Australian Government

Department of the Environment

Supervising Scientist

SUPERVISING SCIENTIST

Annual Report

2014-15

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Australian Government

Department of the Environment

Supervising Scientist

The Hon Greg Hunt MP
Minister for the Environment
Parliament House
CANBERRA ACT 2600

15 October 2015

Dear Minister

In accordance with subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* (the Act), I submit to you the thirty-sixth Annual Report of the Supervising Scientist on the operation of the Act during the period of 1 July 2014 to 30 June 2015.

Yours sincerely

Dr Diana Wright

Supervising Scientist

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Supervising Scientist Branch acknowledges the traditional owners of the lands on which we live and work, and their continuing connection to land, sea and community.

We pay our respects to them and their cultures and to their elders both past and present.

Photos (from top left): Supervision and assessment at the minesite; Late dry season unmanned aerial system (UAS) imagery of Winmurra Billabong; Isopod collected from a radiogenic spring by Aquatic Ecosystem Protection (AEP) programme staff during a 2014 macroinvertebrate survey; Jabiru Field Station employee Royce Namarnyilk in the field with a Leichhardt's grasshopper; Preliminary testing of the 'Swampfox' UAS in the field at Kakadu National Park; AEP programme staff on a qualitative macroinvertebrate survey in 2014; 2014 popnetting crew; Claire Costello from Supervising Scientist Branch Ecotoxicology programme counting water fleas in the lab.

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FOREWORD

Subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* (Cth) 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 Environment
- 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
- a statement of the cost of operations of Supervising Scientist Branch.

SUPERVISING SCIENTIST'S OVERVIEW

The work of the Supervising Scientist Branch over 2014–15 can be broken into two broad outcomes:

- Mine closure.
- Operational oversight and monitoring.

Achievement of these outcomes was complemented by the ongoing integration of the work of the Supervising Scientist Branch with the Science Division, within which the Branch is now located. This allowed increased technical collaboration on several fronts, including access to groundwater expertise within the Office of Water Science also located within the Science Division.

The great majority of the research work of ***eriss*** is now focussed toward the development of closure criteria for Ranger mine. Prioritisation of the research programme will be further refined through the pending completion of a detailed environmental risk assessment focussing on the decommissioning and closure period. This risk assessment will be used as the basis for the pending review of the Alligator Rivers Region Technical Committee Key Knowledge Needs and to ensure that the Supervising Scientist Branch's research programme remains relevant and focussed. The Alligator River Region Technical Committee met twice during 2014–15 and endorsed both the quality and priorities of the research programme.

Despite announcements made by Energy Resources of Australia and Rio Tinto in June 2015 stating that the Ranger 3 Deeps underground mine would not proceed, progress on the development of closure criteria, which is the responsibility of Energy Resources of Australia, has been slow. Despite this, significant rehabilitation milestones were achieved at Ranger mine during 2014–15. Most notably, in February 2015 deposition of mill tailings shifted from the Tailings Storage Facility to Pit 3 following the backfill of ~ 30 million tonnes of stockpiled material. This material provides a level base for tailings deposition in Pit 3 and will form the final repository for process water brines, the waste product from the Brine Concentrator. Capping of tailings within Pit 1 also progressed well during the 2014 dry season, with only a small area of tailings requiring capping during 2015 to complete the project.

The Supervising Scientist Branch has been and will continue to monitor Energy Resources of Australia's progress with site remediation activities and development of closure criteria and will take further action as required to ensure that adequate priority and resources are applied to these processes.

Whilst closure formed a key focus for the Supervising Scientist Branch during 2014–15, several significant operational issues arose. The Supervising Scientist's final report into the December 2013 Leach Tank Failure was released in August 2014 by Senator the Hon Simon Birmingham, Parliamentary Secretary to the Minister for the Environment. The report provided a comprehensive analysis of the effects of the incident on workers, people in the surrounding area, surface water, soil and groundwater both on and off the Ranger mine. The report concluded that the incident had not resulted in any detectable impact to human health or the off-site environment.

Monitoring conducted by Supervising Scientist Branch showed that water quality in Gulungul Creek continued to decline during the 2014–15 wet season with two electrical conductivity events during the latter part of the year exceeding associated trigger levels set for Magela Creek. Supervising Scientist Branch conducted significant additional monitoring work in response to these events to quantify possible environmental impacts. The preliminary findings of this work indicated that any detectible biological effect was unlikely, possibly due to the specific composition of the source waters. The Supervising Scientist will release a comprehensive report of the findings of this work at the end of 2015.

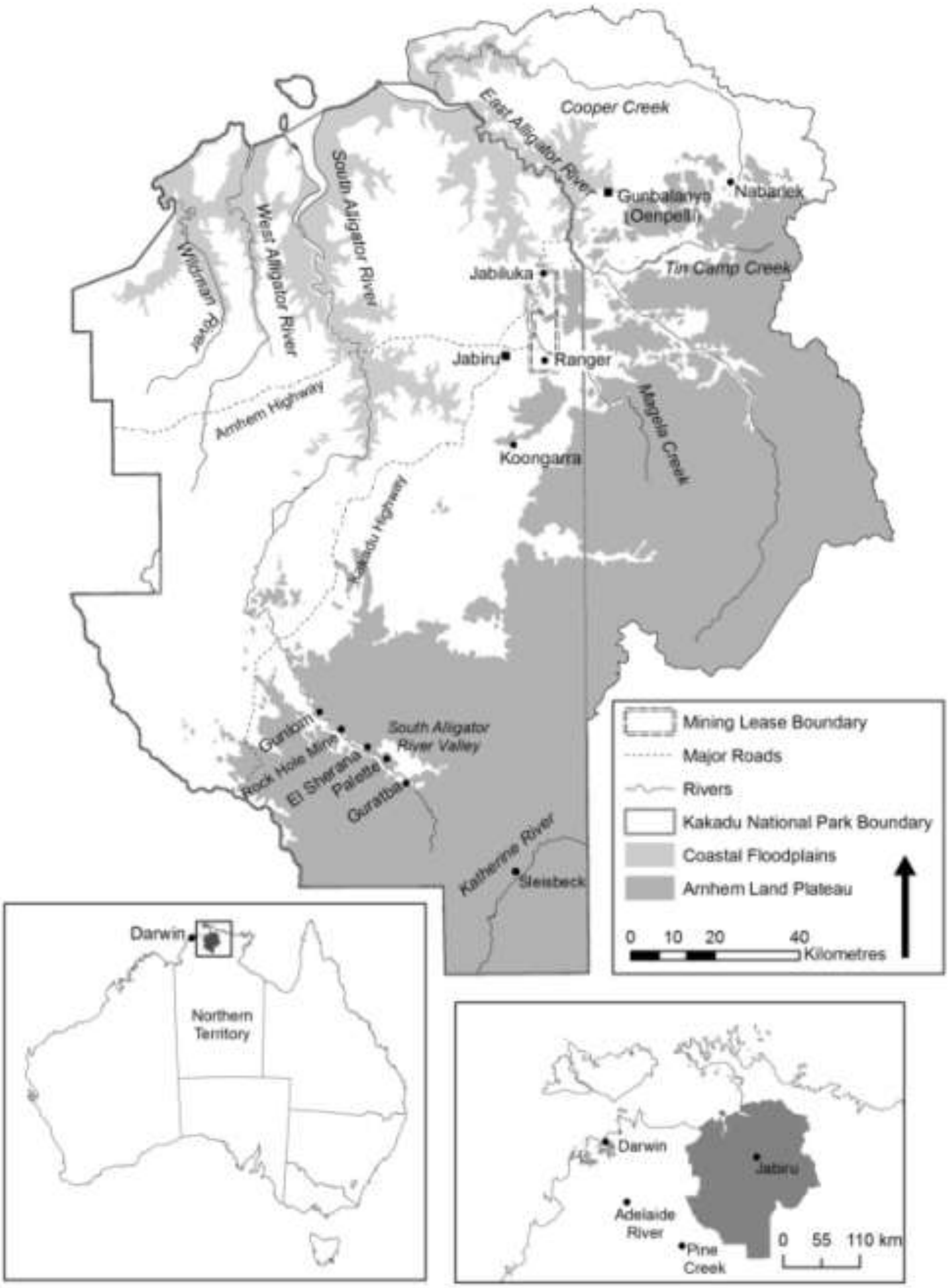
The source of the electrical conductivity was traced to Gulungul Creek Tributary 2, which arises adjacent to the north-western corner of the Ranger Tailings Storage Facility. Late in the 2014 dry season Energy Resources of Australia installed a seepage interception trench which prevented significant amounts of solute from entering the Gulungul Creek system, but it did not fully resolve the issue. More significant remediation work is planned for the area in 2015, and Supervising Scientist Branch will undertake additional monitoring and assessment activities during the 2015–16 wet season.

During 2014–15 Supervising Scientist Branch continued to fulfil its public assurance role through the provision of routine and investigative physico-chemical, radiological, and biological monitoring data. This information was provided via Supervising Scientist's Branch's website, to the biannual meetings of the Alligator Rivers Region Advisory Committee, at community events such as the Mahbilil festival and directly to the local indigenous people through a specialist community liaison officer. A second short movie recorded in the local Kunwinjku language addressing general safety concerns about radiation was also released. This movie was well received by the local people and has attracted attention nationally.

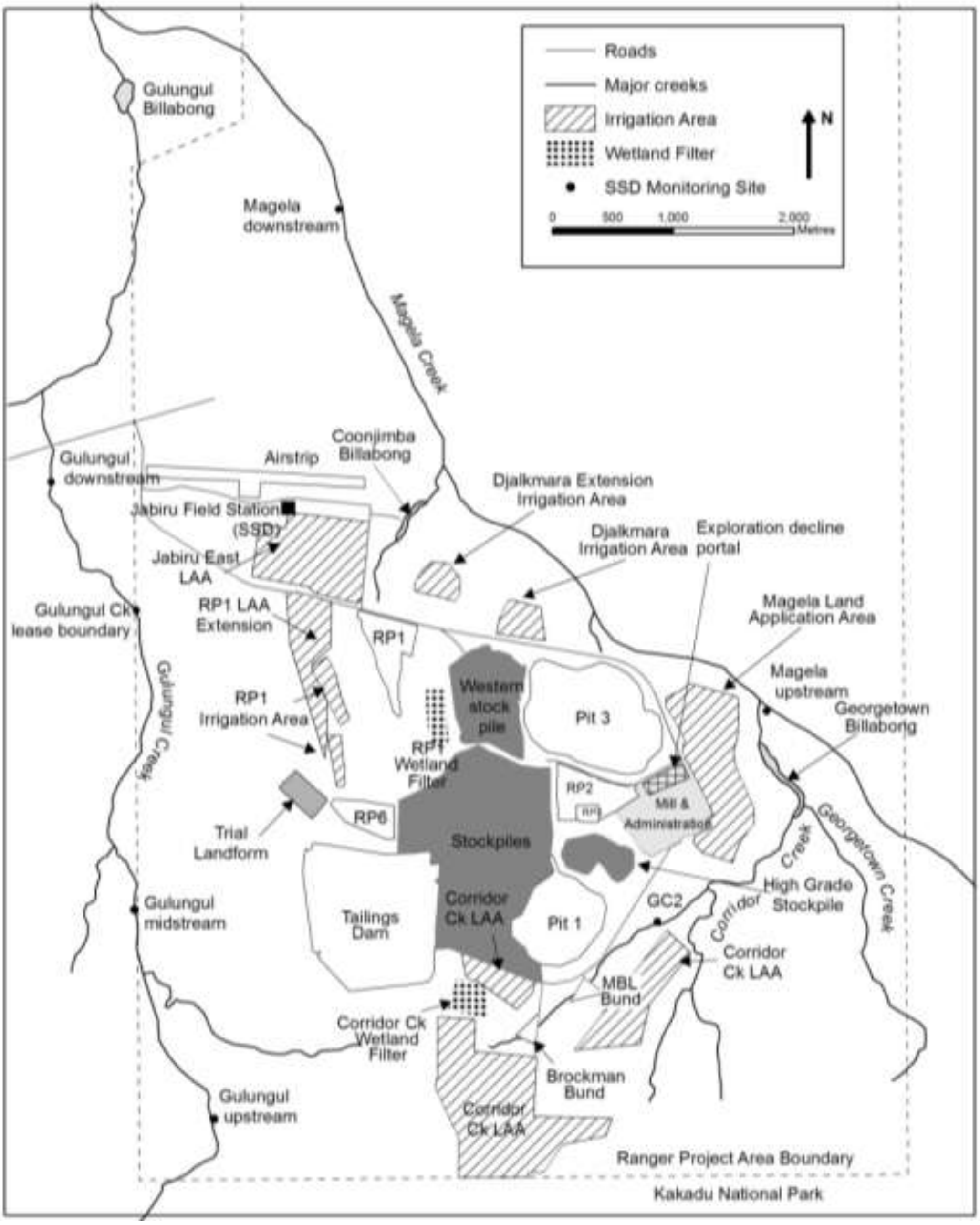
Supervising Scientist Branch has continued with a range of collaborative activities with external entities, including the long-term placement of two officers from Geoscience Australia, input into the United Nations International Atomic Energy Agency *Modelling and Data for Radiological Impact Assessments* (MODARIA) project and a leading role in the revision of the *Australia and New Zealand Guidelines for Fresh and Marine Water Quality*. Additionally, Supervising Scientist Branch has continued to provide technical advice on relevant *Environment Protection and Biodiversity Conservation Act 1999* assessments and maintain a close involvement in the Rum Jungle rehabilitation project. It was also very pleasing to see Supervising Scientist Branch's Swampfox unmanned aerial vehicle project awarded the Secretary for the Department of the Environment's People's Choice Innovation Award – which recognises and rewards innovation achievements within the Department.

I would like to extend my thanks to all the staff at Supervising Scientist Branch for their continued professionalism and enthusiasm. It is a testament to the dedication of the staff that Supervising Scientist Branch has continued to fulfil its role and maintain its reputation for scientific excellence and objective and independent oversight.

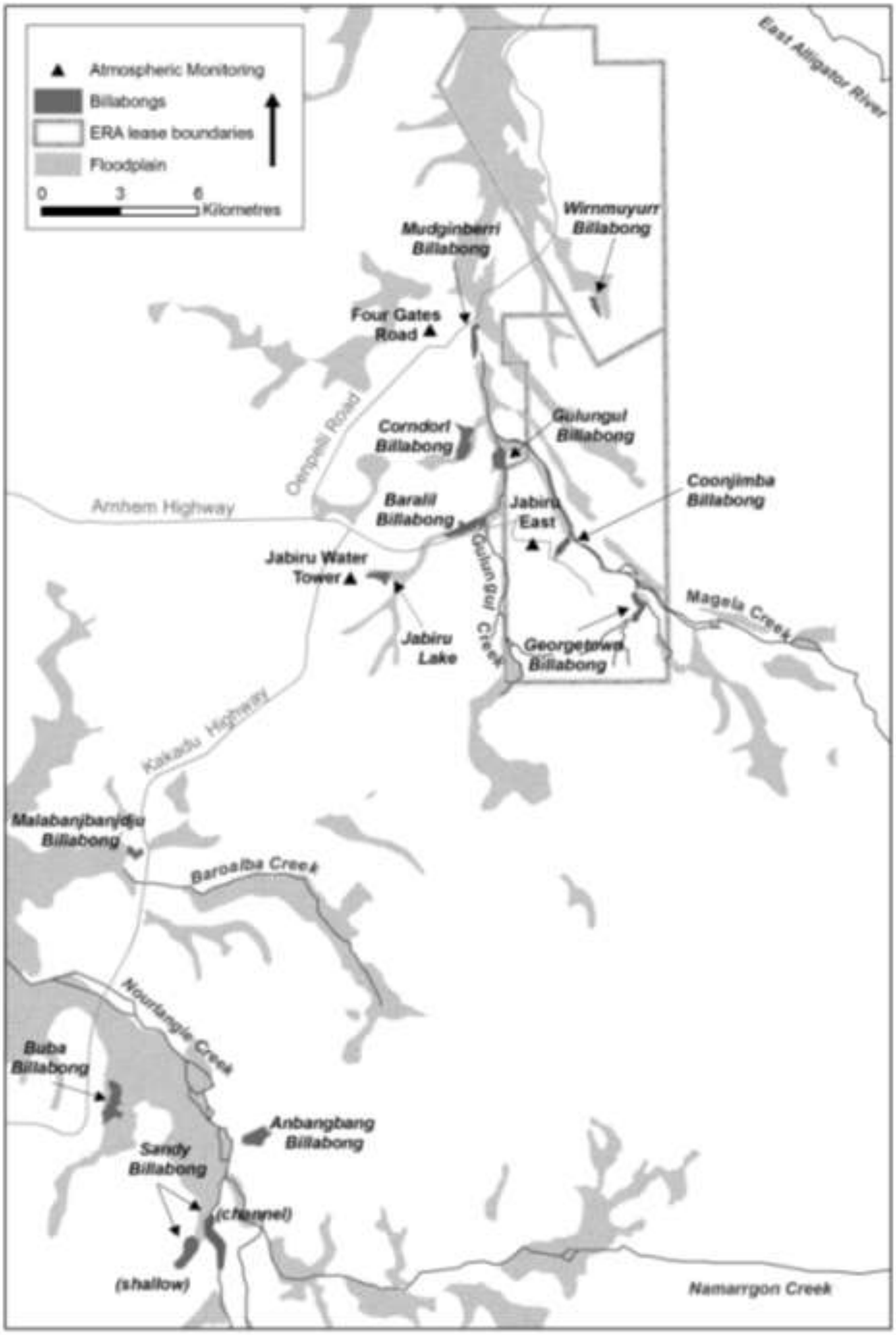
Richard McAllister
Supervising Scientist, 2014–15.



Map 1 Alligator Rivers Region



Map 2 Ranger minesite



Map 3 Location of waterbodies and atmospheric monitoring sites used in Supervising Scientist Branch's environmental research and monitoring programmes

1 INTRODUCTION

1.1 Role and function of Supervising Scientist

The position of the Supervising Scientist was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* 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 **Supervising Scientist Branch** in the Science Division of the Department of the Environment. The Supervising Scientist Branch comprises two parts.

- 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. ***oss*** also provides business and administrative support to Supervising Scientist.
- 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

Supervising Scientist Branch is funded under the Portfolio's departmental output appropriation and contributes to the delivery of Outcome 1: Clean Land:

> *Conserve, protect and sustainably manage Australia's biodiversity, ecosystems, environment and heritage through research, information management, supporting natural resource management, establishing and managing Commonwealth protected areas, and reducing and regulating the use of pollutants and hazardous substances.*

Outcome 1 is divided into six programmes. During the 2014–15 financial year, Supervising Scientist Branch contributed to Programme 1.5 Environmental Regulation. Further details on Supervising Scientist Branch activities during 2014–15 contributing to Programme 1.5 are provided in chapters 2, 3 and 5 of this 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 Supervising Scientist Branch. Of particular importance is the ongoing communication and consultation Supervising Scientist Branch undertakes with the Indigenous people living in the Alligator Rivers Region. Further details on Supervising Scientist Branch communications activities during 2014–15 are provided in chapter 6 of this report.

1.3 Business planning

Supervising Scientist Branch 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. Supervising Scientist Branch prepares an annual business plan that outlines the main goals and challenges 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 surrounded by, but separate from, 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 Alligator Rivers 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. Operations at Nabarlek ceased in 1988 and the site has been substantially 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 2021.

On 11 June 2015 ERA announced that the Ranger 3 Deeps underground mine project would not proceed. ERA stated this decision was based upon uncertainty in the short-term direction of the uranium market, and the economics of the project requiring operations to extend beyond the current Ranger Authority, which expires in 2021.

1.4.2 Jabiluka

The ERA owned Jabiluka mineral lease abuts the northern boundary of the Ranger Project Area. The Jabiluka minesite is situated 20 km north of the Ranger minesite.

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 which represents the area’s traditional Aboriginal 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 tonne 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 Supervising Scientist Branch.

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 southwest 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 lease area was incorporated into Kakadu National Park in 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, Sliesbeck, 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 tonnes 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.

During 2014–15, Supervising Scientist Branch continued to assist Parks Australia with technical advice related to the ongoing monitoring of these rehabilitated sites. Further details on the Branch’s involvement in this work are provided in chapter 3 of this report.

2 STATUTORY COMMITTEES

2.1 Introduction

During 2014–15, Supervising Scientist Branch provided secretariat and administrative support to two statutory committees established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978*: the Alligator Rivers Region Advisory Committee and the Alligator Rivers Region Technical Committee.

These committees play an important role in maintaining trust and facilitating dialogue and information exchange between relevant government, industry and community stakeholders in relation to arrangements for ensuring the ongoing protection of the Alligator Rivers Region environment, including Kakadu National Park, from uranium mining impacts.

2.2 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (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 the results of supervision, assessment and scientific research and monitoring activities undertaken by Supervising Scientist Branch is an important means of providing ongoing assurance to stakeholders and the broader community that the Alligator Rivers Region environment remains protected.

ARRAC comprises an independent Chairperson, Professor Charles Webb, and representatives from the following stakeholder organisations:

- Supervising Scientist Branch, Department of the Environment, Australian Government
- Parks Australia, Department of the Environment, Australian Government
- Australian Radiation Protection and Nuclear Safety Agency, Australian Government
- Department of Industry and Science, Australian Government
- Department of Mines and Energy, Northern Territory Government
- Environment Protection Authority, Northern Territory Government
- Department of Health, Northern Territory Government
- Office of the Administrator of the Northern Territory
- Energy Resources of Australia Ltd
- Cameco Australia Pty Ltd
- Uranium Equities Ltd
- AREVA

- Northern Land Council
- Gundjeihmi Aboriginal Corporation
- Environment Centre Northern Territory.

At each ARRAC meeting, Supervising Scientist Branch provides a detailed report covering the outcomes of audit and assessment activities and the results of water quality and other monitoring activities. Energy Resources of Australia Ltd also provides a report covering business operations, key minesite developments and the status of minesite rehabilitation activities. Reports from stakeholders on their respective activities during the reporting period are also provided.

ARRAC met twice during 2014–15: in Jabiru in September 2014 and in Darwin in April 2015. Key issues considered at these meetings included:

- the status of mine operations, planning and development at Ranger
- the results of Supervising Scientist Branch chemical, biological and radiological monitoring for Ranger and Jabiluka
- Supervising Scientist Branch 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.

ARRAC meeting minutes are available from the ARRAC website at:
environment.gov.au/supervising-scientist/communication/committees/arrac

2.3 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) plays an important role in ensuring the scientific research and monitoring conducted by ***eriss***, Energy Resources of Australia Ltd, Northern Territory Government agencies and others into the protection of the environment from the effects 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.

ARRTC is chaired by Dr Simon Barry, who is also the independent scientific member with expertise in ecological risk assessment, and includes:

- the Supervising Scientist
- a number of independent scientific members (including the Chair) with specific expertise nominated by Science and Technology Australia
- a member representing environment non-government organisations interests

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

ARRTC held two meetings in 2014–15: in November 2014 and May 2015. Key issues considered at these meetings included:

- current and proposed scientific research activities for ***eriss*** and ERA, in the context of the ARRTC Key Knowledge Needs
- outcomes of chemical, biological and radiological research and monitoring being undertaken by Supervising Scientist Branch, ERA and Northern Territory Department of Mines and Energy
- 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 relevant stakeholder organisations.

At its meeting in May 2015, ARRTC endorsed the proposed ***eriss*** scientific research programme for 2015–16. ARRTC also reviewed the status of, and preliminary outputs from, the current Ranger Rehabilitation/Closure Risk Assessment Project. The outcomes of this project are informing the ongoing revision of the ARRTC Key Knowledge Needs.

The ARRTC Key Knowledge Needs are included in Appendix 1 of this report.

ARRTC meeting minutes are available on the ARRTC website at: **environment**.gov.au/supervising-scientist/communication/committees/arrtc

3 ENVIRONMENTAL ASSESSMENTS OF URANIUM MINES

3.1 Supervision process

Supervising Scientist Branch 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. The outcomes of these activities are considered by Supervising Scientist Branch, 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 Branch 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), Supervising Scientist Branch, NLC, GAC and Energy Resources of Australia Ltd (ERA). Representatives from the Australian Government Department of Industry and Science 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, Supervising Scientist Branch and the relevant mining company (currently Uranium Equities Limited).

3.1.2 Audits and inspections

Supervising Scientist Branch, 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. Supervising Scientist Branch staff also participate in audits of exploration operations throughout the Alligator Rivers Region. The El Sherana Airstrip radiological containment facility at South Alligator Valley is also inspected at least annually by Supervising Scientist Branch in conjunction with Parks Australia.

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 Supervising Scientist Branch, DME, NLC and GAC.

Environmental audits are conducted by a team of qualified audit staff from Supervising Scientist Branch, 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 in the second quarter each year to assess the performance of each site against commitments taken from selected environmental management plans or approval documents. The final audit report is tabled at the following meeting of the Alligator Rivers Region Advisory Committee (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.

Audit Grading System

The grading system used for audits is shown in Table 3.1, and is the same as that used by DME for regulatory activities. Use of this ranking system ensures the outcomes of the Ranger auditing process are consistent with that for other mines in the Northern Territory.

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 2008*. The Act provides for alterations to the Authorisation to be issued by the Northern Territory Government.

TABLE 3.1 GRADING SYSTEM FOR MINE SITE AUDITS

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.

The Authorisations require that ERA seek approval for certain activities from the Northern Territory regulatory authority, through DME, which then considers applications after Supervising Scientist Branch, NLC and GAC have assessed the proposal and provided feedback. This provides the primary mechanism for Supervising Scientist Branch's participation in the regulatory processes of the Northern Territory Government. It is supported by section 34 of the Act which requires the Northern Territory Government to act in accordance with the advice of the Australian Government Minister for Industry on issues related to uranium mining.

3.1.4 Incident Investigation Process

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.

Immediately upon receipt of notification of any incident, Supervising Scientist Branch 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, the inspection team reviews the previous month's environmental incident report summary 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 RPI agenda.

3.2 Ranger

Mining in Pit 3 at Ranger ceased in November 2012, with backfill of the pit from the western stockpile commencing shortly thereafter. The mill produced 2044 tonnes of uranium oxide (U_3O_8) during 2014–15 from 2 370 000 tonnes of ore (Table 3.2). 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 3.3.

TABLE 3.2 RANGER PRODUCTION ACTIVITY FOR 2014–15 BY QUARTER 1

	1/07/2014 to 30/09/2014	1/10/2014 to 31/12/2014	1/01/2015 to 31/03/2015	1/04/2015 to 30/06/2015
Production (drummed tonnes of U3O8)	566	599	489	390
Ore treated ('000 tonnes)	646	586	614	524

[1]ERA data

TABLE 3.3 RANGER PRODUCTION ACTIVITY FOR 2010–11 TO 2014–15[1]

	2010–11	2011–12	2012–13	2013–14	2014–15
Production (drummed tonnes of U3O8)	2679	3282	4313	1113	2044
Ore treated (‘000 tonnes)	1305	2404	2487	1164	2370

[1]ERA data

3.2.1 Developments

Ranger 3 Deeps Underground Mine

On 16 January 2013, ERA submitted a referral under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) for the development of the Ranger 3 Deeps underground mine to be constructed on the site of the existing Ranger uranium mine. The Minister for the Environment determined that the proposal would be assessed at the Environmental Impact Statement (EIS) level on 13 March 2013, with EIS guidelines issued on 2 August 2013.

