 3.

SSD's website continued to be redeveloped in keeping with new style and structure guidelines issued by the Department. The upgrade to a modern content management system enables more intuitive content navigation and also meets the intended legal and communication objectives.

In 2013–14, ***eriss*** staff supervised one post-graduate research project:

- The effect of uranium on the structure and function of sediment bacteria communities (PhD, Macquarie University, to be completed January 2017)

SSD staff presented papers at a number of national and international conferences during the reporting period as described in Table 6.1.

TABLE 6.1 CONFERENCE PRESENTATIONS 2013-14

Conference	Place/date (no. Papers)
SETAC-AU 2013, 3rd Conference of the Society for Environmental Toxicology and Chemistry - Australasian chapter	Melbourne, 1–3 October 2013 (4 presentations)
Eighth International Conference on Mine Closure – Eden Project	Cornwall, UK, 14–22 September 2013. (1 Presentation)
GEOBIA 2014, 5th International Conference on Geographic Object-Based Image Analysis	Thessaloniki, Greece, 21–24 May 2014 (2 papers)
IGARSS 2013, IEEE International Geoscience and Remote Sensing Symposium	Melbourne, Australia, July 2013 (1 paper)
17th Radiochemical Conference	Mariánské Lázně, Czech Republic, May 2014 (1 paper)
IUR International Workshop on Worldwide Harmonization of Radioecology Networks	La Baume, Aix-en-Provence, France, June 2014 (1 paper)

Participation in international events allows staff to share their knowledge and expertise with peers and maintain awareness of international best practice in relevant areas. Participation is also seen as important in ensuring SSD maintains its profile as a part of the broader scientific and technical community.

SSD hosts researchers and visitors from other organisations to undertake collaborative funded projects, for sabbatical periods, or to present seminars or training workshops (Table 6.2).

TABLE 6.2 RESEARCHERS AND OTHER VISITORS, 2013–14

Activity	Visitor/organisation	Date
Riparian vegetation assessment on Gulungul Creek.	Dr Anita Chalmers, The University of Newcastle, NSW	15–29 June 2014
Annual data collection and survey of erosion points at Tin Camp Creek for erosion monitoring.	Associate Professor Greg Hancock, The University of Newcastle, NSW	16–19 June 2014
Work on the role of vegetation in stabilising channel islands in Gulungul Creek.	Dr Anita Chalmers, The University of Newcastle, NSW	1–16 June 2014
Collaboration on long-term modelling of a conceptual rehabilitated Ranger mine landform for 10,000 years. Updating and enhancement of the CAESAR model to incorporate weathering and soil development. Presentation to staff.	Professor Tom Coulthard, University of Hull, UK	25 May – 4 June 2014
Discussion on the collaboration on long-term modelling of a conceptual rehabilitated Ranger mine landform for 10,000 years. Presentation to staff.	Associate Professor Greg Hancock, The University of Newcastle, NSW	28–2 May 2014
Swampfox UAS delivery and training.	Lew Woods, Skycam, NZ	28 April – 2 May 2014
Discussion on the collaboration on long-term modelling of a conceptual rehabilitated Ranger mine landform for 10,000 years.	Associate Professor Greg Hancock, The University of Newcastle, NSW	10–14 February 2014
Unmanned Aerial System (UAS) tests at Kakadu.	Dr Peter Erskine, Dr Andrew Fletcher, Ashray Doshi, Centre for Mined Land Rehabilitation, University of Queensland Lew Woods, Skycam, NZ	7–11 October 2013
Collection of annual data for erosion monitoring and landform evolution modelling research (Tin Camp Creek).	Associate Professor Greg Hancock, The University of Newcastle, NSW	22–26 July 2013
Development of a satellite imagery catalogue.	Javier Chen (student), Charles Darwin University, NT	March - May 2013
Processing of UAS imagery.	Sandra Grant (student), Charles Darwin University, NT	March - May 2013
Presentations given at Coffee Break seminar series and met to discuss current and future projects.	Dr Anthony Chariton, CSIRO and Dr Donald Baird, University of New Brunswick, Canada	19 March 2013

7 ADMINISTRATIVE ARRANGEMENTS

7.1 Human resource management

7.1.1 Supervising Scientist

The Supervising Scientist is a statutory position established under the *Environment Protection (Alligator Rivers Region) Act 1978*. Section 8 of the Act requires that the Supervising Scientist be engaged under the *Public Service Act 1999*.

Mr Richard McAllister was appointed to the position in an acting capacity in April 2013.

7.1.2 Structure

SSD consists of two branches, ***oss*** and ***eriss***.

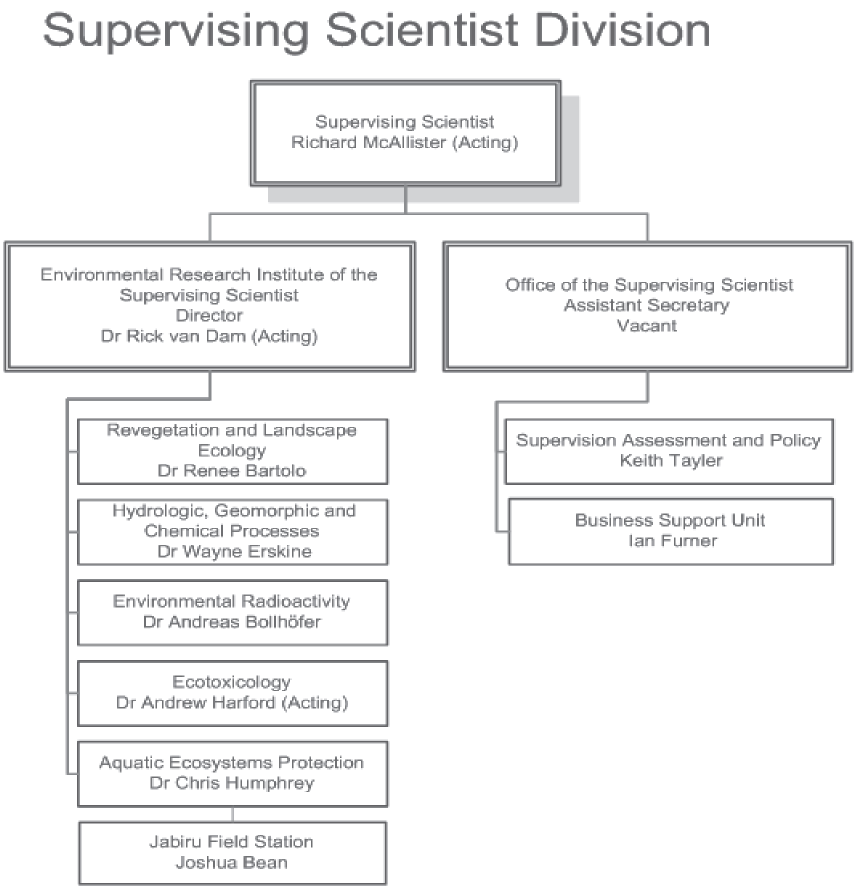


Figure 7.1 Organisational structure of the Supervising Scientist Division (as at 30 June 2013).

The ***oss*** is responsible for supervision, assessment, policy, information management and corporate support activities. The position of Assistant Secretary ***oss*** has been vacant since April 2013.

eriss is responsible for scientific research and monitoring activities. Dr Rick van Dam assumed the role of acting head of ***eriss*** in November 2012.

SSD will become part of the Department's newly-established Science Division on 1 July 2014 although there will be no change in functions or annual reporting.

Average staffing numbers for 2012–2013 and 2013–2014 are given in Table 7.1.

TABLE 7.1 STAFFING NUMBERS (1) AND LOCATIONS

	2012–2013	2013–2014
Darwin	40	37.5
Jabiru	7	7.5
Total	47	45

(1) Average full time equivalent from 1 July to 30 June

7.1.3 Workforce management

SSD has a well established human resource management framework that strives to achieve continuous improvement in workforce capability, retention of staff and achievement of business outcomes. The framework is supported by a proactive performance development scheme with targeted learning and development aligned to achieving business outcomes.