The proposal was determined to be a controlled action under the EPBC Act with the controlling provisions (EPBC Act sections) being:

- World Heritage properties (sections 12 & 15A)
- National Heritage places (sections 15B & 15C)
- Wetlands of international importance (sections 16 & 17B)
- Listed threatened species and communities (sections 18 & 18A)
- Listed migratory species (sections 20 & 20A)
- Protection of the environment from nuclear actions (sections 21 and 22A)
- Commonwealth land (sections 26 & 27A).

ERA lodged the draft EIS for comment on 6 October 2014 with the public comment period concluding on 12 December 2014.

On 11 June 2015 ERA announced that Ranger 3 Deeps project would not proceed. ERA stated this decision was based upon uncertainty in the uranium markets short-term direction and the economics of the project requiring operations to extend beyond the current Ranger Authority, which expires in 2021.

Following the announcement by ERA and also on 11 June 2015, Rio Tinto, the majority shareholder in ERA, released a media statement stating they did not support the future development of Ranger 3 Deeps due to the project’s economic challenges.

ERA commenced discussions with representatives of the Traditional Owners and the Commonwealth Government regarding a possible extension to the Ranger Authority. ERA stated it will engage with Rio Tinto to assess the implications of their position on the Ranger 3 Deeps Project.

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 Northern Territory Resources Minister in early September 2011, with construction of the exploration decline commencing on 1 May 2012.

In September 2014, ERA completed an exploration drilling programme from the decline and construction of the exploration decline was completed in December 2014 with the extraction of a 4000 tonne bulk sample of ore for future metallurgical test work. Testing of the ore sorter using this bulk sample was initially planned, however ERA has confirmed this will no longer occur. Both this bulk sample, and approximately 900 tonnes of mineralised material intersected during the drive development, are temporarily being stored on the surface in designated areas.

In total, the exploration decline is 2525 m long with an approximate depth of RL -400 m. The exploration decline is now in care and maintenance as ERA plans to use the decline as the primary mining access route should Ranger 3 Deeps proceed.

Pit 3 Tailings Deposition

Mining in Pit 3 was completed in November 2012 with backfill of the pit from the western stockpile commencing shortly thereafter. The preparation of Pit 3 to receive tailings was completed on 23 December 2014, including 31.2 million tonnes of rock backfill, the construction of a water relief drain and establishment of brine injection infrastructure in the waste rock floor.

Both Supervising Scientist Branch and DME commissioned independent subject matter experts to review the technical elements of the water relief drain to ensure it is suitable for the proposed drainage activities. A draft report was issued by Supervising Scientist Branch subject matter experts on 21 October 2014. While several concerns were raised in regards to the size of material used in the drain and the effectiveness of the drain to assist with consolidation of tailings, in general the drain was considered suitable for purpose from a design perspective.

On 2 September 2014, ERA submitted an assessment of environmental impacts from the deposition of tailings in Pit 3 to Ranger MTC stakeholders. Supervising Scientist Branch recommended that ERA provide additional information relating to flood mitigation and refinement of the Ranger groundwater monitoring programme to detect potential impacts from the conversion of Pit 3 to a process water catchment.

ERA was initially granted approval for the placement of tailings in Pit 3 in 2007. Following discussion at the Ranger MTC on 12 September 2014, ERA lodged a notification of intent to commence tailings deposition in Pit 3 on 23 January 2015. Following approval by DME on 29 January 2015, deposition of tailings from the processing plant to Pit 3 commenced on 8 February 2015.

ERA intends to commence injection of the brines produced from the brine concentrator into the waste rock floor of Pit 3 from the third quarter of 2015. Brines currently report to the Tailings Storage Facility (TSF).

As of 30 June 2015, 907 000 tonnes of processing tailings have been deposited in Pit 3.

Pit 1 Capping

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 7499 wicks installed in 2012 and accelerate the dewatering of the tailings. During the 2014 dry season, the preload rock placement and approximately 60 percent of the laterite cap was completed. ERA installed a bund prior to the 2014–15 wet season to separate the laterite capped and uncapped sections of the Pit 1 surface. This has resulted in approximately 65 percent of the pit being converted to a pond water catchment, with the remaining 35 percent continuing to report to the process water circuit.

Incident rainfall, and runoff from surrounding areas reporting to the laterite capped section of Pit 1, is managed as pond water while the surface water runoff from the sections still requiring capping continue to be treated as process water. ERA has installed a continuous electrical conductivity (EC) monitor with transfer to the pond water system stopped if the EC exceeds 4000 µS/cm.

TSF Dredging

The Environmental Requirements (ER's) for the Ranger uranium mine set out the Commonwealth's environmental protection conditions for the Authority issued under Section 41 of the *Atomic Energy Act 1953.* Section 11.2 of the ER's requires that by the end of operations all tailings must be placed in the mined out pits.

To achieve this requirement, ERA has developed a dredging project by which tailings currently stored in the above ground TSF will be transferred to the mined out Pit 3.

Commissioning of this dredge has three broad components:

- the development of a rockfill ramp into the TSF to allow the launch of the dredge
- the offsite construction and transportation of the dredge sections and support equipment to site
- assemblage onsite and launching of dredge.

Construction work on the TSF dredge ramp was completed in January 2015 with additional infrastructure, including a workshop, ablution block, office and refuelling station being constructed adjacent to the ramp.

The dredge components, including a support vessel and pontoon arrived on site in the second quarter of 2015 and are currently being assembled adjacent to the launch ramp.

It is anticipated that following launching, dredging activities to transfer tailings from the TSF to Pit 3 will commence in the second half of 2015.

GCT2 Interception System

During the 2013–14 wet season Supervising Scientist Branch detected elevated solute levels in Gulungul Creek as a result of inputs from Gulungul Creek Tributary 2 (GCT2). As a result, in November 2014, ERA installed a 300 m long seepage interception trench adjacent to the north-western wall of the Ranger tailings dam. The trench was excavated to competent rock and is of varying depth, down to approximately 4 m. Water collected in the trench is recovered via two wells and pumped to the adjacent Tailings West Wall Sump and from there transferred to the pond water system. To date the seepage interception trench has collected 58 ML of water. Electrical conductivity of the water collected from the trench has varied between approximately 3000 µS/cm and 7000 µS/cm.

Investigations to date, conducted by ERA, have indicated that the contamination is generally confined to the shallow aquifer system, and the poor quality surface water observed in GCT2 is a result of its surface expression. The exact composition of the seepage source has not been determined; but it is likely to be leachate from the waste rock within the wall of the tailings dam, with a potential contribution from tailings seepage.

Further EC events were observed in Gulungul Creek during the 2014–15 wet season (see section 3.2.3.1), and ERA has committed to the installation of additional remedial works in the GCT2 area during the 2015 dry season.

3.2.2 On-site environmental management

3.2.2.1 Water management

All water on site is managed in accordance with the Ranger Water Management Plan which is updated annually and subject to assessment by the MTC before approval. The 2014–15 Water Management Plan was submitted for approval by ERA on 17 October 2014. Comments were supplied by Supervising Scientist Branch on 24 November 2014 and the document was conditionally approved by DME on 23 December 2014 subject to ERA addressing comments raised. An updated plan addressing comments raised by stakeholders was submitted by ERA on 26 February 2015, with Supervising Scientist Branch supporting acceptance of this revised plan on 13 March 2015. 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 2014–15 wet season was a below average rainfall year with a total of 1143 mm recorded at Jabiru Airport to 30 June 2015 (annual average 1550 mm). Water management, especially that of process water, remains a critical issue at Ranger.

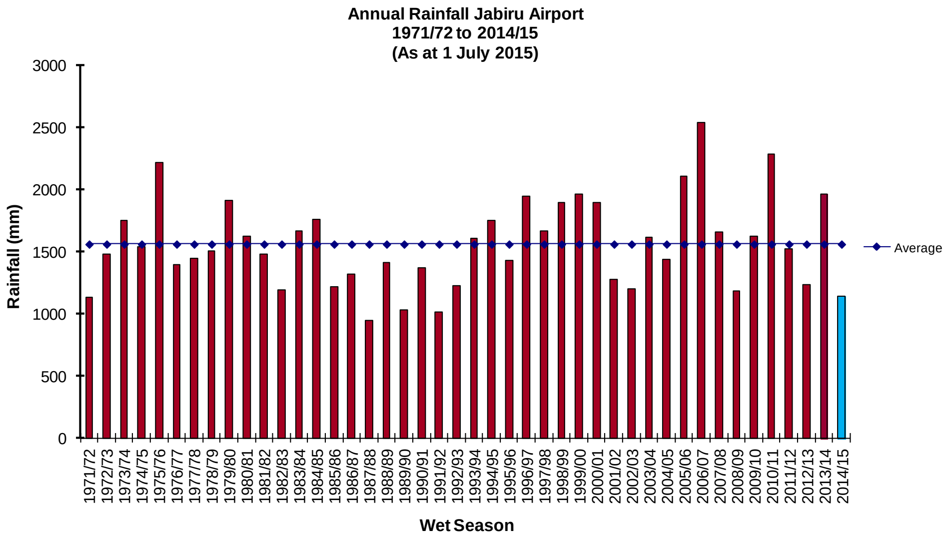


Figure 3.1 Annual rainfall Jabiru Airport 1971–72 to 2014–15 (data from Bureau of Meteorology).

Process water system

Under the Commonwealth ER's, 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 Supervising Scientist Branch. With the commencement of tailings deposition to Pit 3 during the reporting period (section 3.2.1), water contained within Pit 3 is now considered part of the process water inventory. Process water is currently stored in the TSF, Pit 3 and in the portion of Pit 1 yet to be capped.

As of 30 June 2015, the process water inventory was 8497 ML, contained primarily in the TSF and Pit 3 as shown in Table 3.4. This represents a decrease of 1164 ML over the previous year's total of 9661 ML due in a large part to the below average 2014–15 wet season and ongoing treatment of process water through the Brine Concentrator.

TABLE 3.4 RANGER PROCESS WATER INVENTORY[1]

Location	Volume (ML)
Pit 1	2
Pit 3	1924
TSF (Free water volume)	6571
TOTAL	**8497**

[1]ERA data

Process water treatment

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 which was commissioned in September 2013.

The brine concentrator has a nominal capacity to treat 1.83 GL of process water per year. Ecotoxicological testing on the distillate by ***eriss*** indicated it is of a very high quality, but potentially lacking in trace elements, with ammonia identified as the only toxicant of potential environmental significance.

Since commissioning in September 2013, a total of 1420 ML of distillate has been produced over 482 operational days, of which 848 ML of distillate has been produced over 258 operational days since 1 July 2014.

Treated distillate is discharged both to the Corridor Creek wetland filter or Retention Pond 1 (RP1) and, from there, released to Magela Creek during the wet season or to land application during the dry season.

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 2 (RP2), Retention Pond 3 (RP3), Retention Pond 6 (RP6) and the bunded section of Pit 1 that has been capped with laterite. ERA has previously committed that pond water will not be released without prior treatment through wetland filtration or the onsite microfiltration/reverse osmosis treatment plants.

As of 30 June 2015, 1045 ML was contained within the pond water system as shown in Table 3.5, representing a minor increase of 81 ML compared to the total of 964 ML stored at the same time last year. The decreased pond water inventory is primarily due to the transfer of Pit 3 from the pond to process water inventory since the last reporting period and the below average wet season rainfall.

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.

TABLE 3.5 RANGER POND WATER INVENTORY[1]

Location	Volume (ML)
Pit 1	0
RP2	381
RP3	22
RP6	642
TOTAL	**1045**

[1]ERA data

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 WTP were in operation during the reporting period. Volumes of water treated and permeate produced are reported in Table 3.6.

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

TABLE 3.6 RANGER POND WATER TREATMENT PLANT (WTP) VOLUMES[1]

WTP	Volume treated (ML)	Permeate produced (ML)
1	1014	656
2	1245	863
3	752	494

[1]ERA data

Offsite release of 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. 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 Georgetown Creek 2 (GC2) occurred throughout the 2014–15 wet season.

Active release water

Active discharge of pond quality water from the Ranger Project Area may occur from specific on site locations in accordance with regulatory approvals which describe both receiving water body flow conditions and the required quality of the release water. 3.7 details all active releases from the Ranger Project Area over the 2014–15 wet season.

ERA was again granted interim approval through the Water Management Plan for the discharge of RP1 water to Magela Creek from the MG001 site over the 2014–15 wet season. Discharge is managed to ensure EC within Magela Creek is maintained within the specified limits. Controlled discharge occurred on nine occasions between January 2015 and April 2015 during high flow conditions in Magela Creek. A total volume of approximately 171 ML of RP1 water was released via pumping to MG001.

On seven occasions between February 2015 and March 2015, during periods of higher flow in Magela Creek, a total of 283 ML of RP1 water was also discharged by active pumping over the RP1 weir to assist in reducing the overall pond water inventory.

ERA manually controls the discharge of runoff from areas adjacent to the Pit 3 rim via four sluice gates along the Ranger access road. A total of approximately 25 ML of water was released from these sluice gates on sixteen occasions during the 2014–15 wet season, commencing on 31 December 2014.

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.

TABLE 3.7 RANGER WATER RELEASES 2014-2015 WET SEASON[1]

Location	Volume (ML)
RP1 via CB (Sluice)	296
RP1 via CB (pump)	280
RP1 via MG001	171
R3ARC4	20
R3ARC3	5
TOTAL	**772**

[1]ERA data

TABLE 3.8 RANGER IRRIGATION VOLUMES BY LOCATION (ML)[1]

RP1 LAA	Djalkmarra LAA	Jabiru East LAA	RP1 Extension LAA	Corridor Creek LAA
117	51	298	59	564

[1]ERA data

All land application areas, other than the Magela land application area which was taken out of service for rehabilitation trials, were utilised during the 2014 dry season with a total volume of 1116 ML irrigated. Volumes of water disposed of to each irrigation area for the 2014 dry season are shown in Table 3.8.

3.2.2.2 Tailings and waste management

Tailings

Tailings from processing activities ceased reporting to the TSF and commenced reporting to Pit 3 from 6 February 2015 as part of the Tailings and Brine Management (TBM) project. As of 30 June 2015, 907 000 tonnes of tailings had been deposited in Pit 3 directly from processing activities. The TBM project is a subset of the larger Integrated Tailings, Water and Closure (ITWC) project, and includes the dredging and delivery of all tailings contained within the TSF to Pit 3 (Section 3.2.1).

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. During the 2014 dry season, the preload rock placement to activate dewatering wicks and approximately 60 percent of the laterite cap was completed as detailed in section 3.2.1.1.

Waste Management

ERA maintains a system for tracking, recording and reporting waste recycling and disposal. The primary mechanisms for disposal of non-mineral hazardous waste included disposal in Pit 1 by a dedicated tip head, incineration via turbo burning and offsite recycling. Non-hazardous wastes are disposed off either through disposal to landfill or offsite recycling.

3.2.2.3 Radiological exposure of employees

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)[1], 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.

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[1] 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.

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 five years with a maximum of 50 mSv in any one year).

Dose constraints

The ICRP (2006[2]) also 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; that is planned, emergency, or existing.

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 3.9.

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.

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

2014 Annual Worker Dose Summary

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 3.10 shows the annual doses received by designated and non-designated workers in 2014, and a comparison with the average doses from the year before as reported by ERA.

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[2] 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.

The average and maximum radiation doses received by designated workers in the 2014 calendar year were approximately 5 and 21 percent respectively of the recommended ICRP (2007[3]) annual dose limits.

All work groups received their greatest dose from the external gamma pathway. There was a reduction in total dose across all work groups in 2014 when compared to 2013. This reduction in total dose was attributed to a decrease in treated ore volumes, mill head grade, milling rates, extraction rates and recovery rates caused primarily by a lengthy plant shutdown following the Leach Tank failure in December 2013.

TABLE 3.9 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

TABLE 3.10 ANNUAL RADIATION DOSES RECEIVED BY WORKERS AT RANGER MINE

	Annual dose in 2013		*Annual dose in 2014*	
	Average mSv	**Maximum mSv**	**Average mSv**	**Maximum mSv**
Non-designated worker	Not calculated[1]	1.9	Not calculated[1]	2.0
Designated worker	1.4	6.5	1.0	4.1

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.

Overall, doses remain in line with historical results and low when compared to the limit of 20 mSv per annum. The designated worker average dose for the year was 1.0 mSv. This is a decrease over 2013 and remains consistent with doses since 2004. Doses prior to 2004 were in the range of 1.5 mSv to 5.2 mSv. The maximum dose in 2014 was 4.1 mSv which is lower than that observed in 2013.

Consistent with 2013 this maximum dose for 2014 belonged to a Processing Production Operator; 3.7 mSv was from gamma exposure, 0.29 mSv from RDP exposure and 0.4 mSv from dust exposure. In 2014 there was an increased contribution to the maximum dose from

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

RDP and dust exposure as Processing Production Operators were involved in critical non-routine tank descaling, clean-out and inspection activities that followed the Leach Tank failure.

3.2.3 Off-site environmental protection

3.2.3.1 Surface water quality

Under the Ranger 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 Ranger 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 (Supervising Scientist Branch, 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, Supervising Scientist Branch 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: **environment**.gov.au/science/supervising-scientist monitoring/index.html.

The highlights of the monitoring results from the 2014–15 wet season are summarised below.

Chemical and physical monitoring of Magela Creek

Magela Creek runs to the north west of the Ranger mine site. In order to minimise the volume of water contained on the mine site ERA is authorised to dispose of water by managed releases from Retention Pond 1, the former Djalkmara Billabong and Georgetown Creek. These releases are achieved either by passive overflow of weirs or pumping/siphoning directly into Magela Creek. The overflow from Retention Pond 1 enters Magela Creek via Coonjimba Billabong and the overflow from Georgetown Creek enters Magela Creek via Georgetown Billabong. To ensure the protection of the environment ERA is required to meet site specific Water Quality Objectives for Magela Creek. These objectives have been derived using either reference water quality or ecotoxicological data.

Flow was first recorded at the Magela Creek upstream and downstream monitoring sites on 27 December 2014 and continued until 28 May 2015. On 30 May 2015 an unusually late rainfall event occurred with 26 mm of rainfall recorded at Jabiru Airport. This resulted in recommencement of flow in Magela Creek until 15 June 2015.

Continuous monitoring of EC, turbidity, water level and pH was undertaken for the duration of flow in the creek, as shown in Figure 3.2. Electrical conductivity in Magela Creek remained below the 42 µS/cm Limit for the duration of flow. On the occasions when turbidity and pH exceeded their respective guidelines, the exceedances were observed at both the upstream and downstream sites indicating that these events were due to natural catchment sources rather than mine site influence.

Water samples from routine QAQC monitoring and event-based sampling were analysed for uranium, manganese, magnesium and sulfate as shown in Figures 3.3 and 3.4. Concentrations of uranium were generally less than 0.1 µg/L. The highest concentration was 0.68 µg/L observed at the upstream site on 1 April 2015, which is approximately 11 percent of the 6 µg/L Limit. This sample also had elevated concentrations of Mn and Fe indicating the input of suspended sediments or dust. As turbidity was low (< 2 NTU) at the time of collection this suggests potential sample contamination by dust. Both manganese and magnesium concentrations were at or below their respective Focus levels; well below their ecotoxicological Limits (Figures 3.3 and 3.4). Total ammonia nitrogen concentrations were also monitored, with all results being less than 0.046 mg/L, which is less than 7 percent of the Guideline (data not shown).

Surface water samples are collected fortnightly from Magela Creek upstream and downstream of the Ranger mine for radium-226 analysis. 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 2014–15 wet season are compared with previous data ranging back to the 2001–02 wet season (Figure 3.5). The sample results for 2014–15 were within the historic range observed in Magela Creek since 2001.

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 ten year old child. Wet season median differences (shown by the horizontal lines in Figure 3.5) from 2001 to 2015 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 2014–15 wet season was 0.01 mBq L^{-1}. 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 Supervising Scientist Annual Report 2004–05.

Chemical and physical monitoring of Gulungul Creek

Gulungul Creek runs along the western boundary of the Ranger project area. ERA does not release any mine water into the Gulungul Creek catchment other than surface runoff. A number of water collection and diversion systems are installed on the mine site in an attempt to limit the volume of poor quality mine derived water that enters Gulungul Creek. Additional monitoring was undertaken during the 2014–15 wet season to investigate the effect of elevated conductivity waters originating from GCT2, which arises near the northwest corner of the tailings dam. In late 2014 ERA constructed a seepage interception barrier in this location in an effort to reduce solute inputs to Gulungul Creek. For reference, the Gulungul Creek water quality data are routinely compared to the Water Quality Objectives that have been derived for Magela Creek, either using reference water quality or ecotoxicological data.

Flow was first recorded at the Gulungul Creek upstream monitoring site (GCUS) on 31 December 2014 and at the downstream site on 2 January 2015. During the initial weeks of flow EC fluctuated between 16–26 µS/cm at both the upstream and downstream sites (Figure 3.6). Almost all of the conductivity data was in exceedence of the comparable Magela Creek Focus trigger value for conductivity, and was notably higher than that observed historically. This may indicate some impact to the upstream Gulungul Creek monitoring site from mine derived waters. This is being investigated and an additional monitoring site will be installed for the 2015–16 wet season.

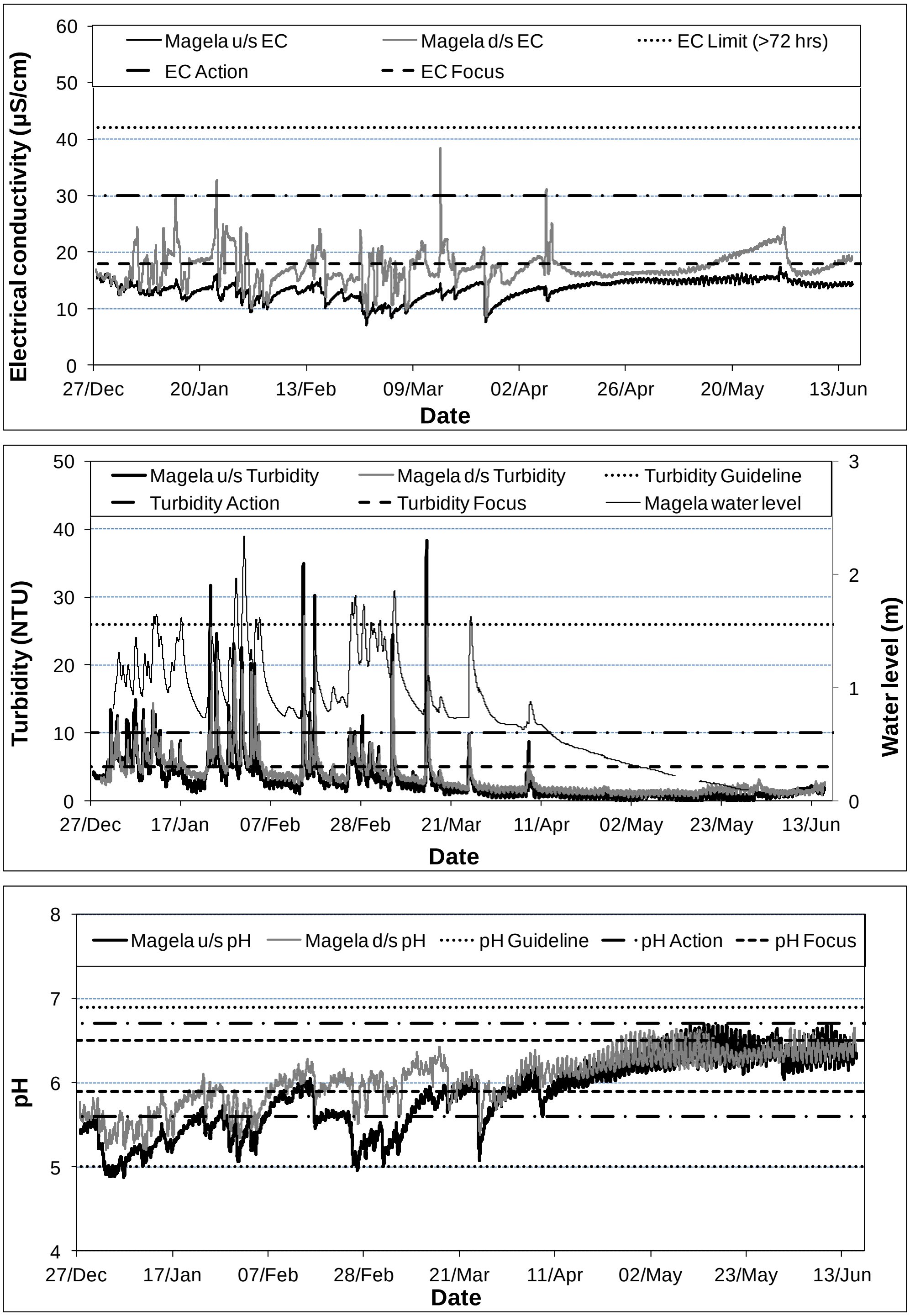

Figure 3.2 Continuous monitoring of EC, turbidity, water level and pH in Magela Creek during the 2014–15 wet season

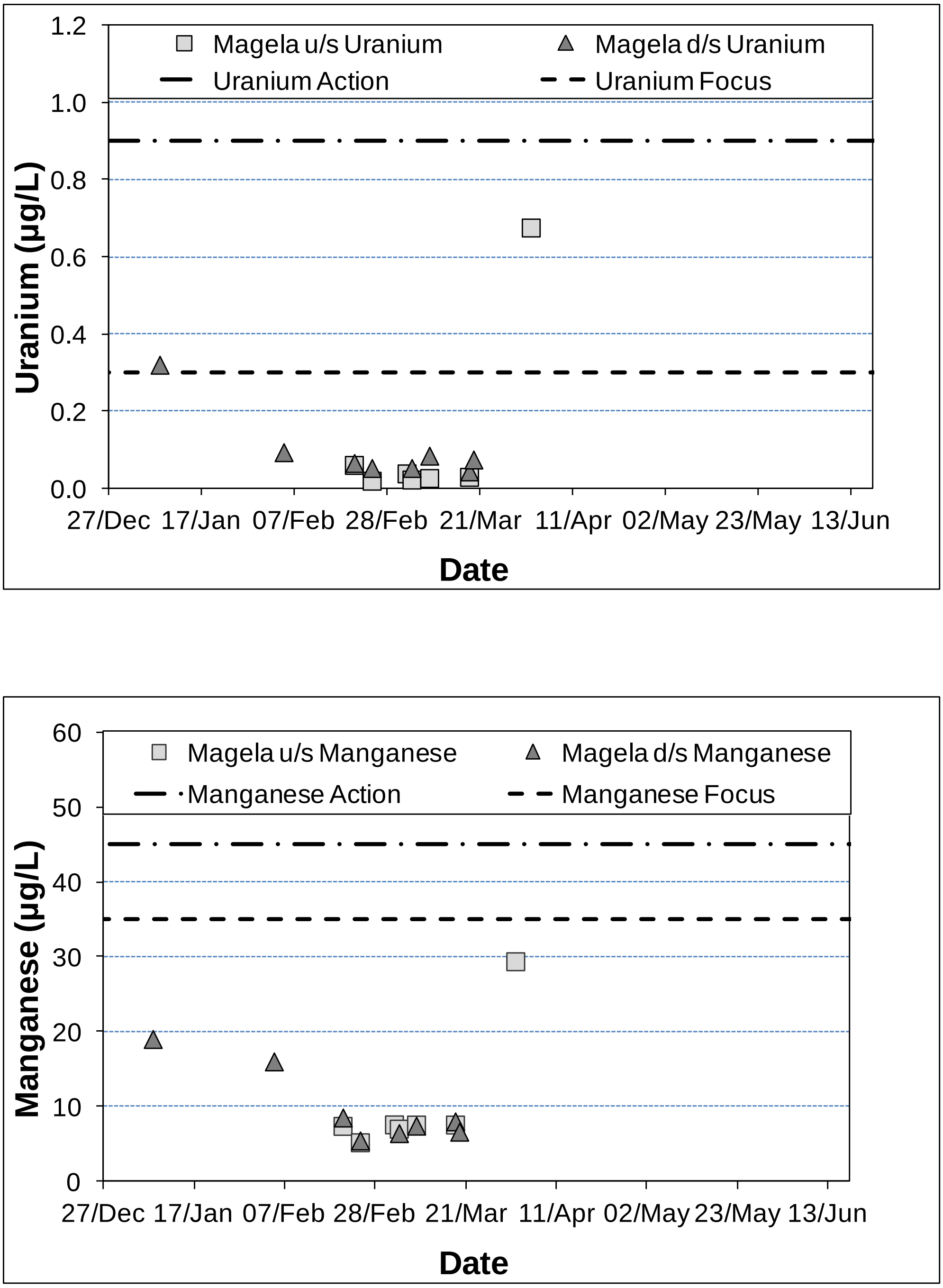

Figure 3.3 Monitoring of uranium and manganese in Magela Creek during the 2014–15 wet season

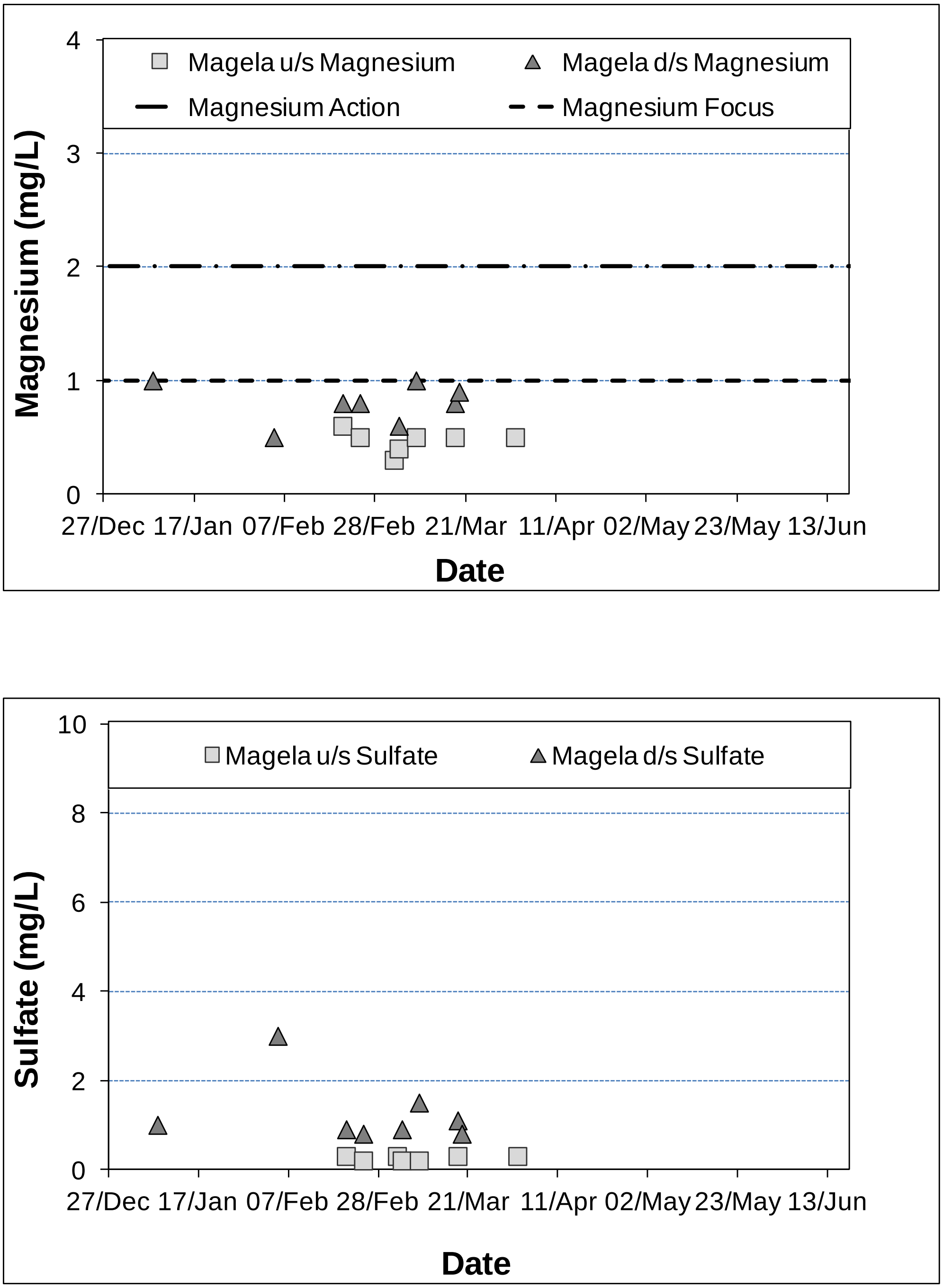

Figure 3.4 Monitoring of magnesium and sulfate in Magela Creek during the 2014–15 wet season

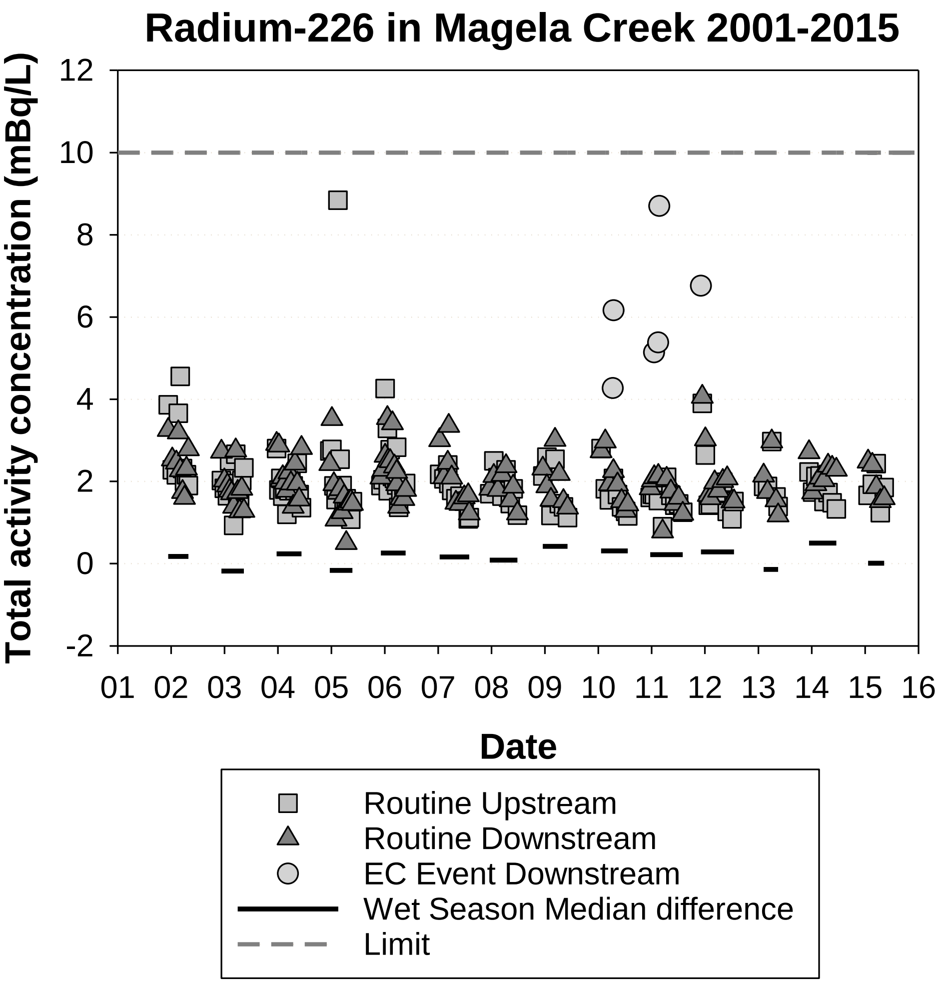

Figure 3.5 ^{226}Ra in Magela Creek 2001–15

Electrical conductivity events observed early in the season did not exceed the EC Limit (derived for Magela Creek), which indicates that these events were not likely to be of environmental significance.

During March and April several EC events were observed (Figure 3.6) which did exceed the Magela Creek EC Limit. These events are discussed in detail below.

Peaks in turbidity correspond directly with increased flow from rainfall events, during which sediments become mobilised and are transported along the creek channel. All peaks that occurred at the downstream site were also observed at the upstream site, indicating that there is little contribution of sediment from the mine site (Figure 3.6).

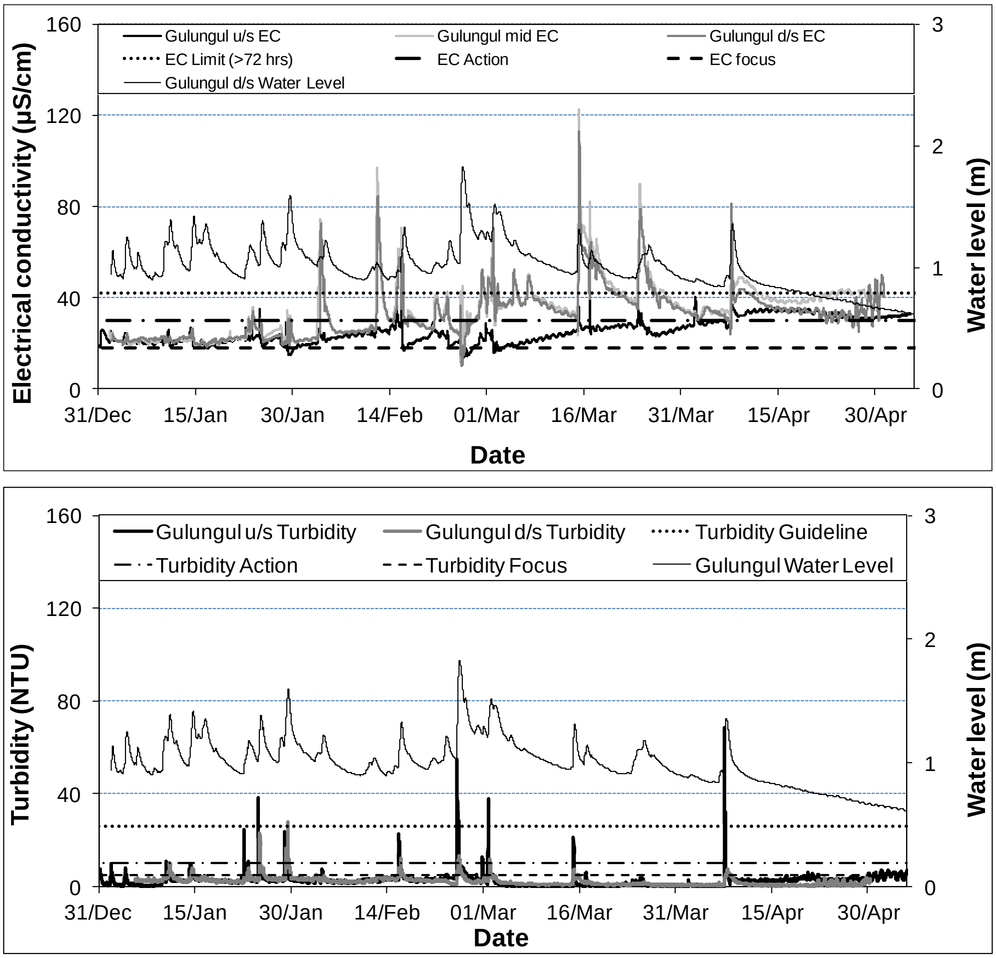

Figure 3.6 Continuous monitoring of EC, turbidity and water level in Gulungul Creek during the 2014–15 wet season

Water samples were analysed for uranium, manganese, magnesium and sulfate as shown in Figures 3.7 and 3.8.

Concentrations of manganese were below the Focus level of 35 µg/L, with the exception of two samples, which were above the Action level. These samples were obtained from Gulungul Creek midstream east bank (GCMIDEB) and Gulungul Creek downstream monitoring sites (GCDS) during the EC event on 15 March 2015.

Concentrations of uranium were generally low, with the exception of autosamples from the Gulungul Creek midstream east bank (GCMIDEB) site collected over conductivity events on 1 and 15 March 2015. The maximum total uranium recorded for each event was 1.25 µg/L and 1.26 µg/L respectively. This would equate to an approximate filtered concentration of 1.1 µg/L (Sinclair, 2015 (in press)[4]). Corresponding downstream samples were not collected for the event on 1 March 2015 due to a malfunction of the autosampler. Downstream uranium samples collected over the 15 March event recorded a maximum total uranium of 0.2 µg/L, showing significant attenuation of uranium as these waters moved down Gulungul Creek. It is likely the source of the elevated uranium was GCT2 which remains the subject of ongoing investigations by Supervising Scientist Branch and ERA.

Elevated levels of magnesium and sulfate were noted on several occasions throughout the season, primarily associated with the flushing of solutes from GCT2. Magnesium concentrations exceeded 3 mg/L on a number of occasions during the wet season (Figure 3.8). The 3mg/L magnesium Limit applies only if concentrations remain above 3 mg/L for a specified period of time. Rather than direct comparison to a limit, magnesium samples are used to verify the Mg/EC relationship during high EC events to confirm if the magnesium toxicity Limit has been exceeded. Such events occurred on two occasions during the 2014–15 wet season and these events are discussed in more detail below.

Cease to flow in Gulungul Creek was agreed by stakeholders on 1 May 2015.

High electrical conductivity events in Gulungul Creek

During the 2014–15 wet season two significant EC events were recorded at the GCDS. One exceeded the chronic EC exposure Limit (above 42 µS/cm for 72 hours) and one exceeded the pulse EC exposure Limit (above 44 µS/cm for 68 hours). The Magela Creek limits are used for comparative purposes as water quality objectives have not yet been defined for Gulungul Creek.

In response to these EC events Supervising Scientist Branch undertook an extensive investigative monitoring programme which included collecting water samples from additional sites (Figure 3.9), deploying additional in-situ toxicity snail tests and undertaking laboratory based toxicity assessments.

The chronic EC exposure Limit was exceeded on 15 March 2015, with the EC remaining above 42 µS/cm for 129 hours. The maximum EC recorded during this period was 113 µS/cm (Figure 3.10). The pulse EC exposure Limit was exceeded on 24 March 2015 (Figure 3.11). The maximum EC recorded during this event was 79 µS/cm (Figure 3.11).

Earlier investigations carried out by Supervising Scientist Branch indicated that these events were caused by input of water from GCT2 which had high concentrations of dissolved solutes arising from the north-western corner of the Ranger tailings dam. Typically catchment wide rainfall flushes GCT2 into Gulungul Creek and the accompanying high flows in the creek provide sufficient dilution to keep the EC relatively low. Towards the end of the 2014–15 wet season, isolated storm events caused the high EC water to flush from GCT2 but did not significantly raise water levels in Gulungul Creek, and thus little dilution was provided by the creek resulting the high EC events.

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[4] Sinclair A 2015 (In press). An assessment of total (dissolved and particulate) and filterable (dissolved) water quality data from 2001–2014. Supervising Scientist Internal Report 640.

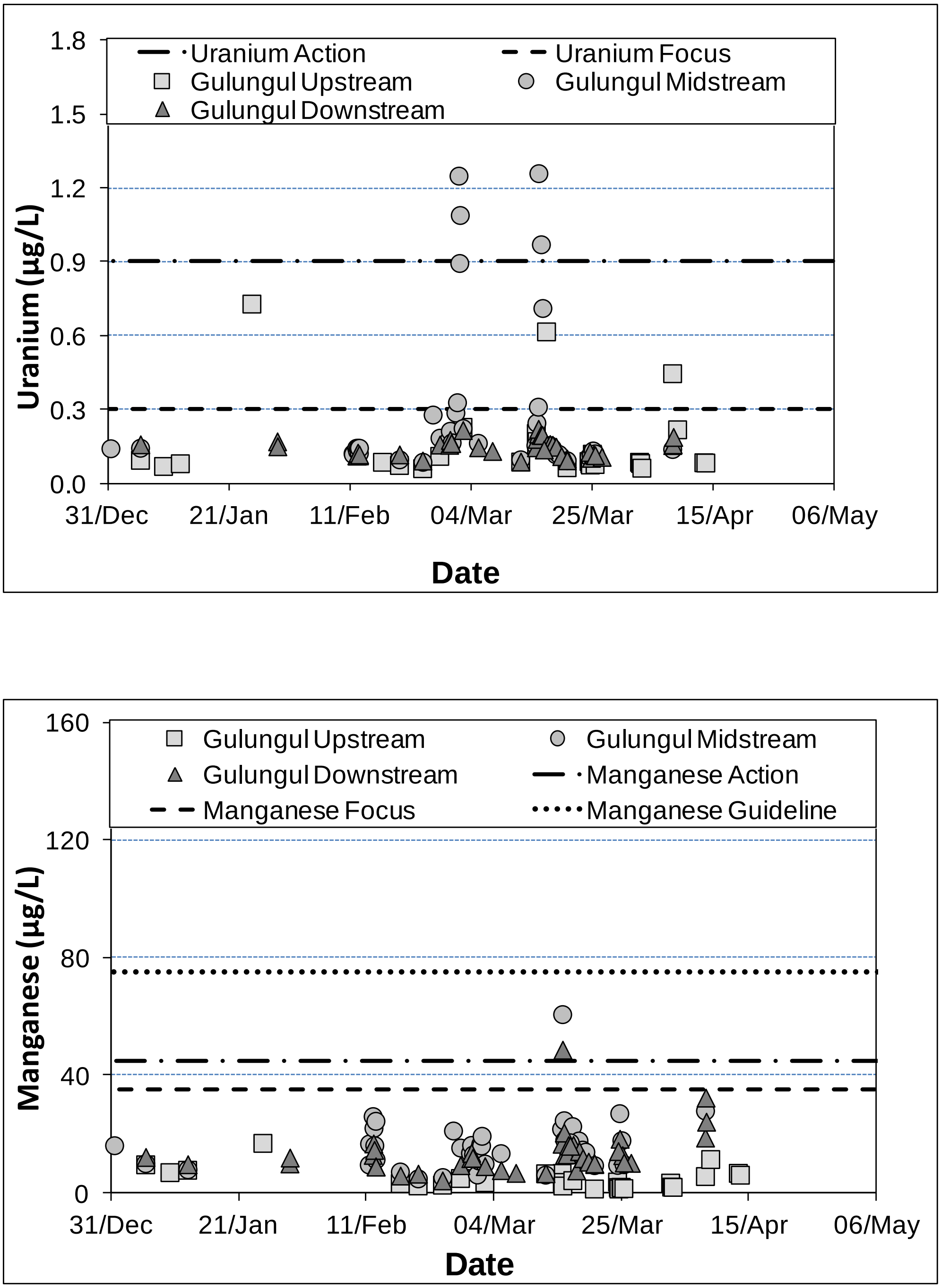
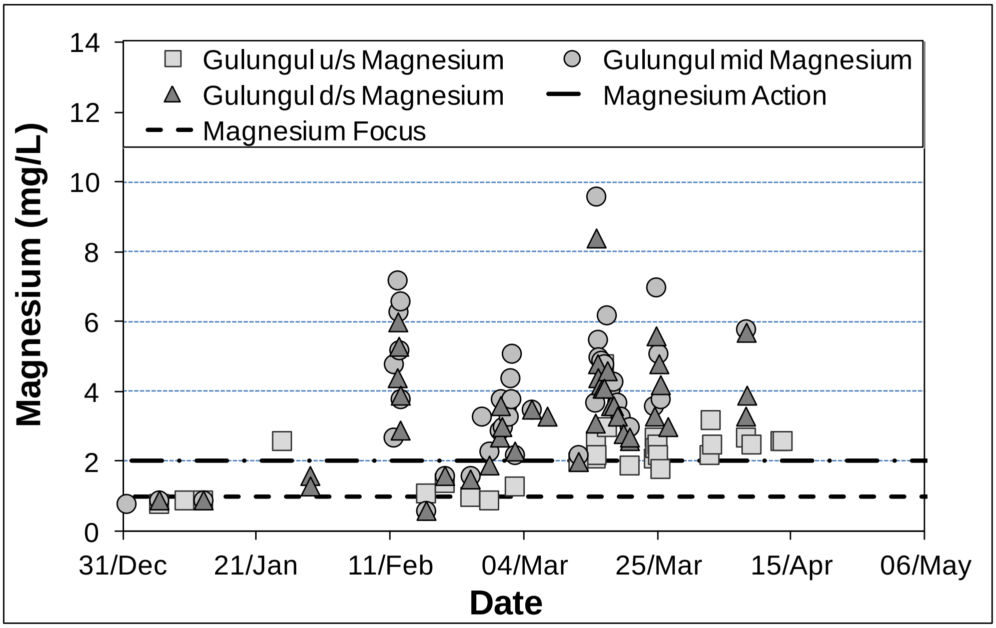


Figure 3.7 Monitoring of uranium and manganese in Gulungul Creek during the 2014–15 wet season



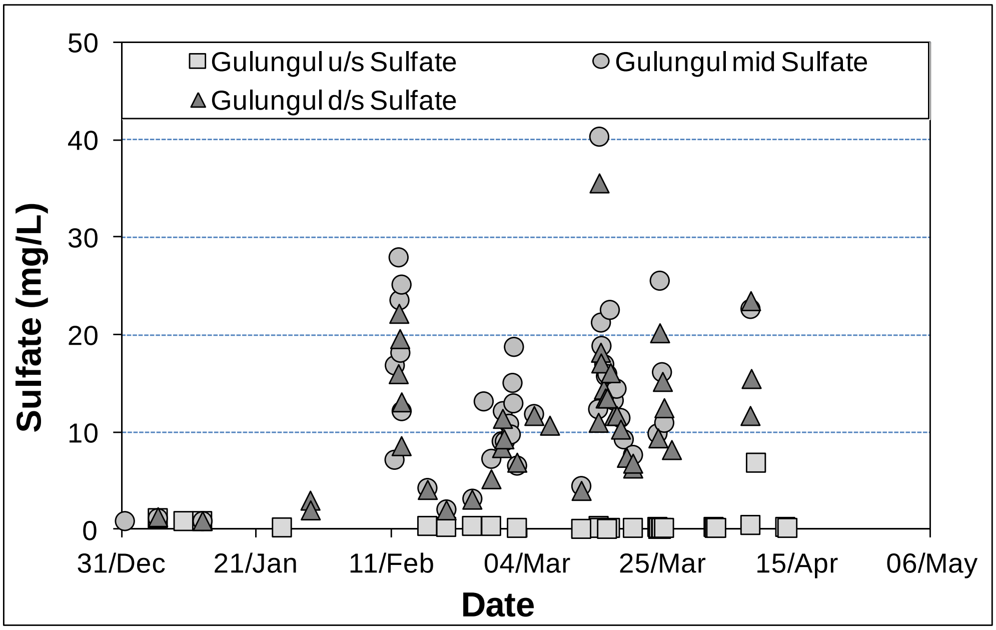


Figure 3.8 Monitoring of magnesium and sulfate in Gulungul Creek during the 2014–15 wet season

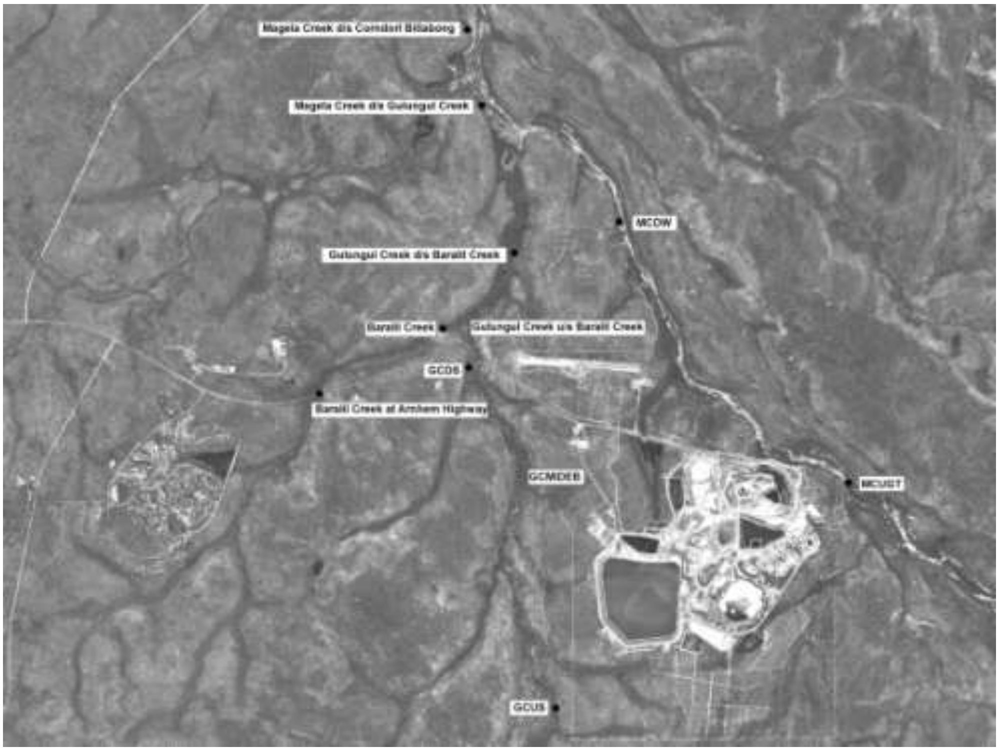


Figure 3.9 The location of monitoring sites in the Gulungul and Magela creek catchments. Throughout the duration of these events Supervising Scientist Branch collected a number of event-based and grab samples from each of the three routine monitoring sites on Gulungul Creek (GCUS, GCMIDEB and GCDS) and from additional investigative sites below the downstream Gulungul Creek monitoring station as shown in Figure 3.9.

The chemistry results from these samples indicated that magnesium, calcium and sulfate were the key solutes contributing to the high EC values, with the concentrations of other major ions and key mine derived contaminants remaining low in all samples. The magnesium, calcium and sulfate concentrations decreased longitudinally along the Gulungul Creek flow path, as shown by a decline in their concentrations at the sites downstream of GCDS.