The SSD leadership group encourages and supports staff to build capability through on-the job training, coaching and mentoring, delivering papers at scientific conferences, and attendance at identified training courses, conferences and internal seminars. Staff are also provided with opportunities to act in higher level positions – this prepares them for advancement and supports the Division's succession plan. Through the Performance Development Scheme, staff identify training requirements to help deliver their work plan outcomes. Courses for project management, performance management, diversity in the workplace, work, health and safety, electronic records management and specialist software applications have been held in-house to assist with staff development. SSD staff have access to Canberra-based seminars and information sessions. Locally-hosted seminars, in addition to the SSD Internal Seminar Series, provide staff with a range of topics relevant to SSD business activities.

SSD is also committed to the training and development of Indigenous and non-Indigenous trainees. SSD acts as a host employer and provides on-the job training and mentoring while trainees enrol and complete a qualification in a course aligned with their on-the-job duties. During 2013–14 SSD engaged a new Indigenous school-based apprentice completing a Certificate II in Lands Conservation Management; had one Indigenous trainee successfully complete a Certificate III in Lands Conservation and Management and continued to host a trainee completing a Certificate IV in Business. During 2013–14 the health and wellbeing programme offered staff access to vaccinations for influenza and a team pedometer challenge. Internal health and wellbeing seminars on the Department's EAP program, mental health awareness and change management have been coordinated for staff. SSD has also supported Cancer Council fund raising events to raise awareness on cancer associated health risks.

7.2 Work Health and Safety

SSD continued to maintain a strong commitment to Work Health and Safety (WHS) during 2013–2014. No workers compensation claims were submitted as a result of a slip, trip or fall incident with the injured worker returning to full time duty following rehabilitation.

In response to a Comcare report into quad bike incidents, SSD phased out the remainder of its quad bike fleet located at JFS and replaced the bikes with new all terrain vehicles which provide workers with a much higher level of safety.

The Work Health and Safety Committee (WHSC) met regularly and focused on reviewing WHS procedures, risk management, chemical management and field work safety.

All senior managers, accompanied by an accredited Health and Safety Representative (HSR), participated in WHS site inspections (which occur every three months) to ensure the safety message is being delivered to workers from a senior level. The number of hazards identified has significantly reduced as a result of improved maintenance systems, reporting and further maturing of the safety culture at SSD.

In 2013–14, safety education for staff focused on:

- flu vaccinations
- crocodile safety
- field work safety
- 4WD training for new all terrain vehicles
- early identification and reporting of hazards

Quarterly reports were provided to the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) in conformance with requirements to confirm SSD's general control, safety and management plans of ionising and non ionising source holdings.

7.3 Finance

SSD is part of the Australian Government Department of the Environment (DoE) and full financial statements for the Department are contained in the Department's annual report (www.environment.gov.au/about/publications/annual-report/index.html).

A summary of the actual expenses of the Supervising Scientist against the Department's outputs are provided in Table 7.2.

TABLE 7.2 SUMMARY OF DIRECT PROGRAMME EXPENSES

PBS Outcome 5	2012–2013	2013–2014
Programme 5.2 – Environmental Regulation *	$9 192 765	$9 164 280
Total*	$9 192 765	$9 164 280

* Excludes Departmental corporate overheads of $5 012 737 in 12–13 and $4,724 426 in 13–14.

7.4 Facilities

7.4.1 Darwin facility

The majority of SSD staff are situated at the DoE Darwin facility adjacent to the Darwin International Airport. This facility consists of office accommodation and laboratories. During the year the SSD library was disbanded and plans have been developed to reuse the space as a meeting room and general amenities area. All of the office and common areas underwent a makeover with floor coverings replaced and internal painting. The office space, library and amenities are shared with Parks Australia, which is also part of the DoE.

Figure 7.2 Library disbandment

7.4.2 Jabiru Field Station

The primary function of the Jabiru Field Station (JFS) is to support the activities of the SSD in the Alligator Rivers Region. JFS staff are a multi-disciplinary team that assist with research, implement environmental monitoring programmes, community extension activities, local administrative and financial management, and the management of assets and minor plant at

JFS and related temporary accommodation. The JFS Manager has overall responsibility for managing the Field Station as well as supervisory and inspection responsibilities.

During 2013–14 three Polaris Ranger all terrain vehicles (ATV's), four Yamaha outboard motors and a new trailer were purchased. Related to this cyclic purchase, ageing plant was disposed of, including three quad bikes (as noted earlier), three ATV's, two trailers and five outboard motors.

Figure 7.3 The new Polaris Rangers at Jabiru Field Station.

7.5 Information management

As noted earlier the SSD library was disbanded in late 2013 with a large volume of material recycled as it was already being held in electronic form, duplicated or no longer required. Important books and reference material were transferred to the Department's library in Canberra or retained at SSD as a special collection.

Electronic records management (SPIRE) was rolled out for SSD in mid 2013 eliminating the need for paper files. A large volume of files have been archived and documents are progressively being scanned so that they can be filed in the SPIRE system. There is also a project underway to transfer electronic documents from the previous electronic records management systems to SPIRE.

7.6 Interpretation of Ranger Environmental Requirements

Section 19.2 of the Environmental Requirements of the Commonwealth of Australia for the Operation of the Ranger Uranium Mine provides for the publication of explanatory material agreed to by the major stakeholders to assist in the interpretation of provisions of the Environmental Requirements. No explanatory material was published during 2013–14.

7.7 Ministerial directions

There were no Ministerial Directions issued to the Supervising Scientist under Section 7 of the *Environment Protection (Alligator Rivers Region) Act 1978* during 2013–14.

7.8 Environmental performance

SSD contributes to the Department's sustainability objectives through a range of measures aimed at continuously improving the environmental performance of our business operations and minimising any associated environmental impacts. The Division reports on its environmental performance in the Department's 2013–14 Annual Report.

7.8.1 Environmental Management System

The Department has committed to extend the scope of its Environmental Management System (EMS) and associated certification to SSD in the future. In the interim, SSD's operations are conducted in a manner consistent with the Department's aim to minimise the ecological footprint on the environment. This involves a range of strategies including complying with legal and other agreements, actively promoting sustainable work practices, preventing pollution as a result of work practices, focusing on continuous improvement, public reporting of environmental performance as part of the Department's annual report and procurement and use of sustainable goods and services.

7.9 Animal experimentation ethics approvals

eriss seeks the approval of Charles Darwin University's (CDU) Animal Ethics Committee (AEC) to undertake scientific experiments involving vertebrate animals. The Animal Welfare Branch of the Northern Territory Government grants the ***eriss*** premises a licence to use animals for research purposes. This licence includes the laboratories in Darwin and Jabiru, as well as field work conducted in the Alligator Rivers Region. Since April 2011, the CDU AEC has begun issuing permits to persons involved or employed by a licensee conducting a teaching or research programme.

A progress report for the project 'Larval fish for toxicity tests at ***eriss***' (ref no A12028) was submitted to CDU AEC and approved on 28 October 2013. A final report will be submitted in September 2014. Individual permits for new ***eriss*** staff conducting research with fish were also granted during this time. This project is due for renewal during August 2014 and the individual permits are valid for two years. The number of fish used in toxicity tests at ***eriss*** was reported in July 2014 to the Northern Territory Government, as part of our licence requirements permitting the use of animals for research purposes.

Progress reports for both fish communities projects - ' Fish community sampling in channel billabongs around Ranger mine using boat visual census (A11034)' and 'Monitoring mining impact using the structure of fish communities in shallow billabongs (A12007)' were submitted to CDU AEC and approved on 5 March and 6 June 2014 respectively. Individual permits for ***eriss*** staff conducting research with fish were also granted at this time. Both project approvals are valid for two years from the approval date. For the 2014 monitoring period, access to Mudginberri Billabong was not possible due to an important time of mourning for the local Indigenous community. The next assessment for the project ‘ Fish community sampling in channel billabongs around Ranger mine using boat visual census (A11034)’ will be undertaken in 2015 and will be reported in the Supervising Scientist Annual Report for 2014–15.