While the concentration of uranium in GCT2 is elevated compared to background, the uranium concentrations measured in Gulungul Creek during the 2014–15 wet season, including the EC events, remained low (Figures 3.12 and 3.13). The highest uranium concentration (1.09 µg/L) was measured at GCMIDEB which is located a short distance downstream of the confluence with GCT2. The highest manganese concentration of 59 µg/L was also measured at this site. Both of these concentrations were below Limits set for Magela Creek, being 6 µg/L for uranium and 75 µg/L for manganese. Investigative monitoring data collected by Supervising Scientist Branch indicated that uranium and other metals were rapidly attenuated within GCT2, with concentrations decreasing significantly along the GCT2 flow path.

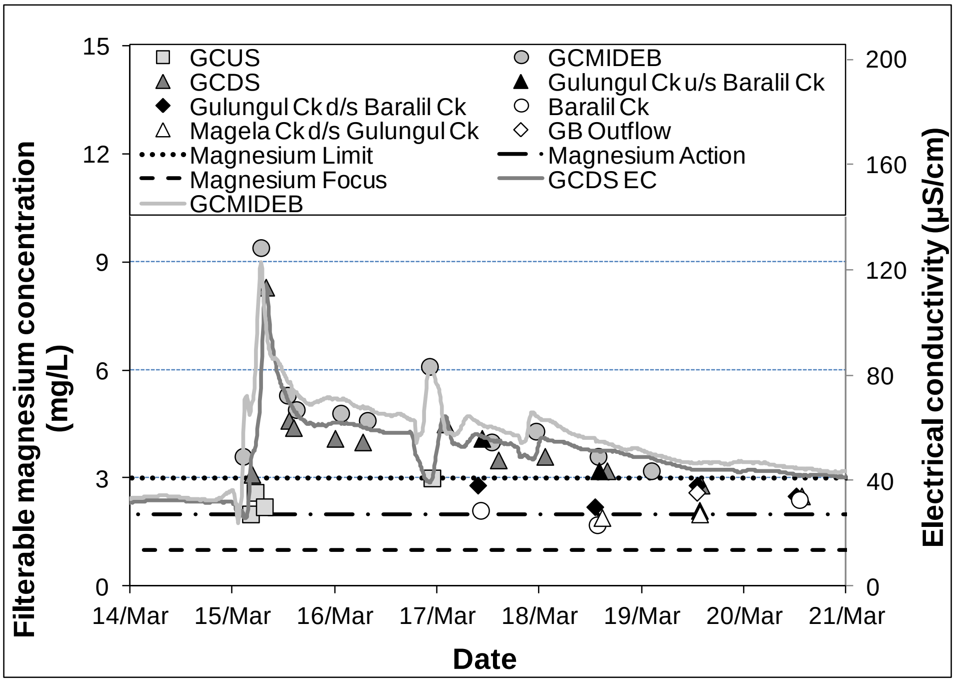


Figure 3.10 Continuous monitoring of EC and water level in Gulungul Creek during 14 to 21 March 2015

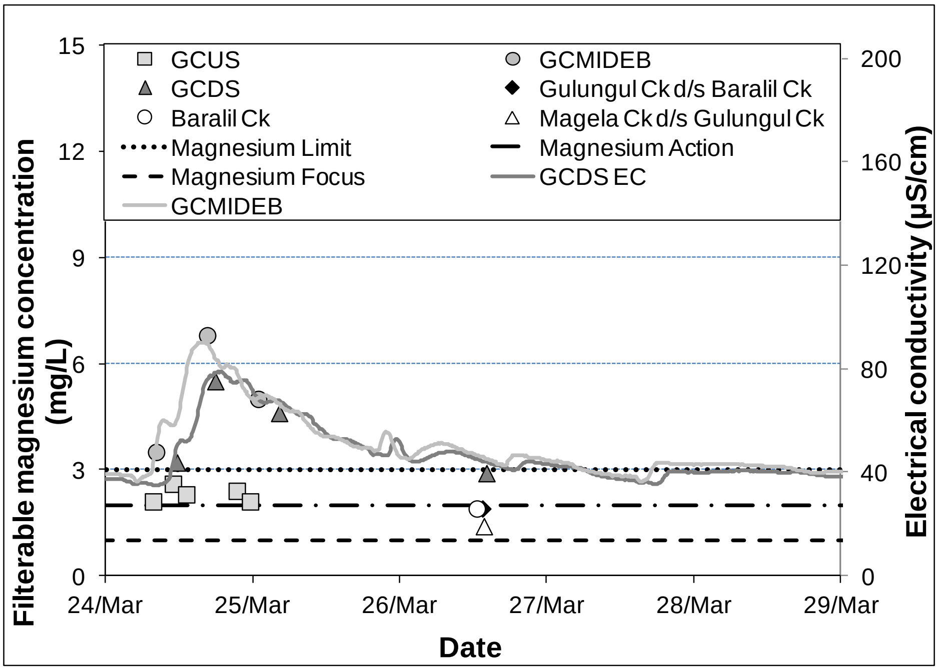


Figure 3.11 Continuous monitoring of EC and water level in Gulungul Creek during 24 to 29 March 2015

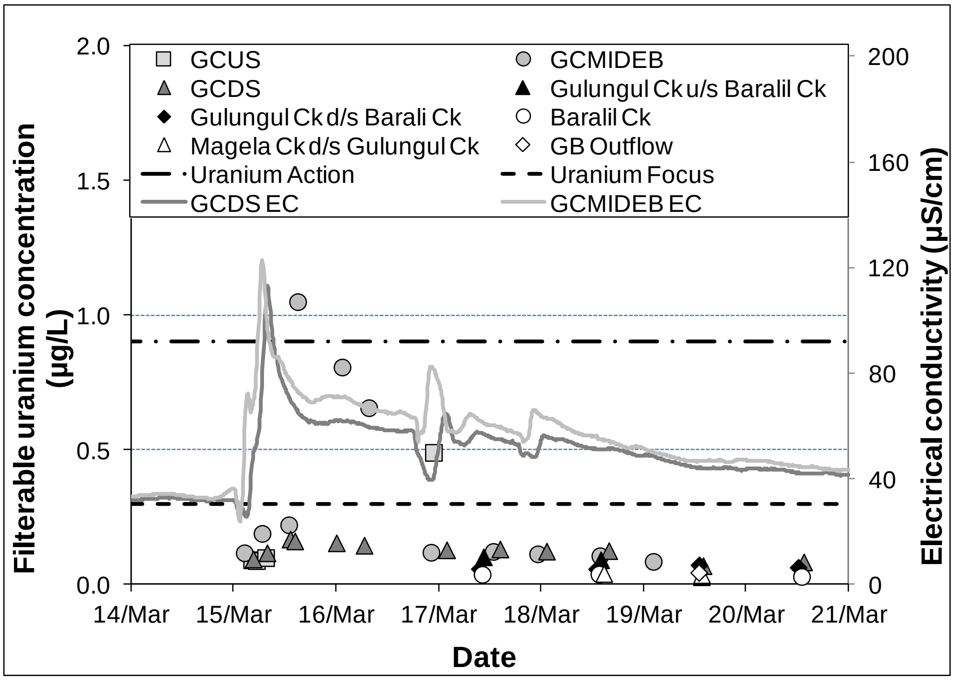


Figure 3.12 Filterable uranium concentration and continuous monitoring of EC in Gulungul Creek during 14 to 21 March 2015

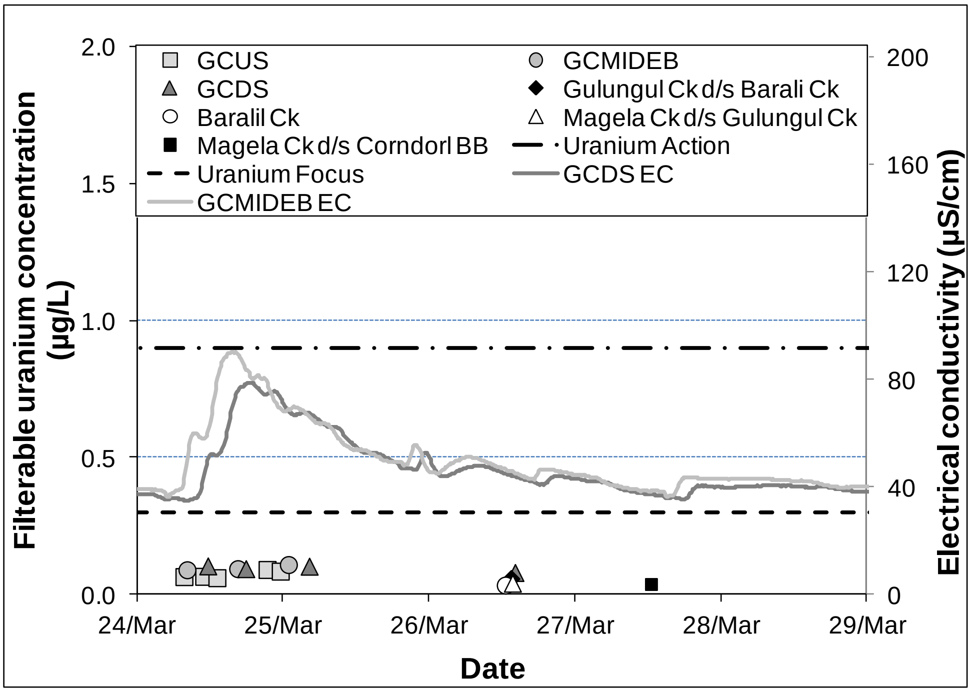


Figure 3.13 Filterable uranium concentration and continuous monitoring of EC in Gulungul Creek during 24 to 29 March 2015

The in-situ toxicity snail tests were deployed during the EC events and they did not show any significant response from exposure to the elevated solute concentrations in the Gulungul Creek water. The direct toxicity of the GCT2 water was assessed using laboratory toxicity testing and the results indicated that the test organisms were relatively tolerant to the GCT2 water at EC levels similar to those observed in Gulungul Creek during the high EC events. It is likely that this tolerance is due to the fact that the high magnesium concentrations in the GCT2 water are accompanied by high calcium concentrations, with a mass ratio of 5:1. Work undertaken by Supervising Scientist Branch has shown that when the mass ratio of Mg:Ca is less than 9:1, the toxicity of magnesium is markedly ameliorated. This, in effect, reduces the potential magnesium toxicity risk.

A water sample was collected from Mudginberri Billabong on 1 April 2015 and showed that concentrations of all analytes were within expected ranges for the billabong, and were well below levels of environmental or human health concern. The EC was 22 µS/cm, the uranium concentration was 0.03 µg/L and the radium activity concentration was 2 mBq/L.

Following the high EC events in Gulungul Creek Supervising Scientist Branch extended its monitoring network by installing an in-situ EC sensor (and datalogger) in the western-most channel of Magela Creek downstream of its confluence with Gulungul Creek (Figure 3.9 *Magela Creek downstream Gulungul Creek*). The EC data revealed that the 72 hour chronic EC Limit was exceeded at this location on the 7 April due to input of high EC water from Gulungul Creek. The maximum EC measured in the western channel of Magela Creek during this event was 62 µS/cm, which corresponded to a maximum EC of 82 µS/cm at GCDS. The background EC at the Magela Creek downstream at the time was 31 µS/cm. While the EC measured in the western channel of Magela Creek exceeded the Limit, it does not reflect the quality of creek water across the entire channel, as Magela Creek waters in this location are poorly mixed due to the braided nature of the creek bed. The water becomes more thoroughly mixed as it travels further downstream, which would result in further dilution. In order to confirm this, and to monitor more far field effects of inputs from GCT2, Supervising Scientist Branch will install additional in-situ EC sensors (and dataloggers) in Magela Creek during the 2015–16 wet season.

The preliminary conclusion from the monitoring data analysed to date is that detectible environmental impact arising from these high conductivity events in Gulungul Creek is unlikely. This is because the key dissolved solutes causing the elevated EC in Gulungul Creek are magnesium, calcium and sulfate; the presence of calcium ameliorates the toxicity of magnesium. This conclusion is supported by the results of in-situ toxicity monitoring, direct toxicity testing and macroinvertebrate studies discussed below. Supervising Scientist Branch will produce a detailed investigative report containing all physio-chemical, biological and toxicity data related to these events for release late in 2015.

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 in Magela and Gulungul Creek sites 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 2014–15 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 subchronic exposure situations, this species has been shown to be among the most sensitive, to both uranium and magnesium, of Supervising Scientist Branch’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 3.14A). 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 Supervising Scientist Annual Report 2007–08 for details). The creekside method was discontinued after the 2007–08 wet season in favour of *in situ* testing. 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 3.14A) are combined. A refinement to this programme has been the extension of toxicity monitoring to Gulungul Creek, with testing commencing in the 2009–10 wet season (Figure 3.14B).

For the 2014–15 wet season, an additional in-situ site in Gulungul Creek was established downstream of the GCT2 junction with Gulungul Creek adjacent to GCMIDEB (Figure 3.9). The rationale for testing at this new location was to observe the reproductive responses of snails exposed to Gulungul Creek waters downstream of GCT2, a site elevated in EC in very recent wet seasons, prior to further dilution at the downstream GCDS site. Complementary to this, continuous EC loggers were installed behind the duplicate floating in situ containers that hold the snails at the GCDS site to capture any differences in EC between the containers (a consequence of the EC gradient between western and eastern banks of the creek at this site).

In order to investigate potential environmental consequences of solutes of relatively high concentration entering Gulungul Creek from GCT2 (discussed under Section 3.2.3.1 - Chemical and Physical Monitoring of Gulungul Creek), the majority of toxicity monitoring tests conducted during the 2014–15 wet season focused on Gulungul Creek. Thus, for 2014–15, thirteen

Gulungul and only three Magela tests were completed. Of these, the second Magela and seventh Gulungul test were conducted concurrently. The tenth Gulungul test was a continuation of the ninth test, utilising the same snails in both tests but removing the vials with egg masses at the 96-hr mark and placing the snails in clean vials for the ensuing tenth test. In addition, due to cyclone conditions and site access restrictions, the tenth test could only be retrieved after 116 (and not 96) hrs. Since all sites received the same treatment, the results of the tenth test were deemed not to have violated test protocol and hence have been included in the analysis of the 2014–15 wet season data.

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 Annual Report 2007–08 (section 2.2.3).

In the past several years, assessment of minewater effects upon snail egg production has also been enhanced with accruing knowledge of water temperature and EC influences on the snail egg laying responses in Magela and Gulungul creeks. An interacting effect between water temperature and EC has been observed such that with increasing EC, snail egg production (i) increases at water temperatures <30°C, and (ii) decreases at water temperatures >30°C. Median EC at Magela and Gulungul downstream sites over the four-day exposure period of each toxicity monitoring test that exceeds approximately 25 µS/cm is indicative of exposure to Ranger mine wastewaters. Thus sustained exposures to mine wastewaters (i.e. median EC >25 µS/cm) have potential to accentuate enhancement and suppression of egg production for median water temperatures <30°C and >30°C respectively (Supervising Scientist Annual Report 2013–14, Section 3.2.3.2).

An assessment of minewater effects upon snail reproduction in both creeks during 2014–15 is provided below.

Magela Creek

Upstream and downstream egg production and difference values for the three toxicity monitoring tests conducted in Magela Creek are displayed in Figure 3.14A. While the mean (upstream-downstream) difference value of 4.0 is contrary to the usual trend of greater downstream egg production, the ANOVA results showed no significant difference between the 2014–15 wet season results and those from all previous wet seasons (Table 3.11).

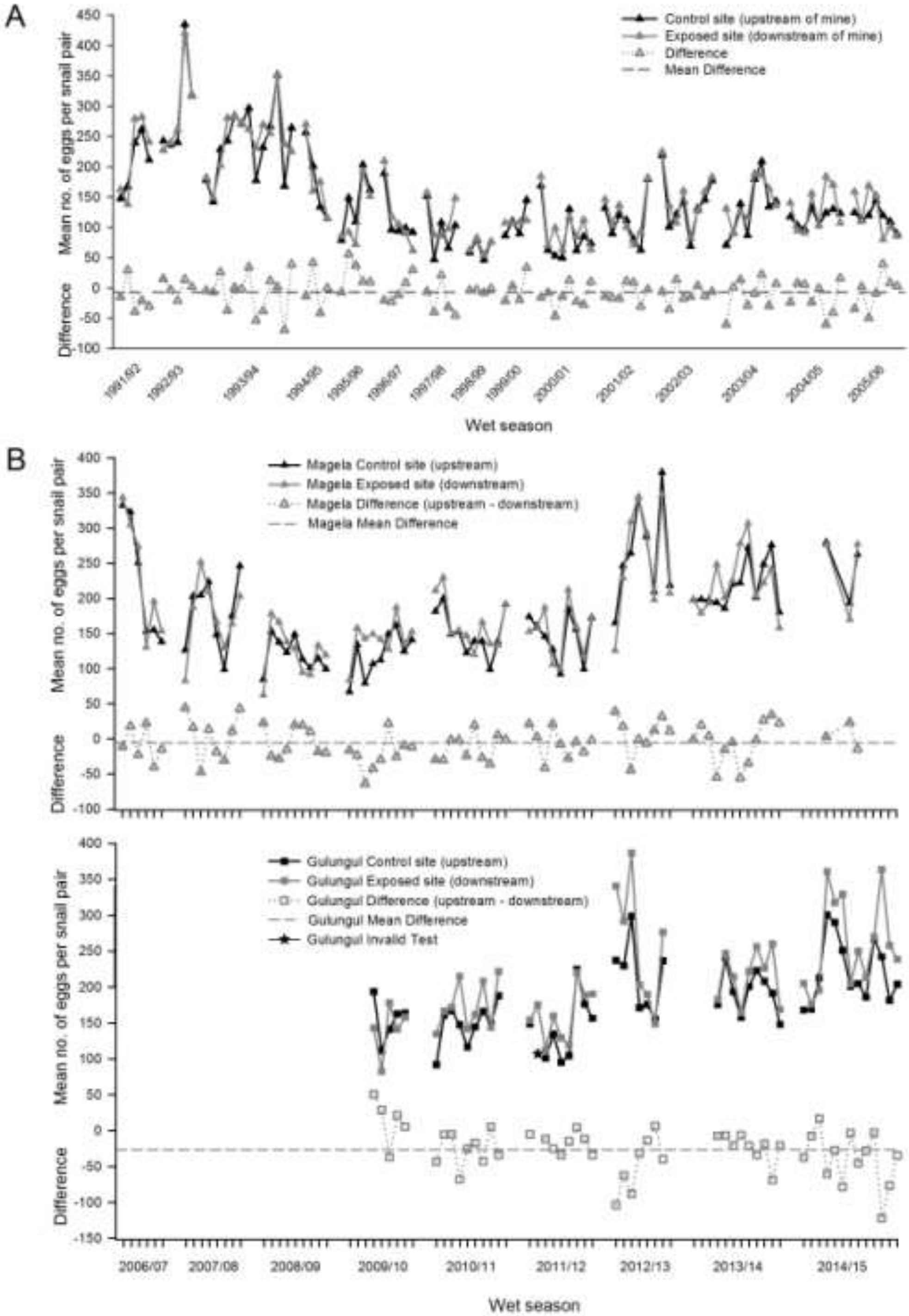


Figure 3.14 Time-series of in situ snail egg production data from toxicity monitoring tests conducted in a) Magela Creek, and b) Gulungul Creek

TABLE 3.11 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	0.083	NS
All previous seasons	2013-14	0.865	NS
All previous seasons	2014-15	0.456	NS

NS = Not significant

TABLE 3.12 MEAN AND ASSOCIATED STANDARD DEVIATION (SD) OF GULUNGUL SITE-PAIR DIFFERENCES IN SNAIL EGG NUMBER AND EC FOR 2015 TOXICITY MONITORING TESTS. SITES CODES ARE GCUS = UPSTREAM, GCDS = DOWNSTREAM AND GCMIDEB = MIDSTREAM.

		GCUS-GCDS		*GCUS-GCMIDEB*		*GCMIDEB-GCDS*	
		Egg	EC	Egg	EC	Egg	EC
Tests 1-5	Mean	-23.05	-2.34	-36.76	-1.76	13.71	-0.58
	SD	29.27	0.14	23.88	0.79	12.10	0.68
Tests 6-13	Mean	-46.01	-11.86	-11.41	-13.01	-34.61	1.14
	SD	35.74	6.09	25.88	7.16	31.57	2.00
All tests	Mean	-37.18	-8.20	-21.16	-8.68	-16.02	0.48
	SD	34.15	6.70	27.30	7.91	35.05	1.80

Gulungul Creek

Upstream, downstream and midstream egg production, with corresponding difference values, for the thirteen tests conducted in Gulungul Creek are shown in relation to previous wet season results in Figure 3.14B and for 2015 alone in Figure 3.15.

Similar to results reported in previous years, egg production in Gulungul Creek continued to be greater at the downstream site (mean difference upstream–downstream for the 13 tests of -38.9). For these two sites, analysis of the 2015 data indicated no significant difference between difference values for this year and values for all previous years ($p = 0.364$). As reported in previous Supervising Scientist annual reports (2011–12, 2012–13 and 2013–14), the inter-annual variability in the 'Before' period continues to be significant (i.e. sets of wet season difference values differ from one another, $p = 0.013$).

Impact assessment is based upon examination of (i) plots of the upstream (GCUS), downstream (GCDS) and midstream (GCMIDEB) egg production, with corresponding difference values (Figure 3.15), (ii) plots of egg production in relation to median EC and water temperature (Figure 3.16) and (iii) mean and standard deviation (SD) of the egg number and EC difference values for the three possible site-pair combinations (Table 3.12). Observations include:

1 Historically, egg production at Gulungul Creek downstream (GCDS) has been higher than upstream (GCUS) (Figure 3.14), and this trend continued for the 2014–15 wet season. Mean egg production at GCMIDEB of 239.3 (eggs per snail pair) sits between the mean egg production for GCUS (218.2) and GCDS (255.3), as would be expected based on the longer term trends. Thus snail egg production at GCMIDEB (and GCDS for that matter) did not appear anomalous for this wet season, despite lack of previous testing at GCMIDEB.

2 Higher EC waters entering GCMIDEB only became evident after the fifth test (i.e. EC mean differences and associated SD for all site pairings are low for tests 1-5, Table 3.12).

3 Median EC recorded at GCMIDEB and GCDS was similar across all 13 tests, indicating little dilution of high EC waters between the sites (Figures 3.15 and 3.16).

4 For the first five tests, egg production at GCMIDEB was most similar to GCDS (lowest mean egg difference value and associated SD, Table 3.12 and Figure 3.15), while for the period of elevated EC entering GCMIDEB, i.e. tests 6 to 11, egg production at GCMIDEB was most similar to GCUS (Table 3.12 and Figure 3.15).

5 When Gulungul 2015 egg production data are separated by median water temperature (<30 and >30°C) (Figure 3.16), results are consistent with those found in previous years. Thus with increasing EC, snail egg production (i) increased at water temperatures <30°C, and (ii) decreased at water temperatures >30°C, though neither of these relationships was statistically significant (Figure 3.16).

6 High EC waters entering GCMIDEB gave rise to contaminant concentrations well in excess of those previously recorded in toxicity monitoring tests – see Figure 3.16. As noted above, such sustained exposures to high EC waters might have been expected to have greatly accentuated enhancement and suppression of egg production for median water temperatures <30°C and >30°C respectively (viz extrapolation of the respective regression relationships). Nevertheless, this was not the case for Gulungul 2015 toxicity monitoring results. Snail egg production at GCMIDEB was not dissimilar to that recorded at GCUS indicating the snail egg laying response was not particularly sensitive to these high (mine-derived) EC waters.

Assessment and conclusions for both creek systems

Despite exposure in Gulungul Creek to GCT2 waters at solute concentrations well in excess of those experienced in previous seasons, no apparent impairment to reproduction in freshwater snails was observed over the 2014–15 wet season. The lower than expected toxicity of the GCT2 water was also noted in the results of laboratory direct toxicity experiments conducted by Supervising Scientist Branch on water collected from GCT2 before it entered Gulungul Creek. Magnesium toxicity is thought to be ameliorated by the relatively high concentrations of calcium present in the GCT2 waters. These results reporting negligible toxicity are further corroborated by the results of annual, recessional flow monitoring of macroinvertebrete communities in receiving waters, including Gulungul Creek. Similarly no downstream effects upon macroinevertebrate communities were observed (see section below).

Bioaccumulation in freshwater mussels

Some metals and radionuclides bioaccumulate in aquatic biota, in particular in freshwater mussels. It is thus essential to check that food items collected from Magela Creek are fit for human consumption and that the concentrations 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. Hence the bioaccumulation monitoring programme serves an ecosystem protection role in addition to the human health aspect.

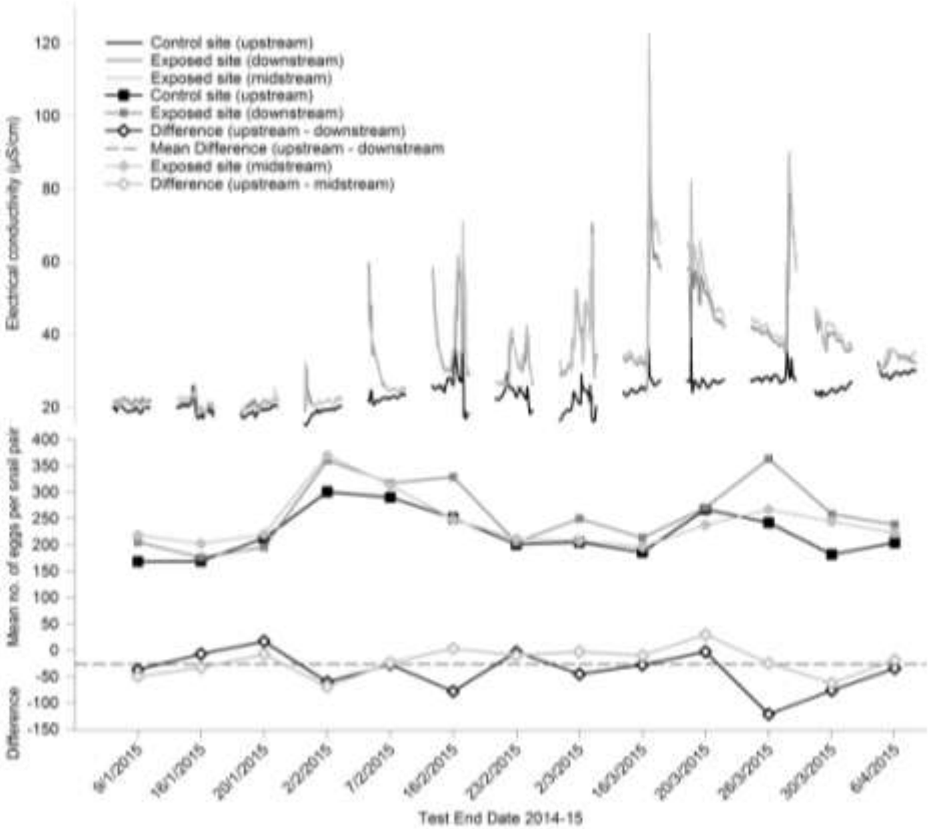


Figure 3.15 In situ snail egg production and median EC data from toxicity monitoring tests conducted in Gulungul Creek during the 2014–15 wet season.

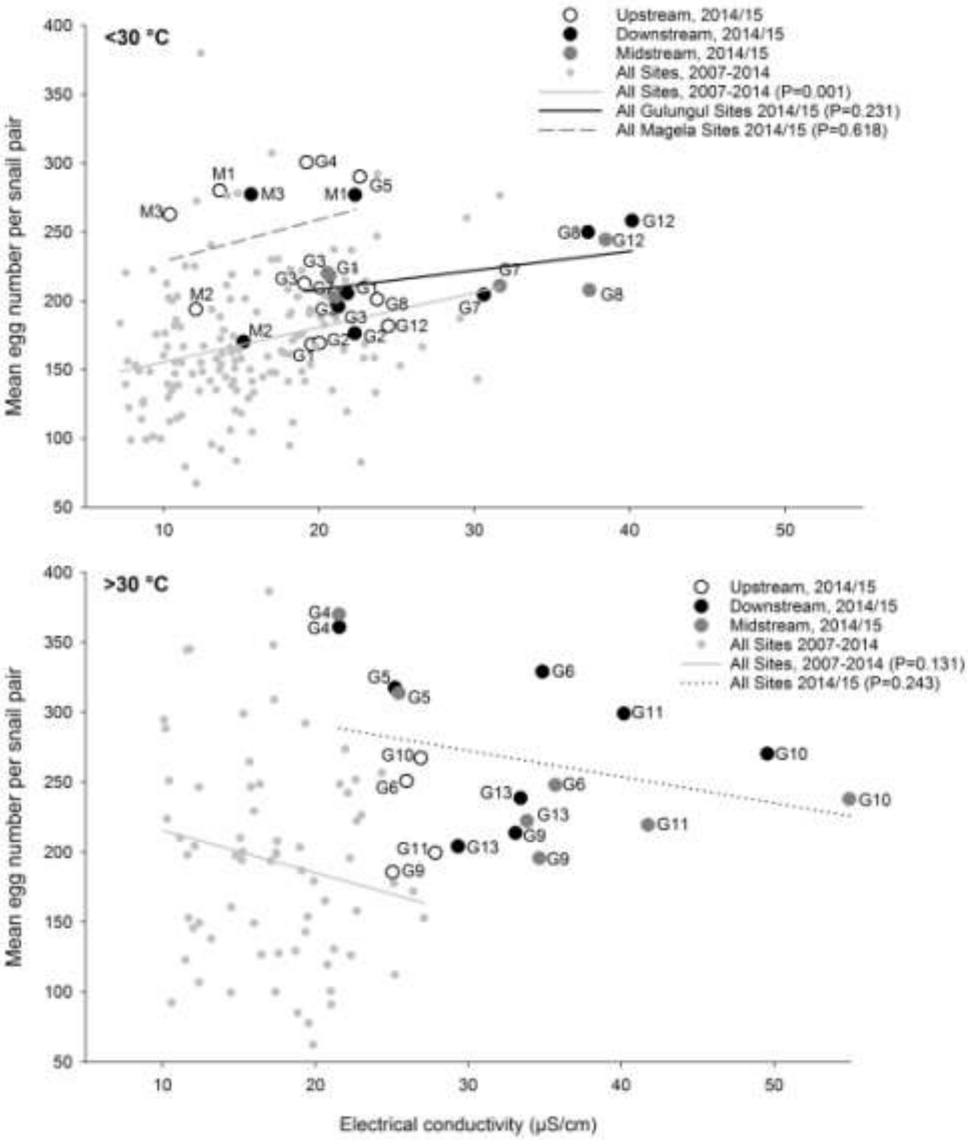


Figure 3.16 Relationships between mean snail egg number for each site in Magela and Gulungul Creeks, and ambient EC and water temperature over the four-day exposure test periods for wet seasons between 2006–07 and 2013–14 (grey symbols) and 2014–15 (symbols indicated in key). Annotated codes are G = Gulungul Creek and M = Magela Creek, with test number (1-13) also indicated.

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. Mussels were collected annually and fish biennially from two sites: Mudginberri Billabong (the potentially impacted site) and Sandy Billabong (the control site in a different catchment, sampled from 2002 onwards).

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 fish sampling programme was discontinued in 2007. Two research projects reported in previous Supervising Scientist annual reports concluded that differences in radionuclide activity concentrations in mussels between Mudginberri and Sandy Billabong were due to natural catchment influences and differences in water chemistry, rather than mining-related inputs to Magela Creek. Hence, the bioaccumulation monitoring was furthermore reduced from 2009, now involving the annual collection and analysis of mussels from Mudginberri Billabong only, with a detailed study (analysis of aged mussels from Mudginberri and Sandy Billabongs) conducted every three years. Sampling at Mudginberri and Sandy Billabongs was conducted in 2013 and results reported in the Supervising Scientist Annual Report 2013–14. However, in 2014 no mussels were collected from Mudginberri Billabong for cultural reasons.

In 2015 mussels will be collected and aged from both, Sandy and Mudginberri billabongs and results will be reported in the next annual report. This is to investigate whether the elevated wet season median difference between water ^{226}Ra activity concentration downstream and upstream of the mine in the 2013–14 wet season are preserved in an increase in ^{226}Ra activity concentrations in mussel tissue.

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 the present. The design and methodology have been refined over this period (changes are described in the Supervising Scientist Annual Report 2003–04, 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).

After the 2014–15 wet season, an additional site in Gulungul Creek (GCT2GCC), was sampled just downstream of the GCT2 junction with Gulungul Creek (Figure 3.9). Elevated EC has been reported in GCT2 in very recent wet seasons (discussed under Section 3.2.3.1 - Chemical and Physical Monitoring of Gulungul Creek) and hence sampling at this new location was designed to assess possible changes to macroinvertebrate communities, prior to further dilution at the downstream GCDS site.

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 different (e.g. higher) dissimilarity values compared with undisturbed sites and/or compared with the same upstream-downstream site configuration from previous years. Compilation of the full macroinvertebrate dataset from 1988 to 2014, and data from the paired sites in the two ‘exposed’ streams, Magela and Gulungul creeks, for 2015, have been completed, with results shown in Figure 3.17. 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 the 2014–15 wet season, the GCT2GCC site was also paired with the current year's Gulungul upstream site to derive an additional dissimilarity value; this value has been plotted on the Gulungul dissimilarity plot (Figure 3.17).

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 or not 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.) Due to a lack of historical data from the GCT2GCC site, data from this site were not included in the ANOVA testing.

Analysis for Magela and Gulungul creeks for 2015 sampling

At the time of preparing this annual report and as noted above, only samples from Magela and Gulungul Creeks from the 2014–15 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 2015. Instead, a modified ANOVA model was run using the factors Before/After (BA; fixed), Year (nested within BA; random) and Stream (upstream versus downstream paired dissimilarities; random) examining just the exposed creeks, Magela and Gulungul, to determine if any change in these streams has occurred. The ANOVA completed on the original sites (i.e. without GCT2GCC data) showed no significant change from the before (pre 2014–15) to after (2014–15) 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). This result is unsurprising given that the dissimilarity values for both creeks for 2015 plot at similar values to those recorded in most previous years (Figure 3.17).

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 3.18 depicts the multivariate ordination derived using replicate with-in site macroinvertbrate data. Data points are displayed in terms of the sites sampled in Magela and Gulungul creeks downstream (including GCT2GCC) of Ranger mine for each year of study (to 2015), relative to Magela and Gulungul upstream (control) sites for 2015, and all other control sites samples up to 2014 (previous years Magela and Gulungul upstream sites, all sites in Burdulba and Nourlangie). Samples close to one another in the ordination indicate a similar community structure.

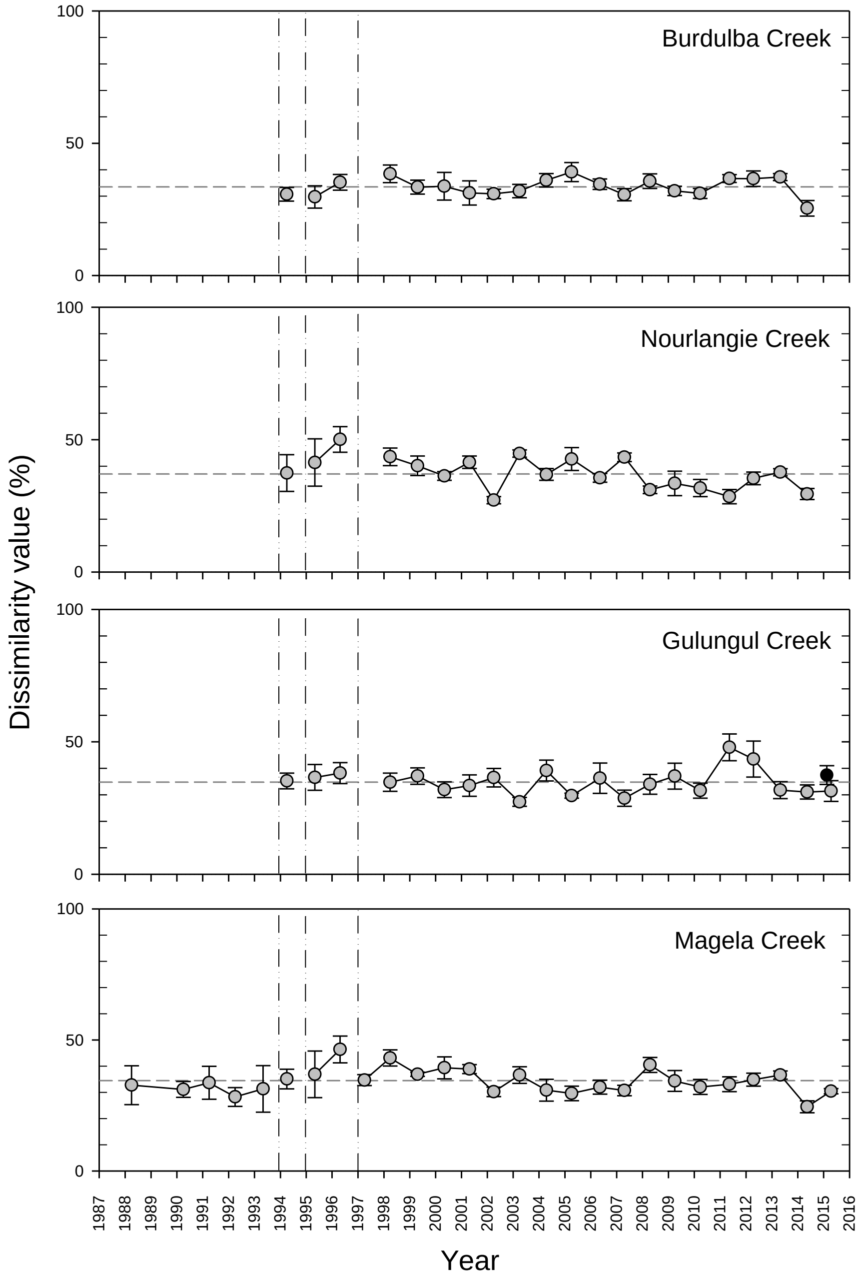


Figure 3.17 Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger mine for the period 1988 to 2015. The black symbol on the Gulungul Creek dissimilarity graph represents the Upstream-Mid stream pairwise comparison. 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 five possible (randomly-selected) pairwise comparisons of upstream-downstream replicate samples within each stream.

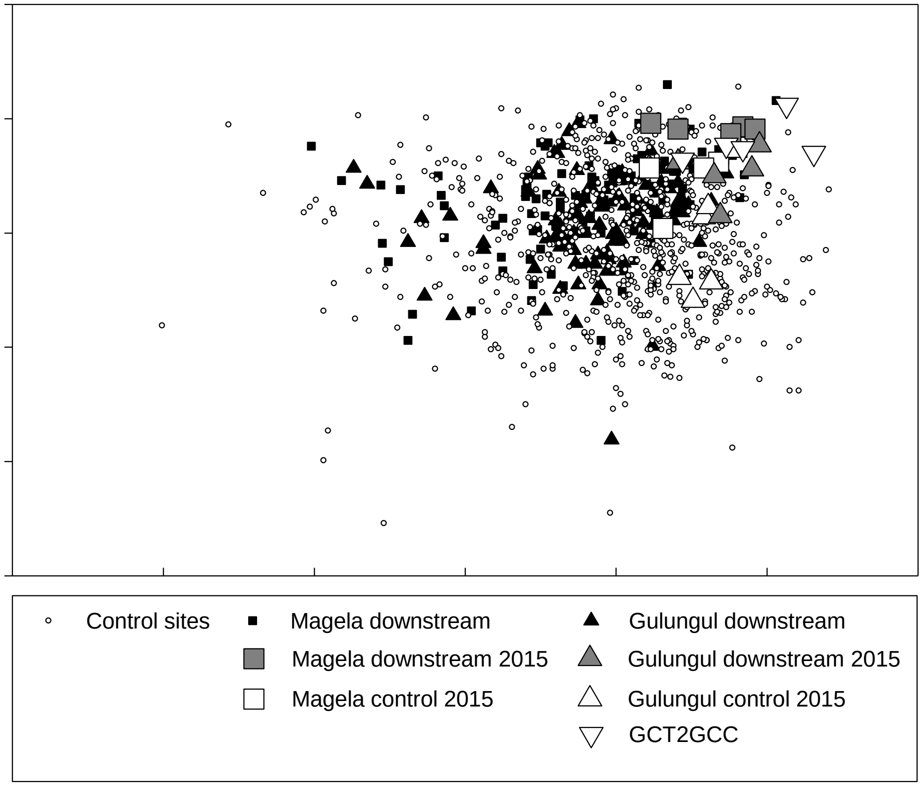


Figure 3.18 Ordination plot (axis 1 and 2) of macroinvertebrate community structure data from sites sampled in several streams in the vicinity of Ranger mine for the period 1988 to 2014. Data from Magela and Gulungul creeks for 2015 are indicated by the enlarged symbols.

Data points associated with the 2015 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 above ANOVA) of the exposed streams (Magela and Gulungul sites, excluding GCT2GCC). This showed no significant difference between the downstream data from 2015 with downstream data from previous years, and no significant difference between the upstream data from 2015 with upstream data from previous years.

GCT2GCC replicates, exposed to higher EC waters than Gulungul and Magela downstream replicates for 2015, are also generally interspersed within control sites. An exception to this is the two GCT2GCC replicates observed in the top right of the ordination plot (Figure 3.18) and separating from the main cluster. The community structure of these two replicates was examined further, with a comparison to other replicate samples collected from Gulungul and Magela sites in 2015. Taxa number and abundances associated with the two samples were generally (but not markedly) higher than those from other Gulungul and Magela samples (data not provided here). Without the addition of control samples from Burdulba and

Nourlangie creek sites, however, it is too early to suggest the samples represent natural or mine-related enrichment.

At this stage and despite exposure in GCT2GCC and Gulungul Creek downstream sites to mine wastewaters at solute concentrations well in excess of those experienced in previous seasons, no apparent impairment to macroinvertebrate communities was observed over the 2014–15 wet season. This interim conclusion is based on paired-site dissimilarity plots for both Gulungul exposed sites (Figure 3.17), ANOVA statistical analyses, and examination of community structure data underlying the all-site ordination (Figure 3.18). This result of ‘no impact’ for macroinvertebrate communities was consistent with the results of toxicity monitoring and ecotoxicity studies reported elsewhere in this report.

Analysis for all creeks for 2014 sampling

As noted above, 2014 data for Burdulba and Nourlangie creeks were not available at the time of preparing the Supervising Scientist Annual Report 2013–14. Compilation of the full macroinvertebrate dataset from 1988 to 2014 enables a complete statistical analysis of 2014 macroinvertebrate data.

A four-factor ANOVA model based upon 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 2014) to the after (2014) periods in the magnitude of upstream-downstream dissimilarity between the control and exposed streams ($p = 0.189$ and $p = 0.838$ for BA and BA*Exposure interaction respectively).

The lower paired upstream-downstream dissimilarity values observed in Magela, Nourlangie and Burdulba creeks compared to previous years (Figure 3.17) may be associated with a combination of the generally lower water levels in the creek at the time of sampling compared to earlier years, and a change in sampling locations required because of unsuitable habitat being available in previously sampled sites (Magela Creek upstream and both Nourlangie creek sites). Lower creek flows can confer more similar macroinvertebrate communities between creek sites (i.e. lower dissimilarity).[5] [6]

Additional graphical and statistical testing of the full 2013–14 dataset are provided in an ***eriss*** Annual Research Summary paper published in 2015[7]. Those collective results provide good evidence that changes to water quality downstream of Ranger as a consequence of

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[5] Supervising Scientist Division 2013 Environmental monitoring protocols to assess potential impacts from Ranger minesite on aquatic ecosystems: Macroinvertebrate community structure in streams (Figure 4). Internal Report 591, July 2013, Supervising Scientist, Darwin.

[6] George A & Humphrey C 2014. Development of turbidity closure criteria for receiving surface waters following Ranger minesite rehabilitation (Figure 3). In ***eriss*** *research summary 2012-2013*. Supervising Scientist report 205, Supervising Scientist, Darwin NT, 88-92.

[7] Chandler L, Hanley J & Humphrey CL 2015. Monitoring using macroinvertebrate community structure. In ***eriss*** *research summary 2013-2014*. Supervising Scientist report 209, Supervising Scientist, Darwin NT, 00-105.

mining during the period 1994 to 2014 have not adversely affected macroinvertebrate communities.

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.

Channel billabongs

For the 2014–15 wet season, the fish communities of channel billabongs were sampled between late April and early May (2015). The similarity of fish communities in Mudginberri Billabong (directly exposed site downstream of Ranger in Magela Creek catchment) to those of Sandy Billabong (control site in the Nourlangie Creek catchment) (see Map 3) is determined using multivariate dissimilarity indices calculated for each annual sampling occasion. A plot of the dissimilarity values from 1994 to 2015 is shown in Figure 3.19. (No monitoring was undertaken during the 2014 monitoring period as access to Mudginberri Billabong was not possible due to an important time of mourning for the local Indigenous community.)

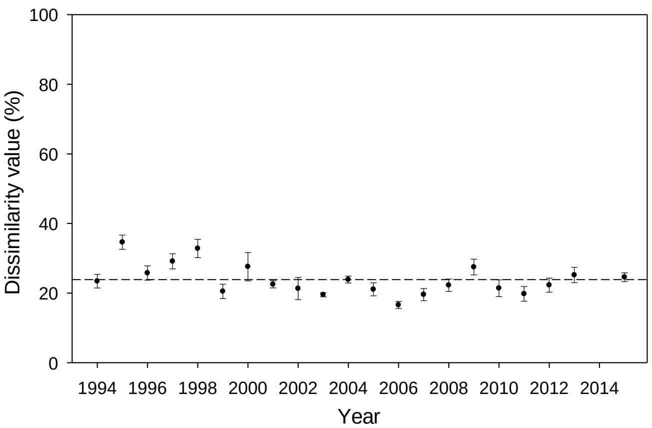


Figure 3.19 Paired control-exposed dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in Mudginberri ('exposed') and Sandy ('control') Billabongs over time. Values are the mean dissimilarity (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of transect data between the two waterbodies. The dashed line is the mean dissimarity over all years.

The paired-billabong dissimilarity values have been analysed using a two-factor ANOVA (Analysis Of Variance), with Before/After (BA; fixed) and Year (nested within BA; random) as factors. In this analysis the 'BA' factor tests whether values for the year of interest (2015) are consistent with the range of values reported in previous years (1994 to 2013) while the factor 'Year' tests for differences amongst years within the before or after periods. The ANOVA results for 2015 show no significant difference between 2015 and other years (BA factor not significant, $p = 0.878$). This indicates the relationship between Mudginberri and Sandy Billabong fish communities has remained consistent with relationships observed in previous years.

The variation in fish assemblage dissimilarity between the two billabongs amongst years (Year factor) continues to be significantly different ($p < 0.001$). This variation, evident in Figure 3.19, has been demonstrated to be mainly associated with the annual variation in the abundance of chequered rainbowfish (*Melanotaenia splendid inornata*) in Magela Creek

(Supervising Scientist annual report 2003–04, section 2.2.3). This species is the most common fish species in Magela Creek.

The annual changes in rainbowfish abundance in Magela Creek have been shown in previous Supervising Scientist annual reports to be negatively correlated with magnitude of wet season discharge (specifically wet season total, January total and February total) measured at G821009 in Magela Creek. More recently, rainfall at Jabiru Airport has been used in place of discharge data as it is considered more representative of regional wet season conditions (Supervising Scientist Annual Report 2011–12). Inclusion of results from 2015 sampling support those from previous years, with negative relationships observed between rainbowfish abundance in Mudginberri Billabong and total annual rainfall ($p = 0.005$) and for the total rainfall in January ($p = 0.022$) and February ($p = 0.025$). This is particularly evident from the plotted data in Figure 3.20 which highlights the comparatively high rainbowfish abundances recorded in both 2013 and 2015, associated with a below-average wet season rainfall for both years.

The 2015 results continue to support previous indications that years of below average rainfall have the potential to reduce upstream migrations of rainbowfish past Mudginberri Billabong, resulting in above average counts in the billabong in those years (Figure 3.20)

Collectively, the analyses described above provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2015 have not adversely affected fish communities in channel billabongs.

Shallow lowland billabongs

Monitoring of fish communities in shallow lowland billabongs is usually conducted every other year, with the exception of 2011 when staff resources were directed to another project (see Supervising Scientist Annual Report 2010–11). The last assessment was conducted in 2014 with results reported in Supervising Scientist Annual Report 2013–14 (section 3.2.3.2). The next assessment is due to be conducted between late April and June 2016.

3.2.2.3 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 1 mSv. This dose is on top of the radiation dose received naturally, which averages approximately 1.5 mSv per year in Australia, but 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 Alligator Rivers Region. 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.

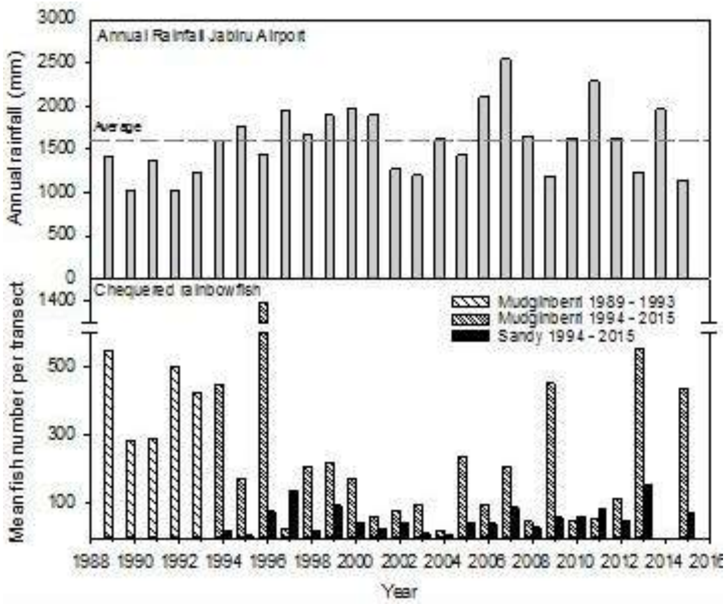


Figure 3.20 Relative abundance of chequered rainbowfish in Mudginberri and Sandy Billabongs from 1989 to 2015 with associated annual wet season rainfall recorded at Jabiru Airport.

Inhalation pathway

Supervising Scientist Branch 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 3.24 and 3.25 show hourly and quarterly average radon progeny potential alpha energy concentration (PAEC) monitoring data from Jabiru town and near Mudginberri community, respectively, for the 2014 calendar year. Coverage was 100 percent of the year for Jabiru town, gaps in the data for the Mudginberri record are due to instrument maintenance and data quality issues.

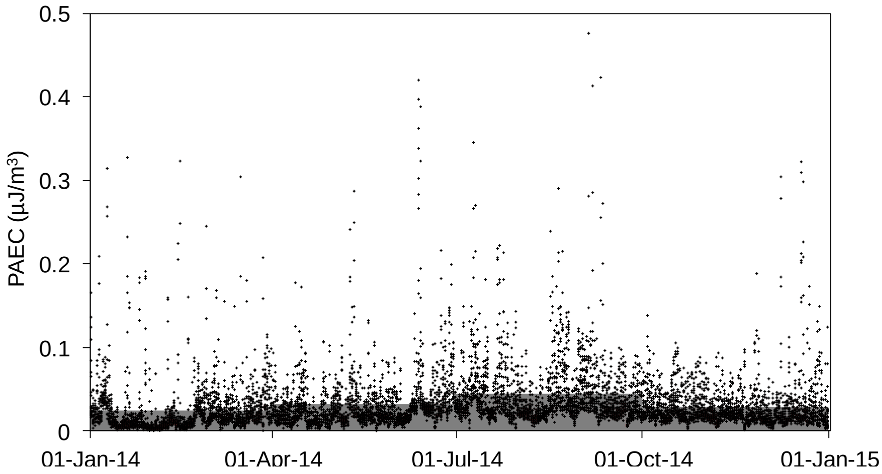


Figure 3.21 Hourly (black crosses) and quarterly average (grey columns) radon progeny PAEC in air at Jabiru town in 2014.

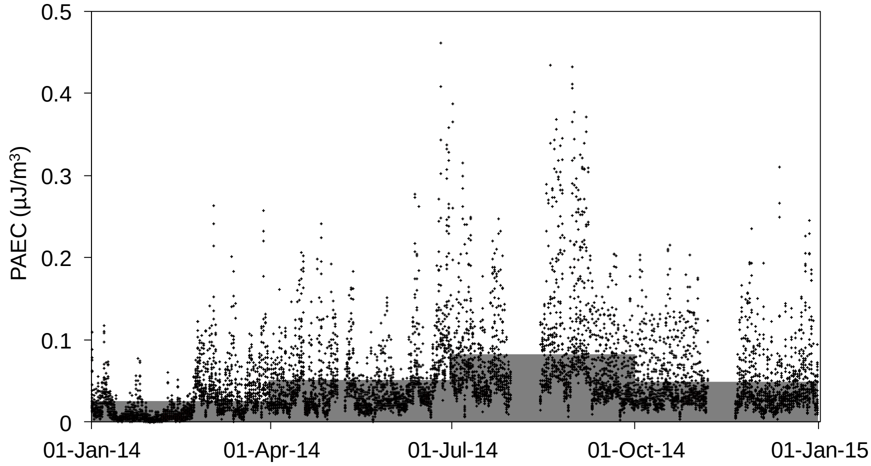


Figure 3.22 Hourly (black crosses) and quarterly average (grey columns) radon progeny PAEC in air at Four Gates Road radon station near Mudginberri community in 2014.

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 3.13 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 is largely due to the contribution from natural background, has been estimated to be 0.313 mSv at Jabiru town and 0.490 mSv at Mudginberri.