Table 7.3 provides information on new applications, renewals of approvals and approval expiries for projects during 2013–14.

TABLE 7.3 ANIMAL EXPERIMENTATION ETHICS APPROVALS

Project title	Ref no	Initial submission	Approval/latest renewal	Expiry
Larval fish toxicity testing at ***eriss***	A12028 (previously 97016)	26 May 1997	2 Aug - Sept 2012	2 Sept 2014
Monitoring mining impact using the structure of fish communities in shallow billabongs	A12007 (previously A09001)	25 Sept 2000	06 June 2014	06 June 2016
Fish community sampling in channel billabongs around Ranger mine using boat visual census	A11034	22 Feb 2012	05 Mar 2014	05 Mar 2016

Appendix 1 ARRTC Key Knowledge Needs: Uranium mining in the Alligator Rivers Region

Overall objective

To undertake relevant research that will generate knowledge leading to improved management and protection of the ARR and monitoring that will be sufficiently sensitive to assess whether or not the environment is protected to the high standard demanded by the Australian Government and community.

Background

In assessing the Key Knowledge Needs for research and monitoring in the Alligator Rivers Region, ARRTC has taken into account current mining plans in the region and the standards for environmental protection and rehabilitation determined by the Australian Government. The assumptions made for uranium mining operations in the region are:

- mining of uranium at Ranger ceased in 2012. This will be followed by milling until about 2020 and final rehabilitation expected to be completed by about 2026.
- Nabarlek is decommissioned but has not reached a status where the NT Government will agree to issue a Revegetation Certificate to the mine operator. Assessment of the success of rehabilitation at Nabarlek is ongoing and may provide valuable data for consideration in the design and implementation of rehabilitation at Ranger.
- Jabiluka will remain in a care and maintenance condition for some years. ERA, the project owner, has stated that further mining will not occur without the agreement of the traditional owners; and
- grant of an exploration title at Koongarra is required under the terms of the *Aboriginal Land Rights (Northern Territory) Act 1976* before the mining company can apply for a mining title. As such, any future activity at Koongarra is subject to the agreement of the traditional owners and the Northern Land Council.

This scenario is considered to be a reasonable basis on which to base plans for research and monitoring, but such plans may need to be amended if mining plans change in the future. ARRTC will ensure the research and monitoring strategy is flexible enough to accommodate any new knowledge needs. The Australian Government has specified primary and secondary environmental objectives for mining at Ranger in the Ranger Environmental Requirements. Similar standards would be expected for any future mining development at Jabiluka or Koongarra.

Specifically, under the Ranger Environmental Requirements (ERs):

The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:

(a) maintain the values for which Kakadu National Park (KNP) was inscribed on the World Heritage List.

(b) maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of KNP).

(c) protect the health of Indigenous and other members of the regional community, and

(d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

With respect to rehabilitation at Ranger, the ERs state that:

> The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of KNP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the KNP.

The ERs go on to specify the major objectives of rehabilitation at Ranger as follows:

(a) revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of KNP, to form an ecosystem the long term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park.

(b) stable radiological conditions on areas impacted by mining so that the health risk to members of the public, including traditional owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area.

(c) erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas.

A secondary environmental objective applies to water quality and is linked to the primary ERs. This ER states:

> The company must not allow either surface or ground waters arising or discharging from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.

While there are many possible different structures that could be used to specify the Key Knowledge Needs, ARRTC has chosen to list the knowledge needs under the following headings:

- Ranger – current operations
- Ranger – rehabilitation
- Jabiluka

- Nabarlek
- General Alligator Rivers Region

1 Ranger – Current operations

1.1 Reassess existing threats

1.1.1 Surface water transport of radionuclides

Using existing data, assess the present and future risks of increased radiation doses to the Indigenous population eating bush tucker potentially contaminated by the mining operations bearing in mind that the current traditional owners derive a significant proportion of their food from bush tucker.

1.1.2 Atmospheric transport of radionuclides

Using existing data and atmospheric transport models, review and summarise, within a risk framework, dose rates for members of the general public arising from operations at the Ranger mine.

1.2 Ongoing operational issues

1.2.1 Ecological risks via the surface water pathway

Off-site contamination during mine operation (and subsequent to decommissioning – refer KKN 2.6.1) should be placed in a risk-based context. A conceptual model of the introduction, movement and distribution of contaminants, and the resultant biotic exposure (human and non-human) has been developed, and the ecological risks (i.e. probability of occurrence x severity of consequence) of some of the contaminant/pathway sub-models have been estimated. This process should be completed for all the contaminant/pathway sub-models, noting, however, that the level of effort for each needs to be proportionate to the level of concern of the issue. It is critical that robust risk assessment methodologies are used, and that they explicitly incorporate uncertainty in both the assessment and subsequent decision making processes. Where ecological risk is significant, additional information may be required (e.g. mass-balance and concentration dynamics, consideration of possible interactive effects, field data). Further, knowledge gaps preventing reasonable estimation of potential risks (i.e. with unacceptable uncertainty) must be filled.

The Magela floodplain risk assessment framework developed to estimate and compare mining and non-mining impacts should be revisited periodically, and updated to the current risk profile. It should be revised in the event that either **(i)** the annual monitoring programme or other sources indicate that the inputs from mining have significantly increased relative to the situation in 2005, or **(ii)** an additional significant contaminant transport pathway from the minesite is identified, or **(iii)** there is a change in external stressors that could result in a significant increase in likelihood of impacts from the site.

1.2.2 Land irrigation

Investigations are required into the storage and transport of contaminants in the land irrigation areas particularly subsequent to decommissioning. Contaminants of interest/concern in addition to radionuclides are magnesium, 139 ecquere and manganese. Results from these investigations should be sufficient to quantify the role of irrigation areas as part of satisfying KKN 1.2.1, and form the basis for risk management into the future.

1.2.3 Wetland filters

The key research issue associated with wetland filters in relation to ongoing operations is to determine whether their capacity to remove contaminants from the water column will continue to meet the needs of the water management system in order to ensure protection of the downstream environment. Aspects of contaminant removal capacity include (i) instantaneous rates of removal, (ii) temporal performance – including time to saturation, and (iii) behaviour under 'breakdown' conditions – including future stability after closure. Related to this is a reconciliation of the solute mass balance particularly for the Corridor Creek System (see KKN 1.2.5).

1.2.4 Ecotoxicology

Past laboratory studies provide a significant bank of knowledge regarding the toxicity of two of the major contaminants, uranium and magnesium, associated with uranium mining in the ARR. Further studies are scheduled to assess (i) the toxicity of manganese and, potentially, ammonia (in the event that permeate produced by process water treatment will contain potentially toxic ammonia concentrations), and (ii) the relationship between dissolved organic matter and uranium toxicity. This knowledge should continue to be synthesised and interpreted, within the existing risk assessment framework (refer KKN 1.2.1), as it comes to hand.

An additional issue that needs to be addressed is the direct and indirect effects on aquatic biota of sediment arising from the mine site. In the first instance, a conceptual model needs to be developed (building on the relevant components of the conceptual model developed under KKN 1.2.1) that describes the movement of sediment within the creek system, including the associated metal-sediment interactions and biological implications. Studies likely to arise from the outcomes of the conceptual model include:

- the effects of suspended sediment on aquatic biota
- the relationship between suspended sediment and key metals, and how this affects their bioavailability and toxicity
- the effects of sediment-bound metals to benthic biota, including, initially, a review of existing information on uranium concentrations in sediments of waterbodies both on- and off the Ranger site, and uranium sediment toxicity to freshwater biota.

Whilst of relevance at present, the above issues will be of additional importance as Ranger progresses towards closure and rehabilitation (refer KKN 2.6.1). Finally, the need for studies to assess the toxicity of various mine waters (treated and untreated) in response to specific supervisory/regulatory or operational requirements is likely to continue.

1.2.5 Mass balances and annual load limits

With the expansion of land application areas and the increase in stockpile sheeting that has occurred in concert with the expansion of the footprints of the waste rock dumps and low grade ore stockpiles, it is becoming increasingly important to develop a solute mass balance for the site – such that the behaviour of major solute source terms and the spatial and temporal contribution of these sources to water quality in Magela Creek can be clearly understood. Validated grab sample and continuous data records are needed to construct a high reliability solute mass balance model.

Related to mass balance is the issue of specifying allowable annual load limits from the site – as part of the site's regulatory requirements. The technical basis for these load limits needs to be reviewed since they were originally developed decades ago. There has since been significantly increased knowledge of the environmental geochemistry of the site, a quantum increase in knowledge about ecotoxicological sensitivity of the aquatic systems and updated data on the diet profile of traditional owners.

1.3 Monitoring

1.3.1 Surface water, groundwater, chemical, biological, sediment, radiological monitoring

Routine and project-based chemical, biological, radiological and sediment monitoring should continue, together with associated research of an investigative nature or necessary to refine existing, or develop new (promising) techniques and models. A review of current water quality objectives for Ranger should be conducted to determine if they are adequate for future water management options for the whole-of-site, including the closure and rehabilitation phase (KKN 2.2.1 and KKN 2.2.2).

ARRTC supports the design and implementation of a risk-based radiological monitoring programme based on a robust statistical analysis of the data collected over the life of Ranger necessary to provide assurance for Indigenous people who source food items from the Magela Creek system downstream of Ranger.

2 Ranger – Rehabilitation

2.1 Reference state and baseline data

2.1.1 Defining the reference state and baseline data

There is a requirement to define the baseline data/reference state that existed at the Ranger site prior to development. This will inform the process of the development of closure criteria which is compatible with the Environmental Requirements. The knowledge need is to develop and perform analysis to generate agreed reference data that cover the range of pre-mining and operational periods.

2.2 Landform

2.2.1 Landform design

An initial design is required for the proposed final landform. This would be based upon the optimum mine plan from the operational point of view and it would take into account the broad closure criteria, engineering considerations and the specific criteria developed for guidance in the design of the landform. This initial landform would need to be optimised using the information obtained in detailed water quality, geomorphic, hydrological and radiological programmes listed below.

Current and trial landforms at Ranger and at other sites such as Nabarlek should be used to test the various models and predictions for water quality, geomorphic behaviour and radiological characteristics at Ranger. The detailed design for the final landform at Ranger should be determined taking into account the results of the above research programmes on surface and ground water, geomorphic modelling and radiological characteristics.

2.2.2 Development and agreement of closure criteria from the landform perspective

Closure criteria from the landform perspective need to be established at both the broad scale and the specific. At the broad scale, agreement is needed, particularly with the traditional owners and within the context of the objectives for rehabilitation incorporated within the Ers, on the general strategy to be adopted in constructing the final landform. These considerations would include issues such as maximum height of the landform, the maximum slope gradient (from the aesthetic perspective), and the presence or absence of lakes or open water. At the specific scale, some criteria could usefully be developed as guidance for the initial landform design such as slope length and angle (from the erosion perspective), the minimum cover required over low grade ore, and the minimum distance of low grade ore from batter slopes. Specific criteria are needed that will be used to assess the success of landform construction. These would include, for example, maximum radon exhalation and gamma dose rates, maximum sediment delivery rates, maximum constituent concentration rates in runoff and maximum settling rates over tailings repositories.

2.2.3 Water quality in seepage and runoff from the final landform

Existing water quality monitoring and research data on surface runoff and subsurface flow need to be analysed to develop models for the quality of water, and its time dependence, that would enter major drainage lines from the initial landform design. Options for adjusting the design to minimise solute concentrations and loads leaving the landform need to be assessed.

There is a need to develop and analyse conceptual models of mine related turbidity and salinity impacts following closure. These models could be analysed in a variety of ways as a precursor to the development of a quantitative model of potential turbidity and salinity impacts off-site caused by surface and subsurface water flow off the rehabilitated mine site. This analysis should explicitly acknowledge knowledge uncertainty (e.g. plausible alternative conceptual models) and variability (e.g. potential for Mg/Ca ratio variations in water flowing off the site) and explore the potential ramifications for the off-site impacts. (see also KKN 2.6.1)

2.2.4 Geomorphic behaviour and evolution of the landscape

The existing data set used in determination of the key parameters for geomorphological modelling of the proposed final landform should be reviewed after consideration of the near surface characteristics of the initial proposed landform. Further measurements of erosion characteristics should be carried out if considered necessary. The current site-specific landform evolution models should be applied to the initial proposed landform to develop predictions for long term erosion rates, incision and gullying rates, and sediment delivery rates to the surrounding catchments. Options for adjusting the design to minimise erosion of the landform need to be assessed. In addition, an assessment is needed of the geomorphic stability of the Ranger mine site with respect to the erosional effects of extreme events.

2.2.5 Radiological characteristics of the final landform

The characteristics of the final landform from the radiological exposure perspective need to be determined and methods need to be developed to minimise radiation exposure to ensure that restrictions on access to the land are minimised. Radon exhalation rates, gamma dose rates and radionuclide concentrations in dust need to be determined and models developed for both near-field and far-field exposure.

The use of potential analogue sites for establishing pre-mining radiological conditions at Ranger should be further investigated to provide information on parameters such as pre-mining gamma dose rates, radon exhalation rates, and levels of radioactivity in dust. This information is needed to enable estimates to be made of the likely change in radiation exposure when accessing the rehabilitated site compared to pre-mining conditions.

2.3 Groundwater dispersion

2.3.1 Containment of tailings and other mine wastes

The primary method for protection of the environment from dispersion of contaminants from tailings and other wastes will be containment. For this purpose, investigations are required on the hydrogeological integrity of the pits, the long-term geotechnical properties of tailings and waste rock fill in mine voids, tailings deposition and transfer (including TD to Pit 3) methods, geochemical and geotechnical assessment of potential barrier materials, and strategies and technologies to access and 'seal' the surface of the tailings mass, drain and dispose of tailings porewater, backfill and cap the remaining pit void.

2.3.2 Geochemical characterisation of source terms

Investigations are needed to characterise the source term for transport of contaminants from the tailings mass in groundwater. These will include determination of the permeability of the tailings and its variation through the tailings mass, strategies and technologies to enhance settled density and accelerate consolidation of tailings, and porewater concentrations of key constituents.

There is a specific need to address the existence of groundwater mounds under the tailings dam and waste rock stockpiles. Models are needed to predict the behaviour of groundwater and solute transport in the vicinity of these mounds and options developed for their remediation to ensure that on-site revegetation can be achieved and that off-site solute transport from the mounds will meet environmental protection objectives. Assessment is also needed of the effectiveness (cost and environmental significance) of paste and cementation technologies for increasing tailings density and reducing the solubility of chemical constituents in tailings.

2.3.3 Aquifer characterisation and whole-of-site model

The aquifers surrounding the tailings repositories (Pits 1 and 3) need to be characterised to enable modelling of the dispersion of contaminants from the repositories. This will involve geophysics surveys, geotechnical drilling and groundwater monitoring and investigations on the interactions between the deep and shallow aquifers.

2.3.4 Hydrological/hydrogeochemical modelling

Predictive hydrological/hydrogeological models need to be developed, tested and applied to assess the dispersion of contaminants from the tailings repositories over a period of 10 000 years. These models will be used to assess whether all relevant and appropriate factors have been considered in designing and constructing an in-pit tailings containment system that will prevent environmental detriment in the long term.

2.4 Water treatment

2.4.1 Active treatment technologies for specific mine waters

Substantial volumes of process water retained at Ranger in the tailings dam and Pit 1 must be disposed of by a combination of water treatment and evaporation during the mining and milling phases of the operation and during the rehabilitation phase. Research priorities include treatment technologies and enhanced evaporation technologies that can be implemented for very high salinity process water. A priority should be evaluation of the potential impact of treatment sludge and brine streams on long term tailings chemistry in the context of closure planning and potential post closure impacts on water quality.