TABLE 3.13 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI DURING 2014*

	Jabiru town	Mudginberri
Annual average PAEC [µJ m^{-3}]	0.032 (0.052)	0.051
Total annual dose [mSv]	0.313 (0.501)	0.490
Mine-derived dose** [mSv]	0.023 (0.041)	0.003

* Values in brackets refer to data from the ERA Radiation Protection and Atmospheric Monitoring Program Report for the year ending 31 December 2014.

** The radon progeny PAEC difference used in Supervising Scientist Branch mine-derived dose calculation was 0.024 µJ/m3 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 8760 hours.

The mine-derived annual dose from radon progeny in air has been estimated to be 0.023 mSv at Jabiru town and 0.003 mSv at Mudginberri, much less than the public dose limit of 1 mSv in a year. 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 2014 were obtained from the Bureau of Meteorology weather station at Jabiru Airport. Analysis of these data suggests that the wind was from the direction of the mine for 2130 hours during the year at Jabiru town (90–110 degree sector) and 234 hours during the year at Mudginberri (140–160 degree sector).

Differences between Supervising Scientist Branch and ERA radon progeny PAEC results and public dose estimates for Jabiru town are most likely due to differences in the monitoring regime. Whereas Supervising Scientist Branch 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.

Figures 3.26 and 3.27 show measured and quarterly average concentrations of dust-bound LLAA radionuclides in air at Jabiru town and near Mudginberri community, respectively, for 2014. Gaps in the data are due to instrument maintenance and data quality issues.

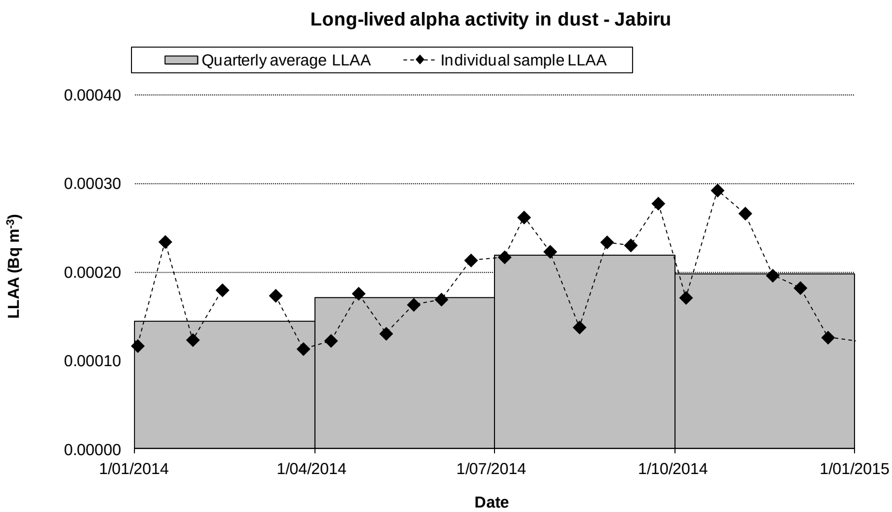


Figure 3.23 Measured (black diamonds) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Jabiru town in 2014.

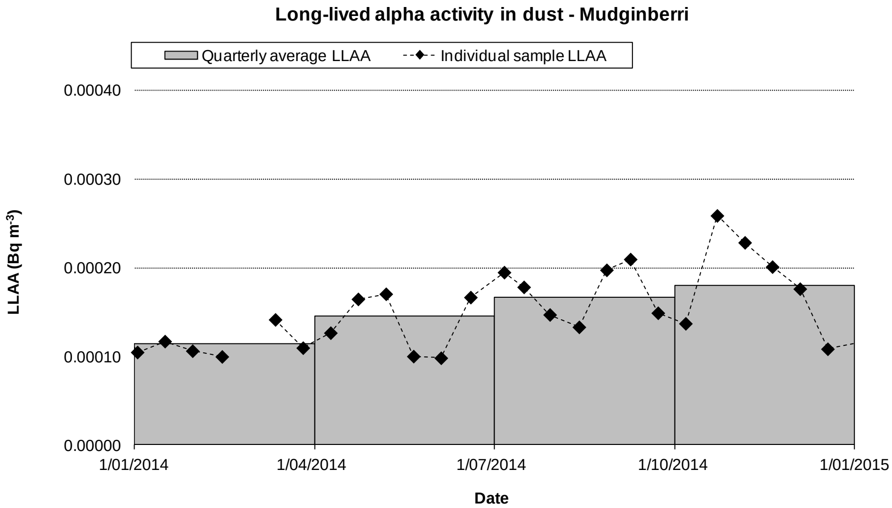


Figure 3.24 Measured (black diamonds) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Four Gates Road radon station near the Mudginberri community in 2014.

Table 3.14 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 0.006 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 8760 hours.

TABLE 3.14 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}]	1.8×10-4	1.5×10^{-4}
Total annual dose [mSv]	0.007	0.006
Mine-related dose* [mSv]	5×10-4	4×10^{-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

Local indigenous people have historically expressed concern about radionuclides in mussels from Mudginberri Billabong as these are a regularly consumed bush food item. Supervising Scientist Branch 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). The 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. In 2014 however, no mussels were collected in Mudginberri Billabong for cultural reasons.

The ^{226}Ra activity concentration in Magela Creek water is routinely monitored by both ERA and Supervising Scientist Branch. The limit for the wet season difference between median water ^{226}Ra activity concentrations upstream and downstream of the mine site is 10 mBq L^{-1}, based on potential dietary uptake of ^{226}Ra by the Indigenous people downstream of the mine through the ingestion of freshwater mussels. The greatest wet season median difference since 2001 was measured in the 2013–14 wet season and reported in last year's Annual Report at 0.5 mBq L^{-1}, but it was essentially zero again in the 2014–15 the wet season. It is important to investigate whether the slight increase in wet season median difference in 2013–14 is also reflected in an increase of ^{226}Ra activity concentrations in mussel tissue, to be collected at the end of the dry season 2015. Up until 2013, no increase in mussels from Mudginberri Billabong has been observed (Supervising Scientist Annual Report 2013–14) and results from the 2015 collection will be provided in next year's Annual Report.

Data on activity concentrations in bushfoods and environmental media from the Alligator Rivers Region sampled by ***eriss*** and other organisations over the past 30 years have been consolidated and are continuously updated into a consistent, quality controlled database (*BRUCE* tool, described in the Supervising Scientist Annual Report 2010–11). 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. Consequently much of the attention has been directed at investigating radionuclide uptake in terrestrial animals and plants. Analysis of the data has shown that, in contrast to the aquatic pathway, the radionuclide contributing most to the potential dose to humans from the ingestion of terrestrial animals and plants is polonium-210 (^{210}Po).

Radionuclide uptake data extracted from the BRUCE tool have also been used to aid in the derivation of a soil radiological quality guideline for wildlife-based protection for uranium mine rehabilitation.

3.2.4 Supervision and Assessment Activities

3.2.4.1 Annual Stakeholder Environmental Audit

2014 Audit Closeout

The 2014 Stakeholder environmental audit of Ranger mine was held on 12–15 May 2014. The following documents were the subject of the 2014 audit:

- 2014 Ranger Radiation Protection Program and Actions arising from the Light Vehicle Incident 3 November 2013

- 2013 Surface Exploration Program
- 2013 One Year Weed Management Plan.

The 2014 audit delivered one category two non-conformance (see Table 3.1 for definitions). Findings from the May 2014 environmental audit were followed up through the RPI process over the 2014–15 reporting period with all non-conformances and conditional findings adequately addressed over the reporting process.

2015 Audit

The 2015 environmental audit of Ranger mine was held on 15–19 June 2015. The audit team was made up of representatives from the NLC, DME, GAC and Supervising Scientist Branch. The focus for the 2015 audit was the evaluation of critical controls associated with the TSF, bulk diesel, and ammonia storage facilities. One hundred and fourteen commitments from the following manuals and procedures were audited against the grading system shown in
Table 3.1.

- TSF operations and maintenance manual.
- Bulk diesel and ammonia unloading procedures.
- Bulk diesel and ammonia tank and primary distribution system inspection and maintenance procedures.
- Bulk diesel and ammonia emergency response procedures.

The results of the 2015 audit are pending finalisation and will be detailed in next year's Annual Report

3.2.4.2 Audit and Routine Periodic Inspections

RPI's were carried out for each month of the 2014–15 reporting year with the exception of June 2015 when the annual environmental audit was conducted. Table 3.15 shows the focus areas for the RPIs for the year.

3.2.4.3 Minesite Technical Committee

The Ranger MTC met six times during 2014–15. Dates of meetings and issues discussed are shown in Table 3.16. Significant agenda items discussed at MTCs included updates from ERA on site activities including, management and monitoring strategies for high EC events in Gulungul creek, TSF tailings dredging, process safety developments, Pit 3 tailings deposition and Pit 1 preload.

3.2.4.4 Authorisations

On 25 November 2014 the Ranger Authorisation granted under the Northern Territory Mining Management Act was amended to include reference to the Ranger Water Quality Objectives. This resulted in Ranger Authorisation 0108-16 being revoked and replaced by Authorisation 0108-17.

TABLE 3.15 RANGER RPI FOCUS AREAS

Date	Foci
17 July 2014	GCT2, Pit 1, Pit 3 backfill, vent raise, upper Gulungul catchment erosion.
21 August 2014	TSF, TSF dredge ramp, brine concentrator.
18 September 2014	Ranger Project Area perimeter fence, Pit 3 drainage works, TSF contingency transfer system, TSF monitoring bores, Western stockpile.
16 October 2014	Surface exploration drilling, laterite plant bund incident, CTS2 pump contingency system, vent raise.
13 November 2014	Vent raise, GCT2, CRS, turbo mister trials (CB2), Pit 3 drainage and brines injection works.
11 December 2014	GCT2, retention ponds, sumps, and water control structures.
13 January 2015	Vent raise, Tailings West Wall Sump (TWWS interception trench, TSF pumping system, TSF dredge ramp, Pit 1, Pit 3 and Exploration Decline.
19 February 2015	Pit 3 tailings transfer from mill, TSF dredge ramp, GCT2 surface water monitoring point, Pit 1 pond water/process water segregation and TWWS seepage interception trench.
23 March 2015	Leach tanks, CCD repairs, mill control room, power station and emergency generator bunds, and Ranger Project Area weed management.
23 April 2015	Pit 1 capping and pumping system, Pit 3 tailings deposition, TSF transfer line booster station (repaired leak), CRS transfer line modification and pump, JELAA and Trial Landform.
22 May 2015	Pit 1 capping and pumping system, density gauges, control room, grinding and crushing circuit, laterite thickener bund, laterite plant, acid delivery bay.

TABLE 3.16 RANGER MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items in addition to standing items
11 July 2014	R3D water management plan, Authorisation and Water Quality Objectives, Gulungul EC spikes, Corridor Creek Wetland Filter vegetation
12 September 2014	Pit 3 tailings deposition, TSF bore monitoring programme report, Pit 1 surface water
7 November 2014	Independent Surface Water Working Group and Closure Criteria Working Group update, Pit 1 & Pit 3 works, Anomaly 5 drilling programme, Gulungul EC spikes
13 February 2015	Process safety, Gulungul EC spikes, Water quality objectives, Pit 3 flood protection and monitoring
10 April 2015	TSF dredging, process safety, Pit 3 tailings/process water MoL, Gulungul ecotoxicological results, radiation protection quarterly radiation reports
22 May 2015	R3D, site wide hydrogeological conceptual model, Gulungul EC spikes, process safety, TSF dredging update.

3.2.4.5 Assessment of reports, plans and applications

The main reports and plans assessed by Supervising Scientist Branch during 2014–15 included:

- Ranger Amended Plan of Rehabilitation No. 40
- Ranger and Jabiluka Wet Season Report
- Ranger Water Management Plan
- Ranger Annual Environmental Report
- Ranger Annual Tailings Dam Inspection Report
- Ranger Wet Season Report 2013-2014
- Ranger Groundwater Report 2013-2014
- Ranger and Jabiluka Radiation Protection and Atmospheric Monitoring Program plan, annual report and quarterly data submissions
- ERA weekly environmental monitoring data and quarterly reports submitted in accordance with the Authorisations
- Application by ERA for amendments to their Authorisations (refer to 3.2.4.4).

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

- 2014 Surface Exploration Program (July 2014)
    - Addendum to 2014 Surface Exploration Program – Anomaly 5 Drilling (February 2015)
- Ranger 3 Deeps (R3D) Exploration Decline 2013 Water Report (September 2014)
- Modification to R3D Water Management Plan (September 2014)
- Pit 1 Surface Water Catchment Report (November 2014)
- 2014 TSF Operation and Maintenance Manual incorporating the Dam Safety Action Plan (April 2015)
- R3D Radiation Management Plan (April 2015)
- 2014–2018 Ranger Mining Management Plan (May 2015).

3.2.2.6 Incidents

During the 2014–15 reporting period, a total of 19 environmental incidents were reported to Supervising Scientist Branch related to activities at the Ranger mine. Incidents for the reporting period are summarised by location and type in Table 3.17. Table 3.18 and Figure 3.25 highlight annual comparisons of incident by year showing a consistent downward trend since 2009. ERA have advised that the significant drop in reported incidents relates to reduced project activity on site in recent years.

Notable Incidents

The following notable incidents or associated investigations occurred or were concluded during the reporting period.

TABLE 3.17 ENVIRONMENTAL INCIDENTS 2014–15

	ADU	Hydrocarbon spill	Process water	Radiation clearance	Wildlife	Other	
Off RPA	-	-	-	1	-	2	**3**
Operational Minesite	-	2	1	-	-	-	**3**
Processing	1	-	2	1	-	-	**4**
RPA	-	4	-	-	-	1	**5**
Tailings Circuit	-	1	2	-	1	-	**4**
	1	**7**	**5**	**2**	**1**	**3**	**19**

TABLE 3.18 ENVIRONMENTAL INCIDENTS BY (CALENDAR) YEAR

	ADU	Diesel / Oil spill	Fire	Pond Water	Potable Water	Process Water	Radiation Clearance	Tailings Spill	Other	
2009	6	28	3	3	2	23	4	5	32	**106**
2010	3	25	1	1	-	17	5	9	29	**90**
2011	1	32	2	1	1	12	5	1	8	**63**
2012	1	39	2	1	-	4	1	-	10	**58**
2013	5	19	-	-	-	7	1	2	8	**42**
2014	-	15	-	-	1	3	1	-	2	**22**
	16	**158**	**8**	**6**	**4**	**66**	**17**	**17**	**89**	**381**

Product Packing Stack Emissions

In November 2014 Supervising Scientist Branch was notified that uranium emissions from the product packing stack at Ranger mine has exceeded the authorised limit in July 2014. Preliminary investigation findings suggested that the product packing scrubber venturi water and demister low flow alarms were set well below target flow rates. This had allowed sup-optimal scrubber water flow rates and venturi pressure differentials to go undetected resulting in stack emissions exceeding authorised limits.

Control system alarms on the packing scrubber system were reprioritised and reset to appropriate levels and a low flow and pressure differential interlock introduced on the scrubber system to prevent a reoccurrence of this emission exceedance.

Supervising Scientist Branch is awaiting further information on this incident.

Ventilation Raise Subsidence

On 9 May 2014 approximately 50-60 m^3 of rock and loose material was observed underground at the base of the vent raise. ERA staff and equipment were removed from the area of the vent raise and a fenced exclusion zone established. By 10 May 2014, an area approximately 18 m by 20 m wide had subsided into the vent raise. The vent raise was needed to provide enhanced ventilation requirements for Phase 2 of the exploration decline, approved on 4 June 2013. Supervising Scientist Branch inspected the subsidence through the RPI process and concluded there is no significant environmental risk from this incident.

The vent raise has been stabilised with shotcrete and no further movement has been detected during the daily surveys. The recovery plan involved lowering a short steel sleeve onto a concrete plug across the base of the collapsed section, inserting a long steel sleeve and shotcreting around the sleeve before backfilling the remainder with crushed rock from the decline mixed with cement. The concrete plug was then drilled through. The recovery operations were completed early October 2014 with the vent operational immediately thereafter.

Leach Tank Incident

At 00.54 am on 7 December 2013 Leach Tank No. 1 at the ERA Ranger uranium mine collapsed, spilling approximately 1400 m^3 of slurry containing ground uranium ore, water and sulphuric acid into the processing area.

It is the conclusion of Supervising Scientist Branch that the leach tank failure has not resulted in any adverse impacts to human health or the surrounding environment, including Kakadu National Park. The findings of Supervising Scientist Branch's investigation have been published in SSR207: **environment**.gov.au/resource/leach-tank-failure-report.

ERA has undertaken to implement the recommendations of Supervising Scientist Branch in relation to the leach tank incident, and this will be tracked through the MTC process.

The DME has retained Noetic Solutions Ltd to monitor the implementation of recommendations related to process safety via a series of quarterly inspections.

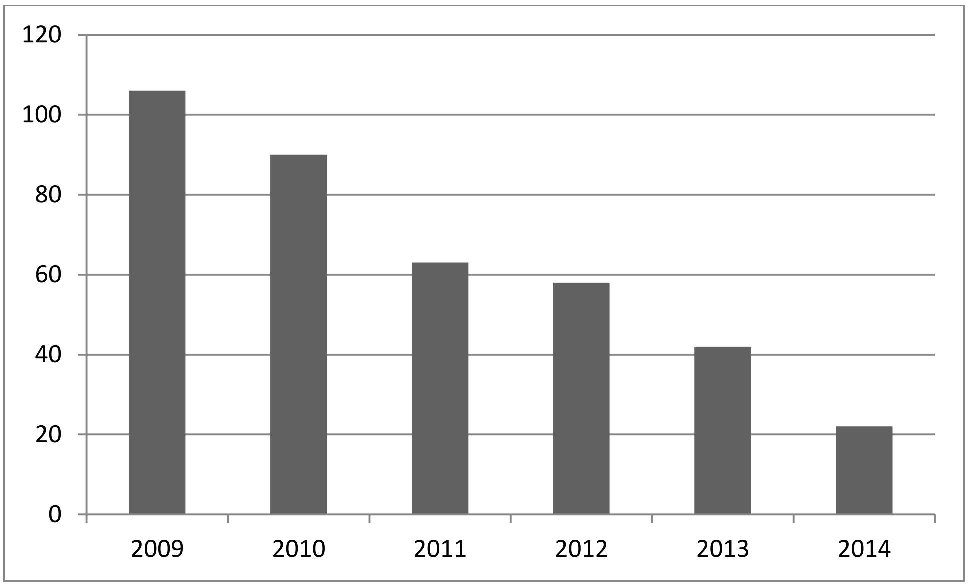


Figure 3.25 Ranger incidents by (calendar) year

3.2.5 Site closure and rehabilitation

Consistent with Northern Territory regulatory arrangements, ERA, as the operator of the Ranger mine, is responsible for proposing relevant closure criteria for consideration by the Northern Territory regulator and relevant stakeholders, including Supervising Scientist Branch. Once finalised, these closure criteria will require approval by both the Northern Territory Minister for Mines and Energy and Commonwealth Minister for Industry and Science.

In order to progress the development of relevant closure criteria, the Ranger MTC established a Closure Criteria Working Group (CCWG) in 2008. The CCWG comprises representatives from Supervising Scientist Branch, the DME, the NLC, the GAC (representing Traditional Owner interests) and is chaired by ERA.

The CCWG oversees the process for developing closure criteria and is the primary forum for reaching consensus between stakeholders on closure objectives and related assumptions including interpretation of the Commonwealth ER’s.

The CCWG has established six Technical Working Groups (TWG) covering the Landform, Radiation, Water and Sediment, Flora and Fauna, Soils, and Cultural themes.

The TWGs are tasked with developing specific closure criteria, and the identification of any scientific knowledge gaps or further research needs under their respective themes. Each TWG is coordinated and led by a representative from ERA, and includes representation from the relevant stakeholder groups, depending on expertise. All of the groups, with the exception of the Flora and Fauna TWG, have met at least once since their establishment. Figure 3.26 provides an overview of how these working groups and the MTC will be utilised to develop closure criteria for ministerial approval.

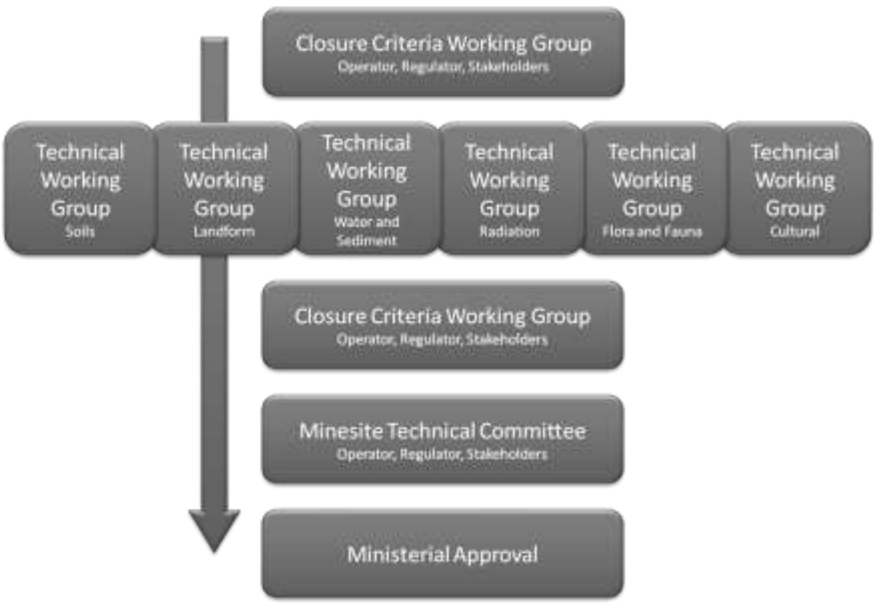


Figure 3.26 The closure criteria development process for Ranger mine.

Since July 2014 the there have been two formal meetings of the CCWG, on 14 August and 17 October 2014. The individual TWG’s have met on a needs basis throughout the financial year to discuss relevant area matters including any issues or resolutions arising from the CCWG meetings.

Rehabilitation works underway during 2014–15 include the backfill of Pit 3, commencement of tailings deposition in Pit 3, ongoing capping works on Pit 1 and preparations for the arrival of the tailings dredge. Transfer of tailings from the tailings dam to Pit 3 is scheduled to commence in quarter 3 2015. Further details on these closure activities may be found under the relevant on-site development heading in Section 3.2.1

3.3 Jabiluka

3.3.1 Developments

The Jabiluka site remains in a long-term care and maintenance mode. In October 2013 work on the removal of the Interim Water Management Pond (IWMP) was completed and the area contoured and prepared for revegetation.

ERA has installed a number of sediment traps to reduce the transport of fine material in surface run off and resulting turbidity in the creek. A boom gate was installed at the Oenpelli road end of the access track in August 2014 to restrict public access to the site.

In the 2014 dry season work was undertaken by ERA to rehabilitate bore sites and remove other exploration infrastructure to the north-east of Mine Valley and along the Oenpelli road. Work commenced in August 2014 and was completed in September 2014. A total of 21 bores were rehabilitated, and numerous items of infrastructure were removed, including cement pads, star pickets, drums, fences, and a toilet.

Supervising Scientist Branch revised the Ngarradj (Swift Creek) water monitoring programme for the 2014–15 wet season including upgrading the continuous monitoring station to include turbidity. ERA has also installed continuous turbidity monitors in both the northern and central tributaries on site.

3.3.2 On-site environmental management

3.3.2.1 Revegetation

Revegetation of the remaining disturbed parts of the Jabiluka Lease aim to recreate local native plant species in similar density and abundance to that existing in undisturbed, adjacent areas.

In late 2013, 3500 tubestock were planted at the former Jabiluka minesite with approximately 4524 additional plantings conducted during November and December 2014. In additon 155 tubestock where planted at the Djarr Djarr site. The six month revegetation survival rate was 48 percent for the planting conducted in late 2013. In November 2014 permanent plots were established in the revegetation area for ongoing montiring of revegetation.

Revegetation has been carried out with local native species, based on a revegetation strategy which will ultimately result in vegetation of similar density and abundance to that existing in adjacent undisturbed areas.

3.3.2.2 Weed Management

ERA has an active programme of weed management within the Jabiluika lease which includes the application of the broad-scale herbicide glyphosate as the primary control mechanism; however other herbicides may be used when appropriate.

The weeds that are present include grasses such as Annual Mission Grass (*Pennisetum pedicellatum*) and Red Natal Grass (*Melinis repens*), legumes such as Buffalo Clover (*Alysicarpus vaginalis*) and Stylo (*Stylosanthes sp.*), and herbs such as Hyptis (*Hyptis suaveolens*) and Tridax Daisy (*Tridax procumbens*).

Weed management, including management of aggressive native pioneer species (such as *Acacia holosericea*), will continue so that a build-up in fuel loads, and the suppression of growth of framework revegetation species, does not occur.

3.3.2.3 Water Management

Water management at Jabiluka was transitioned from an active to a passive system in 2013 with the removal of the IWMP infrastructure, and is currently managed and monitored in accordance with the current Authorisation.

3.3.2.4 Fire Management

For the recently revegetated Jabiluka mine site, fire will be excluded from revegetated areas for approximately three years to allow framework species to devlop sufficiently to withstand a cool burn. The revegetation at the former Djarr Djarr camp site has historically been detrimentally affected by wild fires, which come from the bush areas surrounding Djarr Djarr including the adjacent Kakadu National Park. ERA undertakes annual burning of the area around Djarr Djarr to reduce the chance of wildfires affecting the revegetation. The only reported incident for the Jabiluka site during the reporting period involved a wild fire impacting on the Djarr Djar site as detailed in Section 3.3.2.5.

3.3.2.5 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.

On completion of the rehabilitation works a gamma grid survey will be conducted on the rehabilitated landform to confirm that radiological activity in the rehabilitated area is within acceptable limits. ERA have advised that a gamma survey is scheduled for the 2015 dry season.

3.3.3 Off-site environmental management

3.3.3.1 Surface water quality

Flow was first recorded at the Ngarradj monitoring site on 4 January 2015. The continuous conductivity fluctuated between 13–33 µS/cm (Figure 3.27). These conductivities are higher than those observed historically and much of the measured data was in exceedance of the Ngarradj guideline trigger value of 21 µS/cm. High conductivities are typical of first flush conditions and the monitoring carried out by ERA showed that the conductivity measured upstream of the mine site also exceeded the guideline trigger value, indicating that the solutes were primarily derived from natural catchment sources.

There was a technical malfunction with the turbidity sensors during January that caused a one week period of missing data, from the 7 January 2015. A turbidity peak of 39 NTU on 14 February 2015 corresponded to increased flows when rainfall resulted in water levels increasing by approximately 1.5 m over a 2 hour period, with 24 mm of rain recorded at the monitoring site (Figure 3.29).

Continuous monitoring continued until 1 May 2015 when cease to flow was agreed by stakeholders.

3.3.3.2 Radiological exposure of employees

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.

Supervising Scientist Branch 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 3.25 and 3.27 show radon progeny PAEC and dust-bound LLAA radionuclide concentrations measured in air at Four Gates Road radon station during 2014. Tables 3.14 and 3.15 provide public dose estimates for these exposure pathways for a person living at Mudginberri in 2014.