2.4.2 Passive treatment of waters from the rehabilitated landform

Sentinel wetlands may form part of the final landform at Ranger. Research on wetland filters during the operational phase of mining will provide information relevant to this issue. Research is needed to establish the effect of wet-dry seasonal cycling on contaminant retention and release, since this aspect will influence design criteria and whether such wetlands should be maintained as ephemeral or perennial waterbodies There is also the need to assess the long-term behaviour of the physical and biotic components of the wetlands, their ecological health, and the extent of contaminant accumulation (both metals and radionuclides) in the context of potential human exposure routes.

2.5 Ecosystem establishment

2.5.1 Development and agreement of closure criteria from ecosystem establishment perspective

Closure criteria need to be established for a range of ecosystem components including surface water quality, flora and fauna. The environmental requirements provide some guidance but characterisation of the analogue ecosystems will be an important step in the process. Consultation on closure criteria with the traditional owners has commenced and it is important that this process continues as more definitive criteria are developed.

2.5.2 Characterisation of terrestrial and aquatic ecosystem types at analogue sites

Identification and characterisation of analogue ecosystems (target habitats) can assist in defining the rehabilitation objective and developing robust, measurable and ecologically-based closure criteria. The concept of using analogue ecosystems for this purpose has been accepted by ARRTC and the traditional owners. Substantial work has been undertaken on the Georgetown terrestrial analogue ecosystem while there is also a large body of information available on aquatic analogues, including streams and billabongs. Future work on the terrestrial analogue needs to address water and nutrient dynamics, while work on the aquatic analogue will include the development of strategies for restoration of degraded or removed natural waterbodies, Coonjimba and Djalkmara, on site.

2.5.3 Establishment and sustainability of ecosystems on mine landform

Research on how the landform, terrestrial and aquatic vegetation, fauna, fauna habitat, and surface hydrology pathways will be reconstructed to address the Environmental Requirements for rehabilitation of the disturbed areas at Ranger is essential. Trial rehabilitation research sites should be established that demonstrate an ability by the mine operator to be able to reconstruct terrestrial and aquatic ecosystems, even if this is at a relatively small scale. Rehabilitation establishment issues that need to be addressed include species selection; seed collection, germination and storage; direct seeding techniques; propagation of species for planting; fertiliser strategies and weathering properties of waste rock. Rehabilitation management issues requiring investigation include the stabilisation of the land surface to erosion by establishment of vegetation, return of fauna; the exclusion of weeds; fire management and the re-establishment of nutrient cycles. The sustainable establishment and efficiency of constructed wetland filters, reinstated waterbodies (e.g. Djalkmara Billabong) and reconstructed waterways also needs to be considered (see KKN 2.3.2).

2.5.4 Radiation exposure pathways associated with ecosystem re-establishment

Radionuclide uptake by terrestrial plants and animals on the rehabilitated ecosystem may have a profound influence on the potential utilisation of the land by the traditional owners. Significant work has been completed on aquatic pathways, particularly the role of freshwater mussels, and this now forms part of the annual monitoring programme. The focus is now on the terrestrial pathways and deriving concentration factors for bushtucker such as wallabies, fruits and yams. A project investigating the contemporary diet of traditional owners has commenced and needs to be completed. Models need to be developed that allow exposure pathways to be ranked for currently proposed and future identified land uses, so that identified potentially significant impacts via these pathways can be limited through appropriate design of the rehabilitation process.

2.6 Monitoring

2.6.1 Monitoring of the rehabilitated landform

A new management and monitoring regime for the rehabilitated Ranger landform needs to be developed and implemented. It needs to address all relevant aspects of the rehabilitated landform including ground and surface water quality, radiological issues, erosion, flora, fauna, weeds, and fire. The monitoring regime should address the key issues identified by the ecological risk assessment of the rehabilitation phase (KKN 2.7.1).

2.6.2 Off-site monitoring during and following rehabilitation

Building upon the programme developed and implemented for the operational phase of mining, a monitoring regime is also required to assess rehabilitation success with respect to protection of potentially impacted ecosystems and environmental values. This programme should address the dispersion of contaminants by surface water, ground water and via the atmosphere. The monitoring regime should address the key issues identified by the ecological risk assessment of the rehabilitation phase (KKN 2.7.1).

2.7 Risk assessment

2.7.1 Ecological risk assessments of the rehabilitation and post rehabilitation phases

In order to place potentially adverse on-site and off-site issues at Ranger during the rehabilitation phase within a risk management context, it is critical that a robust risk assessment framework be developed with stakeholders. The greatest risk is likely to occur in the transition to the rehabilitation phase, when active operational environmental management systems are being progressively replaced by passive management systems. A conceptual model of transport/exposure pathways should be developed for rehabilitation and post rehabilitation regimes and the model should recognise the potential that some environmental stressors from the mine site could affect the park and vice versa. Implicit in this process should be consideration of the effects of extreme events and climate change.

Conceptual modelling should be followed by a screening process to identify and prioritise key risks for further qualitative and/or quantitative assessments. The conceptual model should be linked to closure criteria and post-rehabilitation monitoring programmes, and be continually tested and improved. Where appropriate, risk assessments should be incorporated into decision making processes for the closure plan. Outputs and all uncertainties from this risk assessment process should be effectively communicated to stakeholders.

2.8 Stewardship

The concept of Stewardship (including ownership and caring for the land) is somewhat broader and applies to all phases of, in this case, uranium mining. In this context it is considered to be the post closure phase of management of the site, i.e. after relinquishment of the lease. If the rehabilitation phase is successful in meeting all objectives then this stewardship will effectively comprise an appropriate level of ongoing monitoring to confirm this. Should divergence from acceptable environmental outcomes be detected then some form of intervention is likely to be required. The nature, responsibility for, and duration of, the monitoring and any necessary intervention work remains to be determined.

3 Jabiluka

3.1 Monitoring

3.1.1 Monitoring during the care and maintenance phase

A monitoring regime for Jabiluka during the care and maintenance phase needs to be implemented and regularly reviewed. The monitoring programme (addressing chemical, biological, sedimentalogical and radiological issues) should be commensurate with the environmental risks posed by the site, but should also serve as a component of any programme to collect baseline data required before development such as meteorological and sediment load data.

3.2 Research

3.2.1 Research required prior to any development

A review of knowledge needs is required to assess minimum requirements in advance of any development. This review would include radiological data, the groundwater regime (permeabilities, aquifer connectivity etc.), hydrometeorological data, waste rock erosion, assess site-specific ecotoxicology for uranium, additional baseline for flora and fauna surveys.

4 Nabarlek

4.1 Success of revegetation

4.1.1 Revegetation assessment

Several assessments of the revegetation at Nabarlek have been undertaken; the most recent being completed by ***eriss***. There is now general agreement that the rehabilitated areas require further work. Revised closure criteria are currently being developed through the mine-site technical committee and these should be reviewed by relevant stakeholders, including ARRTC. The required works should then be completed on site with further monitoring leading to the relinquishment of the lease.

4.1.2 Development of revegetation monitoring method

A methodology and monitoring regime for the assessment of revegetation success at Nabarlek needs to be developed and implemented. Currently, resource intensive detailed vegetation and soil characterisation assessments along transects located randomly within characteristic areas of the rehabilitated landform are being undertaken. Whilst statistically valid, these assessments cover only a very small proportion of the site. Remote sensing (satellite) data are also being collected and the efficacy of remote sensing techniques for vegetation assessment in comparison to ground survey methods should continue. The outcomes of this research will be very relevant to Ranger.

4.2 Assessment of radiological, chemical and geomorphic success of rehabilitation

4.2.1 Overall assessment of rehabilitation success at Nabarlek

The current programme on erosion, surface water chemistry, groundwater chemistry and radiological issues should be continued to the extent required to carry out an overall assessment of the success of rehabilitation at Nabarlek. In particular, all significant radiological exposure pathways should be identified and a comprehensive radiation dose model developed. Additional monitoring of ground water plumes is required to allow assessment of potential future groundwater surface water interaction and possible environmental effects.

5 General Alligator Rivers Region

5.1 Landscape scale analysis of impact

5.1.1 Develop a landscape-scale ecological risk assessment framework for the Magela catchment that incorporates, and places into context, uranium mining activities and relevant regional landscape processes and threats, and that builds on previous work for the Magela floodplain

Ecological risks associated with uranium mining activities in the ARR, such as current operations (Ranger) and rehabilitation (Nabarlek, Jabiluka, future Ranger, South Alligator Valley), should be assessed within a landscape analysis framework to provide context in relation to more diffuse threats associated with large-scale ecological disturbances, such as invasive species, unmanaged fire, cyclones and climate change. Most key landscape processes occur at regional scales, however the focus will be on the Magela catchment encompassing the RPA. A conceptual model should first be developed to capture links and interactions between multiple risks and assets at multiple scales within the Magela catchment, with risks associated with Ranger mining activities made explicit. The spatially explicit Relative Risk Model will be used to prioritise multiple risks for further qualitative and/or quantitative assessments. The conceptual model and risk assessment framework should be continually tested and improved as part of Best Practice. Where appropriate, risk assessments should be incorporated into decision making processes using advanced risk assessment frameworks such as Bayesian Networks, and all uncertainties made explicit. This risk assessment process should integrate outputs from KKN 1.2.1 (risks from the surface water pathway – Ranger current operations) and the new KKN 2.6.1 (risks associated with rehabilitation) to provide a landscape-scale context for the rehabilitation of Ranger into Kakadu National Park, and should be communicated to stakeholders.

5.2 South Alligator River valley rehabilitation

5.2.1 Assessment of past mining and milling sites in the South Alligator River valley

SSD conducts regular assessments of the status of mine sites in the SAR valley, provides advice to Parks Australia on technical issues associated with its rehabilitation programme and conducts a low level radiological monitoring programme. This work should continue.

5.3 Develop monitoring programme related to West Arnhem Land exploration activities

5.3.1 Baseline studies for biological assessment in West Arnhem Land

ARRTC believes there is a need to determine a baseline for (a) rare, threatened and endemic biota and (b) indicator species or groups such as macroinvertebrates in areas where advanced exploration or proposed mining projects are identified and in line with the current approvals process under the *Aboriginal Land Rights (Northern Territory) Act 1976.*

5.4 Koongarra

5.4.1 Baseline monitoring programme for Koongarra

In line with the current approvals process under the *Aboriginal Land Rights (Northern Territory) Act 1976* a low level monitoring programme should be developed for Koongarra to provide baseline data in advance of any possible future development at the site. Data from this programme could also have some relevance as a control system for comparison to Ranger, Jabiluka and Nabarlek.

Note: The Koongarra Project Area was added to the Kakadu World Heritage Area by the World Heritage Committee on 27 June 2011, and this KKN will need to be revisited pending the possible re-incorporation of the area into Kakadu National Park.

Appendix 2 Publications for 2013–14

Bollhöfer A, Beraldo A, Pfitzner K, Esparon A & Doering C 2014. Determining a pre-mining radiological baseline from historic airborne gamma surveys: A case study. *Science of the Total Environment* 468–469, 764–773.

Bollhöfer A, Schlosser C, Ross JO, Sartorius H & Schmid S 2014. Variability of atmospheric Kr-85 activity concentrations observed close to the ITCZ in the Southern Hemisphere. *Journal of Environmental Radioactivity* 127, 111–118.

Boyden J, Joyce K, Boggs G & Wurm P 2013. Object-based mapping of native vegetation and para grass (*Urochloa mutica*) on a monsoonal wetland of Kakadu NP using a Landsat 5 TM Dry-season time series. *Journal of Spatial Science* 58(1), 53–77.

Doering C & Saey P 2014. Hadley cell influence on 7Be activity concentrations at Australian mainland IMS radionuclide particulate stations. *Journal of Environmental Radioactivity* 127, 88–94.

Erskine WD 2013. Synchronous linked changes in rainfall, floods and river channel changes in south eastern Australia since European settlement. In: E Boegh, E Blyth, DM Hannah, H Hisdal, H Kuntsmann, B Su and KK Yilmaz (eds.), Climate and Land Surface Changes in Hydrology. *International Association of Hydrological Sciences*, Wallingford, Publ. No. 359, 30–37.

Erskine WD 2013. Flood-tidal and fluvial deltas of Tuggerah Lakes, Australia: Human impacts on geomorphology, sedimentology, hydrodynamics and seagrasses. In: G Young and G Perillo (eds.), Deltas: Landforms, Ecosystems and Human Activities. *International Association of Hydrological Sciences*, Wallingford, Publ. No. 358, 159–167.

Erskine WD 2013. The role of overbank deposition in floodplain formation and catastrophic floods in floodplain destruction in south eastern Australia. In: EH Alcantara (ed.) Floodplains Environmental Management, *Restoration and Ecological Implications*. Nova Science, New York, 181–210.

Erskine WD & Borgert R 2013. Geomorphology and sedimentology of the Mogo Creek fluvial delta, NSW, Australia. In: G Young and G Perillo (eds), Deltas: Landforms, Ecosystems and Human Activities. *International Association of Hydrological Sciences*, Wallingford, Publ. No. 358, 218–225.

Erskine F, Chalmers A & Erskine W 2013. Survival of *Casuarina cunninghamiana* on a recovering sand-bed stream in the Wollombi Valley of New South Wales. *Cunninghamia* 13, 295–304.

Erskine WD & Saynor MJ 2013. Hydrology and bedload transport relationships for sand-bed streams in the Ngarradj Creek catchment, northern Australia. *Journal of Hydrology* 483, 68–79.

Hahn T, Diamond J, Dobson S, Howe P, Kielhorn J, Koennecker G, Lee-Steere C, Mangelsdorf I, Schneider U, Sugaya Y, Taylor K, van Dam R & Stauber J 2013. Predicted no effect concentration (PNEC) derivation as a significant source of variability in environmental hazard assessments of chemicals in aquatic systems: An international analysis. *Integrated Environmental Assessment and Management* 10(1), 30–36.

Hancock GR, Willgoose GR, Lowry J 2013 Transient landscapes: gully development and evolution using a landscape evolution model. *Stochastic Environmental Research and Risk Assessment* 28(1), 83–98.

Harford AJ, DR Jones & van Dam RA 2013. Highly treated mine waters may require major ion addition before environmental release. *Science of the Total Environment* 443, 143–151.

Harford AJ, Hogan AC, Jones DR & van Dam RA (in press). Ecotoxicology of actively treated mine waters. *Mine Water and the Environment.*

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APPENDIX 3 PRESENTATIONS TO CONFERENCES AND SYMPOSIA, 2013–14[15]

Chandler L, Humphrey C & George A 2014. Examination of sampling processing methods for macroinvertebrate community monitoring in tropical shallow billabongs. Paper presented at ASFB & ASL Congress, 30 June–3 July 2014, Darwin Australia.

Cheng K, Harford AJ & van Dam RA 2013. Effect of manganese on tropical freshwater species. Paper presented at 3rd SETAC – Australasia Conference, 1–3 Oct 2013, Melbourne Australia.

George A & Humphrey C 2013. Developing turbidity closure criteria for receiving surface waters at Ranger minesite. Paper presented at 52nd Annual Congress of Australian Society for Limnology, 2–5 Dec 2013, Canberra Australia.

George A, Bartolo R, Humphrey C & Harford A 2014. Defining ecosystem processes for rehabilitation of Ranger uranium mine (NT). Paper presented at ASFB & ASL Congress, 30 June–3 July 2014, Darwin Australia.

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Humphrey C & Ellis M 2014. Toxicity monitoring of water quality using the freshwater snail, *Amerianna cumingi*: Investigative studies used to improve annual interpretation of wet season results. Paper presented at ASFB & ASL Congress, 30 June–3 July 2014, Darwin Australia.

Humphrey C 2013. Training presentations at Water quality and the environment: Master class, Australian Water Association, 4–5 September 2013, Perth WA (Names of co-authors and other contributors to individual presentations available on request.).