3.3.4 Supervision and assessment activities

3.3.4.1 Annual Stakeholder Environmental Audit

2014 Audit Closeout

The 2014 Stakeholder environmental audit of Jabiluka was held on 12–15 May 2014. Thirty two commitments taken from the MTC application for IWMP removal and rehabilitation and the One Year Weed Management Plan 2013 were assessed. These commitments and communications were audited against the grading system shown in Table 3.1.

The 2014 audit delivered one category two non-conformance and five conditional findings which were followed up through the RPI process over the 2014–15 reporting period.

2015 Audit Criteria

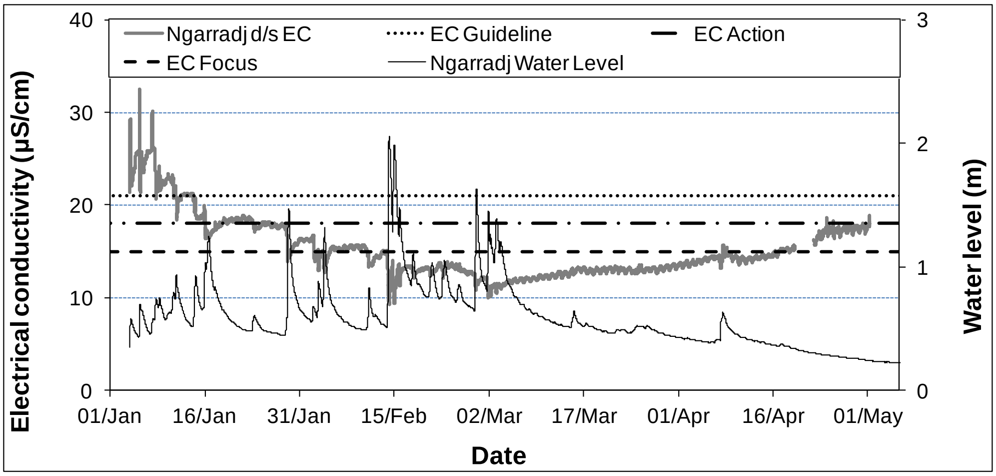
The 2015 environmental audit of Jabiluka was held on 15–19 June 2015. The audit team was made up of representatives from the NLC, DME, GAC and Supervising Scientist Branch.

Twenty four commitments from the 2013–14 Jabiluka Wet Season Report and 2013–14 Jabiluka Interpretative Report were audited against the grading system shown in Table 3.1.

The results of the 2015 audit are pending finalisation and will be detailed in next year's Annual Report

3.3.4.2 Routine Periodic Inspections

Three inspections were undertaken at Jabiluka during 2014–15 (Table 3.19). An inspection was conducted in conjunction with the environmental audit in June 2014 and two discrete RPIs were held in November 2014 and February 2015.



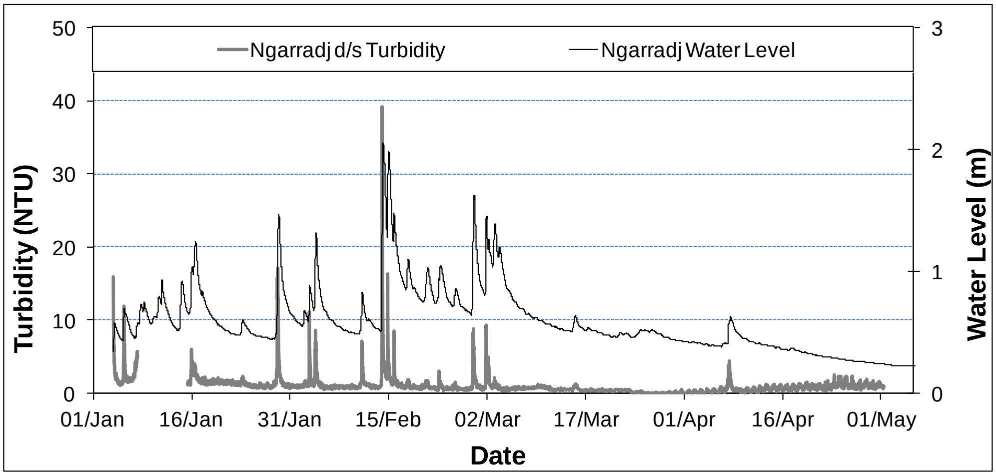


Figure 3.27 Continuous monitoring of EC, turbidity and water level Ngarradj (Swift Creek) during the 2014–15 wet season

TABLE 3.19 JABILUKA RPI FOCUS DURING THE REPORTING PERIOD

Date	Foci
13 November 2014	Progress of rehabilitation and impacts of fire at Djarr Djarr
19 February 2015	Progress of rehabilitation and flight over Djarr Djarr
21 June 2015	General site inspection in conjunction with the annual environmental audit

TABLE 3.20 JABILUKA MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items
11 July 2014	Mine Valley groundwater bores, access track maintenance
12 September 2014	Djarr Djarr rehabilitation, Mine Valley groundwater bores, Jabiluka Annual Plan of Rehabilitation #17, Jabiluka Wet Season Report
7 November 2014	Djarr Djarr fire incident, Jabiluka Annual Plan of Rehabilitation #17, Jabiluka Wet Season Report,
13 February 2015	Djarr Djarr rehabilitation, Mine Valley groundwater bores, Jabiluka Interpretative Report 2013-2014
10 April 2015	Revegetation, Mine Valley groundwater bores, Jabiluka Interpretative Report 2013-2014
22 May 2015	Mine Valley groundwater bores, Jabiluka Annual Plan of Rehabilitation #18

3.3.4.3 Minesite Technical Committee

The Jabiluka MTC met six times during 2014–15. Dates of meetings and significant issues discussed are shown in Table 3.20.

3.3.2.4 Authorisations

No applications to alter Jabiluka Authorisation 0140-05 were received during the reporting period.

3.3.2.5 Assessment of reports plans and applications

The main Jabiluka annual reports and plans assessed by Supervising Scientist Branch during 2014–15 included:

- Jabiluka Amended Plan of Rehabilitation No. 17 and No. 18
- Jabiluka Interpretative Report 2013-2014
- Jabiluka Wet Season Report 2013-2014

There were no applications received for Jabiluka by the MTC during the reporting period.

3.3.2.6 Incidents

During the 2014–15 reporting period, two environmental incidents were reported to Supervising Scientist Branch for the Jabiluka site. Both these incidents involved fires originating from off lease having a minor impact on revegetation at Djarr Djarr. Regrading of the access track around the Djarr Djarr revegetation area was undertaken to improve its effectiveness as a fire break. There was also refinement of the area fire management plan to ensure controlled burns where undertaken as early as possible in the dry season. Stakeholders inspected the impacts of these fires upon the Djarr Djarr rehabilitation area as part of the RPI process.

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.

On 29 October 2014 Supervising Scientist Branch was advised that UEL had moved their head office from Adelaide to Perth.

3.4.2 On site environmental management

3.4.2.1 The 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.

3.4.4 Supervision and Assessment Activities

3.4.4.1 Audits and Inspection

The 2014 post wet-season inspection and audit of the Nabarlek site was undertaken on 10 September 2014. The subject of the audit was the 2014 Nabarlek Mining Management Plan. The audit tested 25 commitments taken from this document. The following significant findings were determined:

- Four conditional findings
- Eight observations.

The four conditional findings related to; a structured programme of integrated controlled burns and weed control required for the site, provision of fire extinguishers in the camp area, replacement of a lock in the mineralised sample storage area and calibration of radiation monitoring equipment.

3.4.4.2 Minesite Technical Committee

The Nabarlek MTC met once during the reporting period. The following items were discussed at a meeting held on 29 July 2014:

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

3.4.4.3 Authorisations and approvals

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

3.4.4.4 Assessment of reports, plans and applications

A Mining Management Plan for the 2014 dry season exploration works was submitted to DME in April 2014 and was approved on 10 June 2014. Exploration drilling works were completed during July 2014. A Mining Management Plan for the 2015 dry season exploration works was submitted to DME in June 2015 and was still undergoing assessment during this reporting period.

3.4.4.5 Incidents

There were no environmental incidents reported at Nabarlek during 2014–15.

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.

Supervising Scientist Branch staff carried out the annual inspection of the containment facility on 26 June 2015. A fire in late 2014 had affected areas of the vegetation on the El Sherana containment. An inspection report was provided to Parks Australia.

3.5.2 Radiological monitoring of the El Sherana containment

The El Sherana airstrip containment is a near-surface disposal facility located in the South Alligator Valley area. It was constructed, filled and covered in the 2009 dry season. Following closure of the facility it is currently in the institutional control period, during which public access to, or alternative use of, the site must be restricted. The containment is managed by Parks Australia with regulatory oversight by the Australian Radiation

Protection and Nuclear Safety Agency. Supervising Scientist Branch currently assists Parks Australia by conducting biennial monitoring to assess the radiological conditions on site.

Supervising Scientist Branch conducted a survey of external gamma dose rates and radon-222 (^{222}Rn) exhalation flux densities across the El Sherana containment in May 2015. This was the fourth survey across the containment since its construction in 2009. External gamma dose rates on top of the containment have not changed and stayed at typical environmental levels. Figure 3.28 shows the results of the ^{222}Rn exhalation flux densities measured from environmental areas nearby and from the top of the containment, in September 2010, September 2012, October 2013 and May 2015. It is obvious that there is a tendency towards higher ^{222}Rn exhalation flux densities from the containment 3, 4 and 5.5 years after construction compared to 1 year after construction in 2010.

The reason for this increase may be associated with changes of the physical properties of the containment cover, as outlined in the Supervising Scientist Annual Report 2012–13. In June 2013 vegetation in the middle of the containment was cleared and approximately 1 m of clean soil placed on top of the existing capping to re-contour the surface and prevent erosion of the capping material at the containment. This additional layer does not appear to have lowered overall radon activity fluxes from the containment measured in October 2013. The apparent decrease for May 2015 is most likely associated with the time of year of the measurements: the survey was conducted in May, at the end of the wet season, when ^{222}Rn exhalation flux densities from soils are typically lower due to the higher soil moisture, compared to peak dry season conditions during the previous three surveys. As shown in the Supervising Scientist Annual Report 2012–13, ^{222}Rn exhalation flux densities measured at the El Sherana containment do not lead to unacceptable radiation doses to workers or the public, and continue to be less than 10 µSv per year.

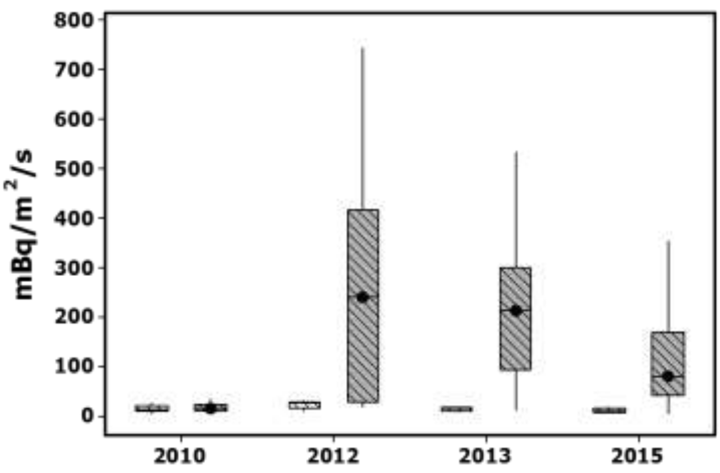


Figure 3.28 Box plot of environmental background (open boxes) and containment (grey boxes) ^{222}Rn exhalation flux densities. The marker indicates the median, the width of the box is the interquartile range, whiskers indicate the upper and lower 25% of the distribution.

3.5.3 Exploration

Supervising Scientist Branch undertakes a programme of site inspections and audits at exploration sites in western Arnhem Land. During the reporting period Supervising Scientist Branch coordinated audits of the following exploration sites in Western Arnhem Land:

- Cameco King River Camp and Arnhem Project
- Alligator Energy Myra Camp and Arnhem Project
- Uranium Equities Limited West Arnhem Joint Venture.

Each operation was audited against commitments from their approved Mining Management Plan and criteria tested were graded in accordance with the classifications presented in Table 3.1.

3.5.3.1 Cameco Arnhem Project

The Annual Environmental Audit of the Cameco Arnhem Project was undertaken on 13-14 October 2014. The audit team was made up of personnel from Supervising Scientist Branch, DME and NLC.

The subject of the audit was the approved 2014 Arnhem Project Mining Management Plan. The audit tested 30 commitments taken from this document.

The following findings were determined:

- One category 2 non-conformance
- Two initial conditional findings downgraded to acceptable
- Seven observations

The category 2 non-conformance related to the maintenance of radiation clearance records.

3.5.3.2 Alligator Energy Arnhem Project

The Annual Environmental Audit of the Alligator Energy exploration project in Arnhem Land was undertaken on 22-23 September 2014. The audit team was made up of personnel from Supervising Scientist Branch, DME and NLC.

The subject of the audit was the approved 2014 Alligator Energy Mining Management Plan. The audit tested 30 commitments taken from this document.

The following findings were determined:

- Six observations.

3.5.3.3 UEL West Arnhem Joint Venture

The Annual Environmental Audit of the UEL, West Arnhem Joint Venture was undertaken on 10 September 2014 in conjunction with the Nabarlek Annual Environmental Audit (Section 3.4.4.1). The audit team was made up of personnel from Supervising Scientist Branch, DME and the NLC.

The subject of the audit was the 2014 West Arnhem Joint Venture Mining Management Plan. The audit tested 23 commitments taken from this document.

The following significant findings were determined:

- Three conditional findings
- Nine observations.

The three conditional findings related to; provision of fire fighting equipment in the camp area, replacement of a lock in the mineralised sample storage area and calibration of radiation monitoring equipment.

3.7 EPBC assessment advice

Supervising Scientist Branch continues to provide advice to the Environmental Standards Division (ESD) of the Department on referrals submitted in accordance with the EPBC Act for new and expanding uranium mines.

During the reporting period Supervising Scientist Branch provided responses on the following assessment activities:

- Cameco - Kintyre Uranium Project, conditions associated with EPBC approval.
- Energy Minerals Australia - Mulga Rock Uranium Project, Environmental Scoping Document.
- Territory Iron - Frances Creek Mine Elizabeth Marion Extension, EPBC referral.
- ERA - Ranger 3 Deeps underground mine, draft EIS. (Section 3.2.1).

Kintyre Uranium Project

On 28 July 2014, the Western Australian Environment Protection Authority (EPA) released the Kintyre assessment report which concluded that the proposal could proceed subject to several recommendations including the following relevant to Supervising Scientist Branch.

Landform evolution model should be developed:

- to assess the trajectory of the landform evolution rather than a specific time scale, on advice from Supervising Scientist Branch
- should be updated in mine closure plans on advice from Supervising Scientist Branch.

The EPA recommended that the Western Australian Department of Mines and Petroleum (DMP) develop a formal agreement with Supervising Scientist Branch for certain aspects of regulating uranium mines. Work on this MoU is well advanced.

On 26 March 2015 the Minister for the Environment approved (with conditions) the Kintyre Uranium Project. Conditions included the submission of an Environment Management Plan (EMP) no later than three months prior to operational commencement. This EMP required several matters related to environmental radiation and mine closure to be addressed to the satisfaction of Supervising Scientist Branch including;

- environmental radiation reference values and modelling for non-human biota which reflects Australian species
- modelling to determine long-term geomorphic stability of final landforms for the tailings management facility and mine pit.

4 ENVIRONMENTAL RESEARCH

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 ARRRI was subsequently renamed the Environmental Research Institute of the Supervising Scientist (***eriss***).

The core work of ***eriss*** comprises research and monitoring to ensure the protection of people and the environment from the effects of uranium mining in the Alligator Rivers Region. The details and outcomes of the monitoring programmes are reported in chapter 3, with the highlights of the research programme for 2014–15 reported here. The expertise of the ***eriss*** is also applied to conducting research on the environmental protection of tropical rivers and their associated wetlands, and to providing advice to the Department of the Environment and other government organisations on 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 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. These Key Knowledge Needs define the key research needs within each of the geographic domains in the Alligator Rivers Region relating to monitoring, closure and rehabilitation for current (Ranger), rehabilitated (Nabarlek and Jabiluka) and legacy (South Alligator River Valley) sites. The charter and activities of ARRTC are described in chapter 2 of this report and the current list of Key Knowledge Needs is provided for reference in Appendix 1.

eriss focuses its research in the following scientific fields:

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

As noted above, highlights from the 2014–15 ***eriss*** research programmes are presented in this chapter. Specifically, nine projects that cover all the above-listed research fields are discussed. They represent a snapshot of the broader research programme within ***eriss***, which covered over 30 projects. Of these, eight were completed, 14 were commenced and the remainder were continuing projects. The full research project suite is listed in Appendix 4. The majority (~95 percent) 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 Supervising Scientist and Internal Report series. Publications by Supervising Scientist Branch staff in 2014–15 are listed in Appendix 2, while presentations given during the year are listed in Appendix 3. More information on Supervising Scientist Branch's publications, including the full list of staff publications from 1978 to the end of June 2015, is available on the Department of the Environment website at: **environment**.gov.au/supervising-scientist/publications.

4.1 Development of a soil radiological quality guideline for wildlife protection in uranium mine rehabilitation

4.1.1 Introduction

The need to consider above-background radiation exposures to wildlife resulting from human activities has been recognised internationally by the International Commission on Radiological Protection (ICRP) and nationally by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Such exposures are usually quantified as an absorbed dose rate and can be placed in a risk context by comparing to a benchmark dose rate, which is a value of absorbed dose rate considered to provide an acceptable level of radiological protection to wildlife; generally the prevention of harmful impacts to wildlife populations and ecosystem biodiversity.

For terrestrial ecosystems, the risk context can also be established by comparing the measured or predicted above-background soil radionuclide activity concentrations in the environment to those that would result in an absorbed dose rate to wildlife equal to that of the benchmark dose rate. This equivalent soil activity concentration can be back-calculated from the benchmark dose rate as:

Equivalent soil activity concentration (Bq kg^{-1}) = *BDR*/*F*

where:

BDR (µGy h^{-1}) is the benchmark dose rate; and

F (µGy h^{-1} per Bq kg^{-1}) is the absorbed dose rate to the organism per unit activity concentration of the radionuclide(s) in soil.

This study aims to derive a soil radiological quality guideline value for the protection of wildlife which can be considered at the landform design stage of rehabilitation planning and help inform the development of radiological closure criteria for Ranger mine.

4.1.2 Methods

4.1.2.1 Radionuclides

The surface substrate of the Ranger rehabilitated landform is expected to comprise low uranium grade waste rock material. The radionuclides in the substrate that will contribute to post-rehabilitation environmental exposures of wildlife will be those of the ^{238}U-series. Secular equilibrium (i.e. equal activities of all radionuclides) within the ^{238}U-series has been assumed to occur in the substrate in this study, as waste rock is a natural and unprocessed material.

4.1.2.2 Reference organisms

Kakadu National Park includes a large diversity of terrestrial wildlife and it is not possible to make an assessment for each species individually. Reference organisms have instead been used to collate data and make assessments for general taxonomic groups (Table 4.1). The approach is consistent with international best practice approaches for environmental radiological assessment and with those for organising data on radionuclide transfer to wildlife for use in such assessments.

4.1.2.3 Benchmark dose rate

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is the international authority on effects of ionising radiation. They have reviewed the radiation effects data for non-human biota and concluded that *'chronic dose rates of less than 100 µGy/h to the most highly exposed individuals would be unlikely to have significant effects on most terrestrial communities'*. This conclusion assumes reproductive success as the most critical endpoint for species population success and is based on observed effects levels reported in the scientific literature.

4.1.2.4 Radionuclide transfer

Radionuclide transfer was quantified as the concentration ratio ($CR_{wo\text{-}soil}$) between the activity concentration in the whole organism wet mass and the soil dry mass. The generic $CR_{wo\text{-}soil}$ values from the ERICA Tool v1.2 were used in the first instance. A second assessment was also made using site-specific $CR_{wo\text{-}soil}$ values for mammal and reptile, which were derived from radioactivity measurements made on samples collected by ***eriss***. No site-specific data were available for other organism types.

TABLE 4.1 REFERENCE ORGANISMS

Organism	Comments
Amphibian	Primarily used to make an assessment for frogs because of the ecological niche that they occupy.
Arthropod	Primarily used to make an assessment for termites due to their high importance to the nutrient cycle in northern Australia.
Bird	Primarily used to make an assessment for small terrestrial birds due to a number of threatened species in the region.
Grass	Primarily used to make an assessment for native wild grasses due to their importance to the seasonal fire cycle of the region.
Mammal	Some mammals have Aboriginal cultural significance as totemic species and traditional food items.
Reptile	Primarily used to make an assessment for squamate reptiles (i.e. snakes, goannas and lizards) due to a number of threatened species in the region.
Tree	Some trees have Aboriginal cultural significance in ceremonies, traditional medicines and the manufacture of wooden articles.

4.1.2.5 Analysis approach

The ERICA Tool v1.2 was used to determine probabilistically the organism absorbed dose rate per unit activity concentration of ^{238}U-series radionuclides in the waste rock substrate of the Ranger rehabilitated landform. The 95th percentile value of the output probability distribution was chosen to represent *'the most highly exposed individuals'* of each reference organism and was subsequently used in the back-calculation of equivalent soil activity concentrations from the 100 µGy h^{-1} benchmark dose rate adopted from UNSCEAR.

4.1.3 Results and discussion

Figure 4.1 shows the total (background+incremental) activity concentration of ^{238}U-series radionuclides in waste rock that would result in an above-background absorbed dose rate of 100 µGy h^{-1} to the most highly exposed individuals (95th percentile) of each reference organism. Results are shown for assessments using both the ERICA Tool v1.2 $CR_{wo\text{-}soil}$ values and the site-specific $CR_{wo\text{-}soil}$ values for mammal and reptile.

The background and incremental components of the total activity concentration have been resolved in Figure 4.1. The background component of 360 Bq kg^{-1} is the average pre-mining soil activity concentration of the Ranger mine site determined by ***eriss*** from historic airborne gamma surveys of the area[8]. The incremental component is the equivalent soil activity concentration back-calculated from the benchmark dose rate.

The limiting reference organism for the ecosystem was reptile and comes from the assessment using site-specific $CR_{wo\text{-}soil}$ values. The corresponding ^{238}U activity concentration of 1100 Bq kg^{-1} is suggested as an interim soil radiological quality guideline value for the waste rock substrate of the Ranger rehabilitated landform. By comparison, Ranger waste rock has a maximum ore grade equivalent to approximately 2100 Bq kg^{-1} of ^{238}U and lower average ore grade.

The results for both reptile and mammal indicate that the use of site-specific $CR_{wo\text{-}soil}$ values gives soil ^{238}U activity concentrations which are less than half those obtained using the generic ERICA Tool $CR_{wo\text{-}soil}$ values. If this same trend is true for the other taxonomic groups, then the guideline value could reduce based on the result for grass. However, site-specific $CR_{wo\text{-}soil}$ data is needed to verify this.

[8] 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.

4.1.4 Conclusions

The rehabilitation of Ranger mine may lead to above-background radiation exposures of terrestrial wildlife if average radionuclide activity concentrations in the substrate of the rehabilitated landform are greater than those pre-mining. This situation is likely to occur, as the expected substrate for rehabilitation is low uranium grade waste rock. The results of this study suggest a soil radiological quality guideline value for wildlife of 1100 Bq kg^{-1} of ^{238}U in secular equilibrium with progeny in the waste rock substrate of the rehabilitated landform. However, the guideline value should be considered interim due to the lack of site-specific data for some organism types.

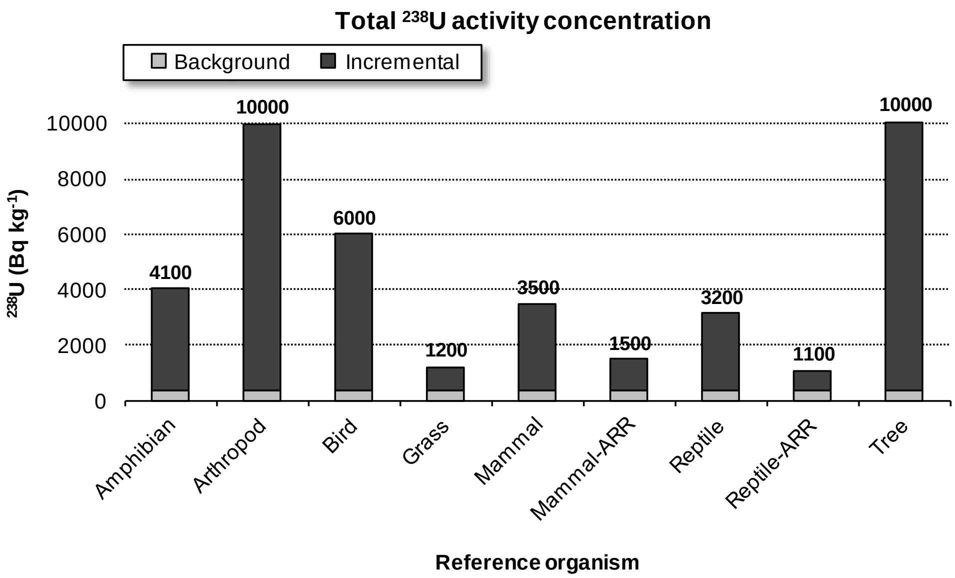


Figure 4.1 Total (background+incremental) activity concentration of ^{238}U-series radionuclides in the waste rock substrate of the Ranger rehabilitated landform that would result in an above-background absorbed dose rate of 100 µGy h^{-1} to the most highly exposed individuals (95th percentile) of each reference organism. The -ARR suffix on the organism name indicates assessment results using site-specific $CR_{wo\text{-}soil}$ data for the Alligator Rivers Region; all other results use $CR_{wo\text{-}soil}$ data from the ERICA Tool v1.2.

4.2 Monitoring mine site rehabilitation using an unmanned aerial system

4.2.1 Introduction

In 2014, ***eriss*** acquired an unmanned aerial system (UAS) with a multispectral photogrammetric platform for the purpose of establishing a framework/methodologies/programme to monitor landscape condition at a fine scale. This includes monitoring the success of mine site rehabilitation. A test project has been established to monitor the progress of the Jabiluka minesite rehabilitation. Rehabilitation work was undertaken at the minesite in October 2013 with additional plantings conducted late 2014. The project aims to develop methods for data collection, data processing and data analysis suitable for monitoring change over time. The Revegetation and Landscape Ecology (RLE) group at ***eriss*** has recently received its UAS Operator's Certificate from the Civil Aviation Safety Authority (CASA). All researchers in the RLE group are CASA certified remote pilots and have each undertaken numerous missions using the unmanned aerial vehicle (UAV).

The UAS acquired is the Swampfox X5 delta wing (Figure 4.2a). The UAV has a 2.3 m wingspan and is pushed by an electric motor and controlled via telemetry from a mobile ground control station. The payload for this project consists of two Sony Nex-5 cameras, one standard RGB (Red, Green, Blue) and the other converted to capture near infrared (NIR, >720 nm) imagery (Figure 4.2b).