Lowry J, Hancock G & Coulthard T 2014. Using the *CAESAR-Lisflood* and SIBERIA landform evolution models to assess the evolution of a post-mining landscape at millennial time scales. Paper presented at European Geosciences Union General Assembly 2014, 27 April – 2 May 2014, Vienna Austria.

Medley P 2014. Optimising a method for low-level analysis of 210Pb via Liquid Scintillation Counting. Paper presented at the 17th Radiochemical Conference, 11–16 May, Mariánské Lázně, Czech Republic.

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15 Presentations to conferences and symposia that have been externally published in 2012–13 are included in Appendix 2, Published.

Sinclair A, Tayler K, van Dam R & Hogan A 2013. From leading practice technology to regulation – the development of a framework for regulating short-term pulse exposures to mine water. Paper presented at 12th Australia Institute of Mining and Metallurgy (AUSIMM) International Uranium conference, 11–12 June 2013, Darwin Australia.

Trenfield MA, van Dam J, Streten-Joyce C, van Dam RA, Harford AJ, Gibb K & Parry DL 2013. Aluminium toxicity to the tropical algae *Isochrysis galbana*. Paper presented at 3rd SETAC – Australasia Conference, 1–3 Oct 2013, Melbourne Australia.

van Dam RA, Harford AJ & Hogan AC 2013. Revision of the national and Magela Creek site-specific freshwater quality trigger values for uranium. Paper presented at 3rd SETAC – Australasia Conference, 1–3 Oct 2013, Melbourne Australia.

Whiteside T & Bartolo R 2014. Object-based analysis of interannual variation within RAMSAR wetlands using time-series WorldView-2 multispectral imagery. Paper presented at GEOBIA 2014: 5th International Conference of Geographic Object -based Image Analysis, 21–24 May 2014,Thessaloniki, Greece.

Whiteside T, Bartolo, R, Erskine, P & Fletcher, A 2014. Object-based characterisation of reference sites for mine site closure using hyperspatial multispectral UAV imagery. Paper presented at GEOBIA 2014: 5th International Conference of Geographic Object-based Image Analysis, 21–24 May 2014,Thessaloniki, Greece.

APPENDIX 4 LIST OF *eriss* RESEARCH PROJECTS, 2013–14

Project Code	Project Title	Work group*
Completed		
RES-2000-003	Radiological assessment of the South Alligator River Valley	EnRad
RES-2008-001	Characterisation of contamination at Land Application Areas at Ranger uranium mine	EnRad
RES-2012-001	Effect of manganese on tropical freshwater species	Ecotox
RES-2012-004	Model geomorphic stability of Ranger Pit 1 landform	HGCP
RES-2012-012	Ranger Rehabilitation & Closure Ecological Risk Assessment: Phase 1, problem formulation	RLE
RES-2012-015	The effect of multiple magnesium pulses on tropical freshwater species with an emphasis on recovery and carry over toxicity	Ecotox
Continuing		
RES-1996-002	Radionuclide uptake in traditional aboriginal foods	EnRad
RES-2005-002	Development of surface water quality (solutes) closure criteria for Ranger billabongs using macroinvertebrate community data	AEP
RES-2005-003	Use of analogue plant communities as a guide to revegetation and associated monitoring of the post-mine landform at Ranger	AEP
RES-2006-003	Assessing the impact of extreme rainfall events on the geomorphic stability of the rehabilitated Ranger landform using the CAESAR landscape evolution model	HGCP
RES-2007-002	Loads of suspended sediment, metals and radionuclides in Magela and Gulungul creeks	HGCP
RES-2007-004	Assessing landslips in the Upper Magela Catchment	HGCP
RES-2008-002	Development and implementation of a remote sensing framework for environmental monitoring within the Alligator Rivers Region (focus on the Magela Floodplain)	RLE
RES-2009-002	The toxicity of uranium (U) to sediment biota of Magela Creek backflow billabong environments	Ecotox
RES-2009-003	Effects of fine suspended sediment on billabong limnology (development of turbidity closure criteria)	AEP
RES-2009-004	Radon exhalation from the Ranger uranium mine trial landform	EnRad

RES-2009-009	Geological provenance of fine suspended sediment within the Magela Creek catchment	RLE
RES-2009-011	Ranger trial landform erosion and chemistry studies	HGCP
RES-2010-007	Assessing the geomorphic stability of the Ranger trial landform	HGCP
RES-2012-002	Dose rates to non-human biota	EnRad
RES-2012-003	Toxicity of ammonia in Magela Creek water	Ecotox
RES-2012-008	Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine	EnRad
RES-2012-011	Magela Creek floodplain vegetation mapping	RLE
RES-2012-013	Toxicity monitoring research in Magela and Gulungul creeks	AEP
RES-2012-014	The sensitivity of *Moinodaphnia macleayi* to uranium	Ecotox
Commenced		
RES-2007-005	Development of a spectral library for mine site rehabilitation assessment-vegetation components (Re-activated after being suspended)	RLE
RES-2013-002	Analysis of landscape change on the Ranger site pre-mining using historical aerial photography	RLE
MON-2013-006	El Sherana containment radiological monitoring	EnRad
RES-2013-009	Radionuclide fluxes in runoff from the trial landform	EnRad
RES-2013-010	Aquatic ecosystem knowledge assessment and evaluation	AEP
RES-2013-011	Ranger Rehabilitation & Closure Ecological Risk Assessment: Phase 2, Risk Analysis	RLE
RES-2013-012	Demonstrating the utility of unmanned aerial vehicles (UAVs) for monitoring rehabilitation and revegetation of the Ranger mine site	RLE
RES-2013-013	Ecotoxicological assessment of distillate from the Ranger uranium mine brine concentrator plant	Ecotox
RES-2013-017	Development of a method for continuous monitoring of vegetation regrowth on a rehabilitated minesite using a simple LED spectroradiometer	RLE
RES-2014-001	Effects of uranium on the structure and function bacterial sediment communities	Ecotox
RES-2014-002	Vegetation analogue review project	RLE

RES-2014-003	Developing monitoring methods using a UAS: Jabiluka and Magela B LAA revegetation	RLE
RES-2014-004	Atmospheric dispersion of radon and radon daughters from the rehabilitated landform	EnRad
RES-2014-006	East Alligator Slackwater deposits	HGCP

* AEP: Aquatic Ecosystems Protection; Ecotox: Ecotoxicology; EnRad: Environmental Radioactivity; PCP: Physico-chemical Processes; SSDI: Spatial Sciences and Data Integration.

Glossary of terms, abbreviations and acronyms

ADG	Australian Dangerous Goods
AEC	Animal Ethics Committee
AIMS	Australian Institute of Marine Science
application	A document stating how the mining operator proposes to change the conditions set out in the mining Authorisation. These changes need to be approved by all MTC stakeholders.
AREVA	AREVA, France – (formerly - Afmeco Mining and Exploration Pty Ltd)
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARR	Alligator Rivers Region
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
authorisation	For mining activities authorisation is required under the Northern Territory *Mining Management Act* (MMA*)* for activities that will result in substantial disturbance of the ground. It details the authorised operations of a mine, based on the submitted mining management plan and any other conditions that the Northern Territory Minister considers appropriate.
becquerel (Bq)	SI unit for the activity of a radioactive substance in decays per second [s^{-1}].
bioaccumulation	Occurs when the rate of uptake by biota of a chemical substance, such as metals, radionuclides or pesticides is greater than the rate of loss. These substances may be taken up directly, or indirectly, through consumption of food containing the chemicals.
biodiversity (biological diversity)	The variety of life forms, including plants, animals and micro-organisms, the genes they contain and the ecosystems and ecological processes of which they are a part.
biological assessment	Use and measurement of the biota to monitor and assess the ecological health of an ecosystem.
BoM	Bureau of Meteorology
closure criteria	Performance measures used to assess the success of minesite rehabilitation.
concentration factor	The metal or radionuclide activity concentration measured in biota divided by the respective concentration measured in the underlying soil (for terrestrial biota) or water (for aquatic biota).

CCWLF	Corridor Creek Wetland Filter
CDU	Charles Darwin University
DME	Northern Territory Department of Mines and Energy (formerly Northern Territory Department of Resources)
DoE	Department of the Environment
DoI	Department of Industry
dose coefficient	The committed tissue equivalent dose or committed effective dose Sievert [Sv] per unit intake Becquerel [Bq] of a radionuclide. See definition of Sievert and Becquerel.
dose constraint	The International Commission on Radiation Protection (ICRP) defines dose constraint as '*a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation*' for assessing site remediation options.
DRET	Department of Resources, Energy and Tourism
early detection	Measurable early warning biological, physical or chemical response in relation to a particular stress, prior to significant adverse effects occurring on the system of interest.
electrical conductivity (EC)	A measure of the total concentration of salts dissolved in water.
EIRs	Environmental Incident Report summary
EIS	Environmental Impact Statement
EMRAS	Environmental Modelling for Radiation Safety
EMS	Environmental Management System
ERA	Energy Resources of Australia Ltd
eriss	Environmental Research Institute of the Supervising Scientist
ERs	Environmental Requirements
ERMP	Environmental Review Management Programme
FASTS	Federation of Australian Scientific and Technological Societies
FORUM	Fostering Radioecology by Uniting Members
fulvic acid	A component of dissolved organic carbon that is especially reactive and forms strong complexes with metals. Fulvic acids account for a large part of the dissolved organic matter in natural water.
GAC	Gundjeihmi Aboriginal Corporation

GC2	Georgetown Creek 2 (ERA monitoring site)
GCDS	Gulungul Creek Downstream (downstream monitoring site)
GCLB	Gulungul Creek left bank
GCT2	Gulungul Creek Tributary 2
GCUS	Gulungul Creek Upstream (upstream monitoring site)
GHS	Globally Harmonised System
grab sampling	Collection of a discrete water sample for chemical analysis
gray (Gy)	Name for absorbed dose 1 Gray = 1 Joule·kg^{-1}. The absorbed dose gives a measure for the energy imparted by ionising radiation to the mass of the matter contained in a given volume element.
GHS	Globally Harmonised System
GTB	Georgetown Billabong
half-life	Time required to reduce by one-half the concentration (or activity in the case of a radionuclide) of a material in a medium (e.g. soil or water) or organism (e.g. fish tissue) by transport, degradation or transformation.
HSR	Health and Safety Representative
IAEA	International Atomic Energy Agency
IC50	The concentration of a compound that causes a 50% inhibition in a particular response (e.g. growth, reproduction) of an organism relative to that of a control organism (i.e. an organism not exposed to the compound).
ICP-MS	Inductively coupled plasma mass spectrometry
ICRP	International Commission on Radiological Protection
ionising radiation	Sub-atomic particles (α, β) or electromagnetic (γ, x-rays) radiation that have enough energy to knock out an electron from the electron shell of molecules or atoms, thereby ionising them.
IMDG	International Maritime Dangerous Goods
in situ	a Latin phrase that translates to ‘on site’
ISWWG	Independent Surface Water Working Group
IT	Information Technology
IWMP	Interim Water Management Pond
JFS	Jabiru Field Station

JMB	Joint Management Branch
KKN	Key Knowledge Needs
KNP	Kakadu National Park
KRAC	Kakadu Research Advisory Committee
LAA	Land Application Area
land application	A method for management of excess accumulated water by spray irrigation. The method depends on the evaporation from spray droplets, and from vegetation and ground surfaces once it reaches them.
laterite	In the Ranger mine context, laterite is a local term used to describe well weathered rock and soil profile material that consists primarily of a mixture of sand and silt/clay size particles. It may or may not exhibit characteristics of a fully-developed laterite profile.
LC50	The concentration of a compound that causes the death of 50% of a group of organisms relative to that of a control group of organisms (i.e. a group of organisms not exposed to the compound).
LLAA	Long-lived alpha activity
LNG	Liquefied Natural Gas
MCDW	Magela Creek Downstream West (downstream monitoring site)
MCUGT	Magela Creek Upstream Georgetown (upstream monitoring site)
MODARIA	Modelling and Data for Radiological Impact Assessment
MOL	Maximum Operating Level. The maximum level at which a liquid containing impoundment can be operated.
MMP	Mining Management Plan
MNES	Matters of National Environmental Significance
mRL	Reduced Level metres
MTC	Minesite Technical Committee
near Infrared	0.7 to 1.3 µm
NERP	National Environmental Research Program
NGO	Non-government Organisation
NLC	Northern Land Council
NPA	National Partnership Agreement

NRETAS	(formerly Department of Natural Resources, Environment, the Arts and Sport)
NT	Northern Territory
NTU	Nephelometric Turbidity Units
ore	A type of rock that bears minerals, or metals, which can be extracted.
oss	Office of the Supervising Scientist
PAEC	Potential alpha energy concentration
permeate	The higher purity stream produced by passage of water through a reverse osmosis (RO) treatment process.
pH	a measure of the acidity or basicity of an aqueous solution
polished	Water that has been passed through a wetland filter.
polonium (Po)	A radioactive chemical element that is found in trace amounts in uranium ores.
pond water	Water derived from seepage and surface water runoff from mineralised rock stockpiles as well as runoff from the processing areas that are not part of the process water circuit.
process water	Water that has passed through the uranium extraction circuit, and all water that has come into contact with the circuit. It has a relatively high dissolved salt load constituting the most impacted water class on site.
RAA	Radiologically Anomalous Area. Area that displays significantly above background levels of radioactivity.
radionuclide	An atom with an unstable nucleus that loses its excess energy via radioactive decay. There are natural and artificial radionuclides. Natural radionuclides are those in the uranium (^{238}U), actinium (^{235}U) and thorium (^{232}Th) decay series for example, which are characteristic of the naturally occurring radioactive material in uranium orebodies.
radium (Ra)	A radioactive chemical element that is found in trace amounts in uranium ores.
RDP	Radon decay products
RJTWG	Rum Jungle Technical Working Group
RL	Relative Level. The number after RL denotes metres above or below a chosen datum (also known as Reduced Level)
RPA	Ranger Project Area
RPI	Routine Periodic Inspection

RP1	Retention Pond 1
RP2	Retention Pond 2
RP3	Retention Pond 3
RP6	Retention Pond 6
R3D	Ranger 3 Deeps
R&D	Research and Development
SAR	South Alligator River
SETAC	Society of Environmental Toxicology and Chemistry
sievert (Sv)	Unit for equivalent dose and effective dose 1 Sievert = 1 Joule·kg^{-1}. In contrast to the Gray, the Sievert takes into account both the type of radiation and the radiological sensitivities of the organs irradiated, by introducing dimensionless radiation and tissue weighting factors, respectively.
SPERA	South Pacific Environmental Radioactivity Association
SSD	Supervising Scientist Division
stable lead isotopes	Lead has four stable isotopes, three of which, ^{206}Pb, ^{207}Pb and ^{208}Pb, are end members of the natural uranium, actinium and thorium decay series, respectively. ^{204}Pb is primordial only.
tailings	A slurry of ground rock and process effluents left over once the target product, in this case uranium, has been extracted from mineralised ore.
TAN	Total Ammonia Nitrogen
TLD	Thermoluminescent dosimetry
toxicity monitoring	The means by which the toxicity of a chemical or other test material is determined in the field over time. The monitoring comprises field toxicity tests which are used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical).
trigger values	Concentrations (or loads) of the key performance indicators measured for an ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should ‘trigger’ some action, either further ecosystem specific investigations or implementation of management/remedial actions.
TSF	Tailings Storage Facility
UAS	Unmanned Aerial System
UEL	Uranium Equities Ltd

uranium oxide	An oxide of uranium which occurs naturally or is produced by a uranium extraction process. This is the product from the Ranger mine.
water treatment plant (WTP)	The process system that removes undesirable chemicals, materials, and biological contaminants from water thereby decreasing its ability to harm the environment.
WHS	Work Health and Safety
WHSC	Work Health and Safety Committee

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