4.2.2 Work to date

To date, five missions have been undertaken capturing nadir (straight down)-looking RGB and NIR photos over the Jabiluka mine site (Table 4.2) at approximately 2-3 month intervals. The whole site can be covered in less than 30 minutes. During the flights, photos are taken to ensure at least 80 percent forward overlap and 60 percent side overlap. Concurrent with each mission, a number of differential Global Positioning System (dGPS) referenced ground control points (GCPs) were placed across the site to assist with orthorectification of the photos (Figure 4.3). In addition, bright and dark spectral reference panels were also placed to assist with the radiometric calibration of the imagery.

4.2.2.1 Pre-processing

All imagery is corrected for vignetting (the attenuation of brightness toward the image edge) using flat field correction and sensor noise (i.e. pixel irregularities) using dark frame extraction. The digital photos are then converted from RAW to TIFF format for photogrammetric processing.

(a) (b)

Figure 4.2 (a) The Swampfox preparing for flight, and (b) the RGB and NIR camera payload.

TABLE 4.2 FLIGHT DETAILS		
Date	**RGB images**	**NIR images**
28 April 2014	578	578
13 June 2014	408	408
23 September 2014	361	361
23 December 2014	458	458
23 April 2015	433	433

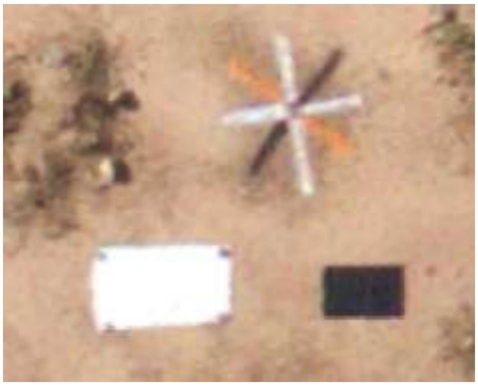


Figure 4.3 Example of a ground control point (yellow cross) and white and black spectral reference panels at Jabiluka mine site from December 2014.

4.2.2.2 Photogrammetric processing

Using the UAV's 3D GPS position and attitude (pitch, roll and yaw) for each photo, and the GCPs, our photogrammetric software calculates the camera's pose for each photo. The software then automatically identifies thousands of tie points between pairs of images and, using triangulation, undertakes the geometric correction of each photo. This information is then used to create 3D point clouds from which surface models and terrain models are produced. The terrain model is then used as the geometric model for creating a single orthomosaic from the photos. The RGB and NIR orthomosaics are then merged into a single four band image and analysis undertaken.

4.2.3 Results to date

For each of the dates we have produced a RGB orthomosaic, a NIR orthomosaic, digital surface (DSM) and terrain (DTM) models (Figure 4.3), as well as a dense 3D point cloud. These data sets will be analysed to determine the success of revegetation over the time frame.

Early analysis of a sample area of the imagery has shown that, within the area, the vegetation has changed quite noticeably over the time period (Figure 4.3). Of the 107 plants detected from the April data, only 68 were still alive in June (Figure 4.4a). Eight volunteer plants (plants that have germinated on their own) appeared during that period. Between June and September, a further 25 plants died within the subset area with another 13 volunteer plants appearing (4.4b).

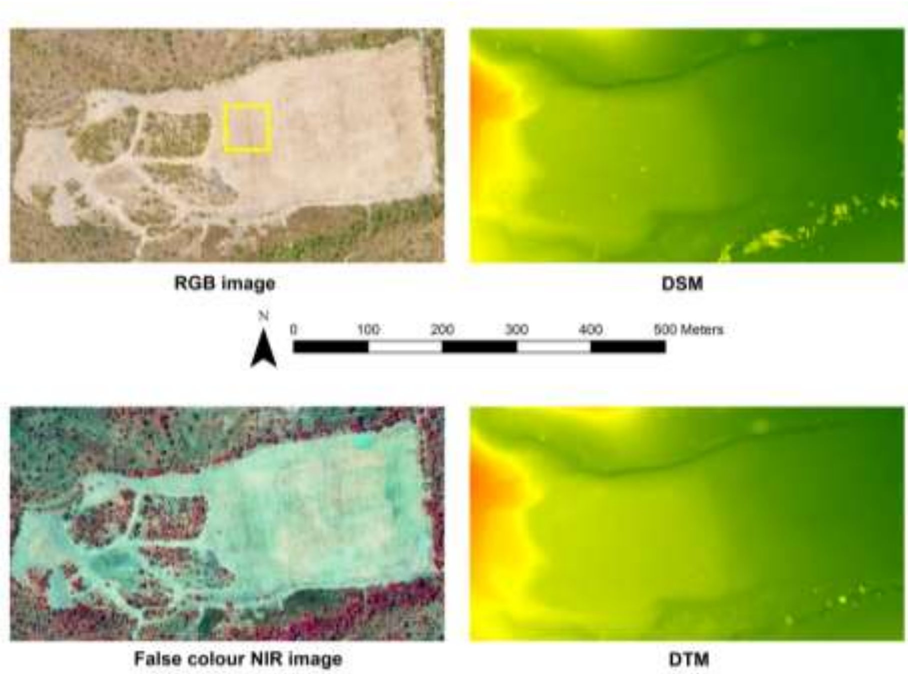
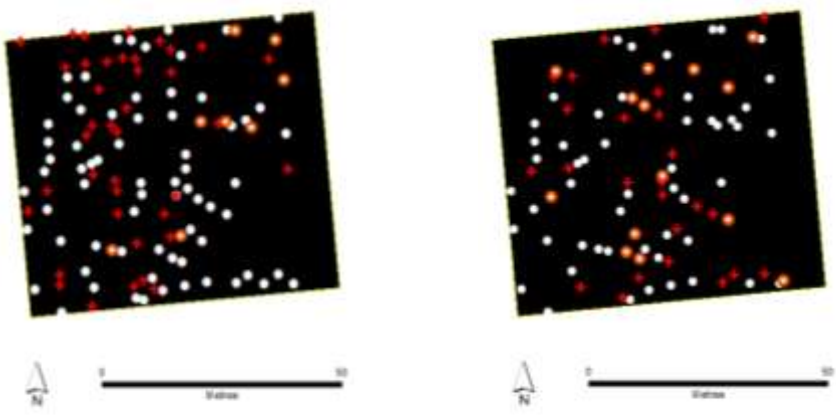


Figure 4.3 Products from the September 2014 flight over Jabiluka mine site. The yellow square is the sample area shown in Figure 4.4.



(a) (b)

Figure 4.4 Change in the sample area between April and June 2014 (a) and June and September 2014 (b). The white dots are plants that are alive at the start and end of each time period. The red crosses are plants that have died between the start and end of each time period. The orange circles are volunteer plants that have emerged.

4.2.4 Conclusions and future work

The data we have collected so far enables us to show how the rehabilitation of Jabiluka minesite has been progressing. Further analysis will give us a quantitative measure of change over the site for the time period. The detailed findings of this research will be published in peer-reviewed journals.

Further research for this project includes:

- the refinement of the photogrammetric workflow that produces outputs specific to the requirements of ***eriss***
- the development and testing of automated approaches to image analysis to provide land cover information
- the investigation of robust change detection methods for the time series data.

In addition, we have recently acquired two new sensors for integration into the UAS. One is a multispectral camera with five narrow wavebands (Blue, Green, Red, Red edge and NIR) to improve our vegetation mapping. The extra spectral information will enable the accurate calculation of vegetation indices. In addition, a hyperspectral pushbroom sensor has also been acquired to test its applicability in monitoring vegetation.

4.3 Analysis of aquatic vegetation community data from shallow waterbodies of the Alligator Rivers Region

4.3.1 Background

Development of closure criteria for aquatic ecosystems associated with the rehabilitation of Ranger Uranium Mine has, to date, focused primarily on key water quality variables. As the mine moves towards rehabilitation, a wider range of ecological information will be required to ensure that site conditions, biological communities and key ecological processes meet the Environmental Requirements.

A review of aquatic ecosystem literature for the Alligator Rivers Region highlighted a knowledge gap associated with aquatic vegetation in sandy creek channels and shallow billabongs of the lowlands. While aquatic vegetation data are collected as the ‘habitat’ component of current monitoring projects for macroinvertebrate and fish communities, these data have not been analysed and evaluated for their own value, both in terms of responses of aquatic vegetation to natural and mine-related stressors, and in the context of ecosystem establishment and rehabilitation targets.

A recurring theme in discussions around aquatic vegetation is that rehabilitation targets will need to capture natural variation within vegetation communities. Rather than relying solely on (early) baseline vegetation data, which may have changed over time, targets will need to reflect natural changes associated with contemporary reference or analogue conditions.

This project aims to evaluate the natural variation of aquatic plant communities in shallow waterbodies around Ranger by analysing existing data collected by ***eriss*** between 1993 and 2014. The objective of the study is to characterise aquatic vegetation communities, determine the level of spatial and temporal community change and seek possible environmental determinants of the patterns observed. Such knowledge may inform establishment methods and targets for rehabilitation of aquatic systems both on- (within the Ranger Project Area) and off-site.

The first task associated with the project was to evaluate and amalgamate relevant datasets in a form that could address the key research needs. Having undertaken this, the following research questions could then be posed:

- Do the aquatic vegetation communities of shallow, lowland mine disturbed and reference waterbodies differ?
- Have shifts in vegetation community composition occurred over time?
- For any spatial or temporal differences or shifts in composition observed, are there specific taxa distinguishing these changes or differences?

4.3.2 Methods

4.3.2.1 Data preparation

Aquatic vegetation data were compiled from two key ***eriss*** programmes:

- billabong macroinvertebrate monitoring
- shallow lowland billabong fish monitoring.

These programmes examined 15 shallow waterbodies in total. Of these, five are considered to be mine-disturbed, either through changes in water quality and/or catchment alteration (RP1 and RP2, and Georgetown, Coonjimba and Djalkmara billabongs). The remaining waterbodies are all considered to be reference sites for the purposes of this study (Gulungul, Corndorl, Baralil and Wirnmuyurr billabongs and Jabiru Lake (Magela Creek catchment); Buba, Sandy Shallow, Angbangbang and Malabanbandju billabongs (Nourlangie Creek catchment); and Cathedral Billabong (East Alligator River catchment)) (see Map 3).

Aquatic vegetation communities were assessed by visual estimation methods (percent cover). Genus-level assessments were undertaken, except for *Najas*, *Nitella*, *Chara* and *Utricularia*, which are submerged fine-feathery taxa that in some early years were not distinguished in the field. These taxa were combined under a 'submerged feathery' category. To account for different methods of vegetation assessment, presence/absence data were used for all analyses, removing bias in percent estimation assessments amongst years and between (macroinvertebrate and fish) programmes. Further validity in combining aquatic vegetation datasets from macroinvertebrate and fish monitoring studies is provided in Section 4.6.3.1 below.

4.3.2.2 Data analyses

Community composition data from replicate locations within the different waterbodies have been collated and analysed using community summaries and multivariate statistical techniques in PRIMER. Community summaries are based on number of taxa (mainly genus). Multivariate techniques included:

1. Hierarchical cluster analysis, where samples of similar assemblages are grouped, with the groups forming clusters at lower levels of similarity. A group average linkage was used to derive the resultant dendrogram;
2. Multi-Dimensional Scaling (MDS) ordination, depicted as two-dimensional plots based on the sample by sample Bray-Curtis similarity matrices;
3. Analysis of Similarity (ANOSIM), examining the degree and significance of separation of *a priori* groups in ordination space. (ANOSIM is effectively an analogue of the univariate ANOVA based upon rank similarities between samples in the underlying Bray-Curtis similarity matrices.); and
4. SIMPER, examining taxa that are contributing to the differences in groups identified from ANOSIM analyses.

A priori groups used for these analyses included:

1. Reference versus mine-disturbed sites; and
2. Three year-class intervals determined on the basis of (i) a relatively abrupt change in water chemistry observed in RP1, Coonjimba and Georgetown billabongs9 (i.e. between interval 1993–2000 and interval 2001–2011), together with (ii) examination of ordination plots for the vegetation data for each billabong separately (results not shown here), which showed the last three years (i.e. interval 2012–2014) in most waterbodies grouping and separating out together in ordination space.

4.3.3 Results and discussion

4.3.3.1 Spatial and temporal patterns in aquatic plant communties

The median number of taxa per reference waterbody was consistently higher than that in mine-disturbed billabongs (Figure 4.5). There also appears to be a trend of increasing taxa number for both reference and mine-disturbed sites over time.

A hierarchical cluster analysis was run to examine any patterns of grouping in the data. Significant clusters, as determined by the SIMPROF permutation test, indicated that the highly modified artificial waterbodies, Jabiru Lake and Retention Pond 2 (RP2), were significantly separated from all other sites, while mine disturbed sites were generally separated from reference sites (results not shown here). RP2 and Jabiru Lake data were subsequently removed from the analyses due to a tendency to greatly skew the data.

The MDS ordination for all remaining waterbodies is shown in Figure 4.6. Amongst reference sites and confirming the cluster analysis, there was interspersion of billabongs occurring in Magela and other (including Nourlangie Creek) catchments (Table 4.3), indicating that any separation of mine-disturbed and reference waterbodies evident in Figure 4.6 was not due to catchment. Reference sites were also interspersed according to

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[9] Humphrey C & Chandler L 2015 Developing water quality closure criteria for Ranger billabongs using macroinvertebrate community data In: ***eriss*** *research summary 2013-2014*. Supervising Scientist Report 209, Department of the Environment, Darwin NT,

macroinvertebrate and fish sampling programmes indicating, similarly, no method artefact amongst the reference billabongs (Table 4.3). In all other respects, the ordination was consistent with the cluster analysis. While some separation of the data was evident between mine-disturbed and reference waterbodies (Figure 4.6), ANOSIM indicated that such separation was minor (Table 4.3).

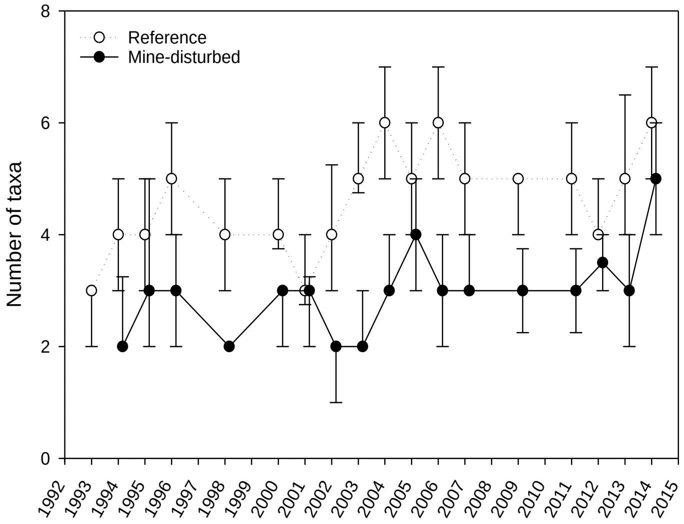

Figure 4.5 The median number of taxa for each year of sampling per reference and mine-disturbed waterbody. Error bars are 25th and 75th percentiles. No mine-disturbed sites are represented in 1993. Data from years 2006, 2011 and 2013 were derived from macroinvertebrate sampling, years 1993, 1994, 1998, 2000-2005, 2007, 2009, 2012 and 2014 from fish sampling, and 1995 and 1996 from both macroinvertebrate and fish sampling.

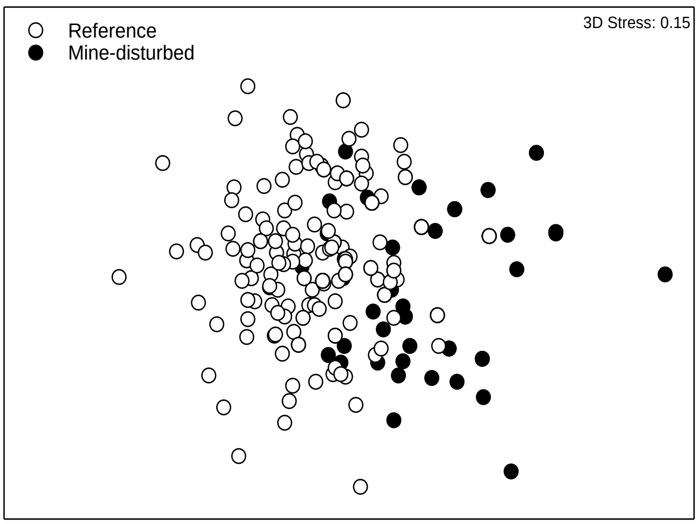

Figure 4.6 Ordination plot of plant composition (showing axis 1 and 2) for all years.

Compositional shifts over time were examined from ordinations derived separately for reference and mine disturbed waterbodies (Figure 4.7a). For both waterbody types, all pairwise combinations of year groups were barely separable in ordination space (Table 4.3; R-statistic <0.25), indicating negligible changes in plant composition over time, even though mine-disturbed sites did show a slightly stronger separation between early years and latter years than reference sites for the same time comparison.

4.6.3.2 Plant taxa distinguishing the observed spatial and temporal differences

SIMPER analysis was applied to the main (combined waterbody) ordination (Figure 4.6), as well as the separate mine-disturbed and reference waterbody ordinations (Figure 4.7a). *Caldesia*, submerged feathery species and *Nymphoides* had greater occurrences in reference billabongs while the emergent *Eleocharis* occurred more often in mine-disturbed waterbodies. The primary plant taxa contributing to the difference between time periods and waterbody type were submerged feathery species and *Eleocharis.* These two taxa categories are presented as bubble plots over the MDS ordinations in Figure 4.7(b) and 4.7(c), respectively. The size of the bubbles in these plots is related to the number of occurrences at each site over time. For both mine-disturbed and reference waterbodies, submerged feathery genera tended to be absent from earlier years (1993–2000), with generally greater frequency of occurrences in the reference billabongs, as noted above. *Eleocharis*, conversely, has tended to be more prevalent in the mine-disturbed sites (as noted) with consistent very low frequency of occurrence in just a few reference billabongs, including Corndorl, Sandy and Malabanbandju, over time.

TABLE 4.3 ANOSIM RESULTS

Groups	R-Statistic[1]	Significance level %
Magela vs other reference billabongs		
Global Test	0.102	0.01
Macroinvertebrate vs fish reference data		
Global Test	0.154	0.01
Mine-disturbed versus reference waterbodies		
Global Test	0.209	0.01
Year intervals in mine-disturbed waterbodies		
Global Test	0.082	1.1
1993-2000 vs 2001-2011	0.057	1.4
1993-2000 vs 2012-2014	0.208	0.6
2001-2011 vs 2012-2014	0.013	41.1
Year intervals in reference billabongs		
Global Test	0.042	4.8
1993-2000 vs 2001-2011	0.057	0.1
1993-2000 vs 2012-2014	0.079	9.2
2001-2011 vs 2012-2014	-0.024	64.7

1 The degree of separation between groups is denoted by the R-statistic, where R-statistic > 0.75 = groups well separated, R-statistic >0.5 = groups overlapping but clearly different, and R-statistic <0.25 = groups barely separable. A significance level of <5% =- significant effect/difference.

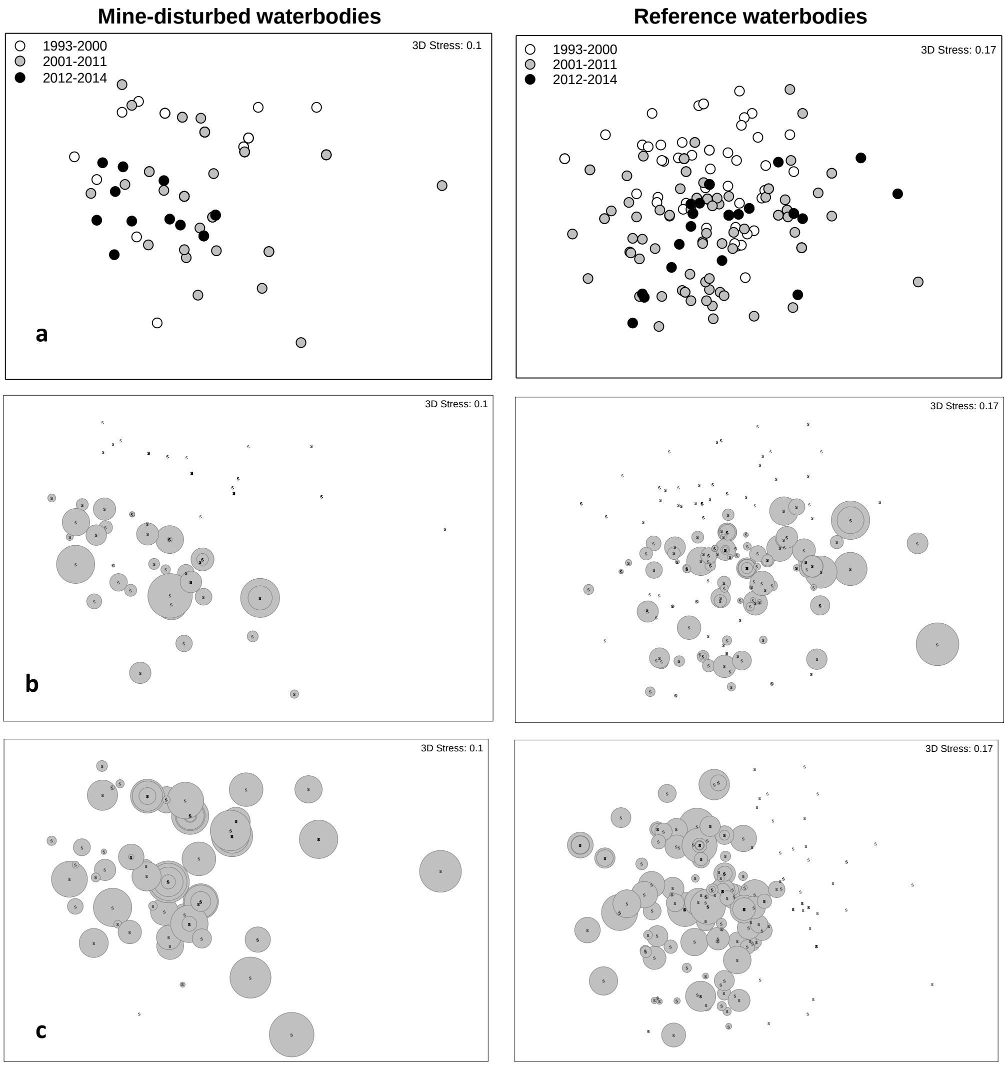

Figure 4.3 (a) Ordination plots showing axis 1 and 2 for mine-disturbed sites only (left) and reference sites only (right). Sites are classified by year groups. Bubble plots superimposed on the mine-disturbed and reference ordinations of influential species identifed by SIMPER (b) *Utricularia* and (c) *Eleocharis*.

4.6.4 Conclusions and further work

Initial analyses of aquatic vegetation data from shallow waterbodies indicate only a small difference in community composition between reference and mine-disturbed waterbodies, and only slight shifts in composition in both waterbody types since 1993 to 2014. Submerged feathery species and emergent *Eleocharis* appear to be significant indicators of aquatic vegetation change between mine-disturbed and reference billabongs and for submerged feathery species, also over time.

Future analyses will seek relationships between key environmental variables and the multivariate patterns observed. The small changes noted in plant communities of mine-disturbed waterbodies over time are consistent with those similarly observed in reference billabongs, suggesting little influence of mine-related water quality. Supporting this, the magnitude of differences in taxa number between the two waterbody types has been similar over the study period, a period that has included significant changes in water quality in the mine-disturbed sites (i.e. post-2000) (Figure 4.5). This could indicate that natural factors such as differences in waterbody morphometry or catchment size are more important determinants of plant community composition. Understanding possible causal mechanisms will be enhanced through further time series analyses, comparing the current dataset with species lists compiled during the 1980s.[10]

Incorporation into the statistical analyses of additional aquatic vegetation data collected by Energy Resources Australia Ltd (ERA) from smaller on-site (constructed) waterbodies will also potentially inform (i) water quality tolerances of aquatic vegetation and (ii) decisions on whether on-site waterbodies generally, natural and constructed, have potential to host the broader suite of aquatic plant communities found in similar shallow billabongs of Kakadu National Park.

4.4 Chronic uranium exposure to the aquatic snail, *Amerianna cumingi*

4.4.1 Background

Recently revised derivation methods for national water quality guideline values provide clearer and prescriptive definitions of acute and chronic testing criteria and, where possible, encourage the use of local species to derive high reliability guideline values (GVs) for contaminants entering the aquatic ecosystem. Specifically, tests performed on adult macro-invertebrates should ideally be a minimum of 14 days to be considered chronic. This criterion was developed based on data from a range of temperate species. Therefore, it is acknowledged that exceptions might exist when this criterion is applied to tropical species which have faster generational rates. In these instances it is acceptable to reduce test duration where sufficient evidence is available[11].

The aquatic snail, *Amerianna cumingi*, is commonly used to derive toxicity estimates for toxicants of concern in tropical northern Australia. The standard protocol developed for this species is an egg production test conducted over a 96-hour period. Therefore, it does not fit

[10] Finlayson C, Thompson K, von Oertzen I & Cowie I 1994. Vegetation communities of five Magela Creek billabongs, Alligator Rivers Region, Northern Territory. Technical memorandum 46, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

[11] Batley GE, van Dam RA, Warne MStJ, Chapman JC, Fox DR, Hickey CW & Stauber JL (2014). Technical Rationale for Changes to the Revised Method for Deriving Australian and New Zealand Water Quality Guideline Values for Toxicants (Draft). Prepared for the Council of Australian Government's Standing Council on Environment and Water (SCEW). June 2014.

the definition of a chronic duration and is an acute toxicity test. Theoretically, to use this data for GV development an acute-to-chronic-ratio (ACR) should be applied.

The current site-specific GV for U in Magela Creek is 6 µg L^{-1} U[12]. This was derived using the available toxicity data for local species, which at that time included five endpoints (*Chlorella* sp., *Hydra viridissima*, *Moinodaphnia macleayi*, *Mogurnda mogurnda* and *Melanoteania splendida inornata*)[2]. Since this GV was established additional chronic toxicity data have been generated or improved, increasing the dataset to eight local species. Hence, the site-specific GV is currently being revised.

To ensure current and ecologically relevant data were included in the site-specific GV revision, it was important to include *A. cumingi* in the dataset given the sensitivity of this snail's egg production to contaminants. However, chronic toxicity estimates were needed before inclusion into the GV derivation. The present study hypothesised that extending the standardised *A. cumingi* toxicity test duration from 4 to 14 days would result in higher toxicity and, consequently, a more conservative toxicity estimate. This study aimed to develop and apply a chronic toxicity test using 14 day *A. cumingi* egg production as an endpoint.

4.4.2 Method

The chronic toxicity of U to the aquatic snail (*A. cumingi*) was assessed by modifying the duration of the standardised toxicity test from 96 hours to 14 days, thereby meeting the generically recommended chronic test duration for an adult macroinvertebrate. A total of six treatments were included in each of the 14 days tests, i.e. one control of Magela Creek Water (MCW) and MCW with five varying U concentrations. Two valid toxicity tests were conducted, encompassing a range of 10 to 800 µg L^{-1} U. The concentrations of total and dissolved U in the treatments were measured using inductively coupled plasma mass spectrometry (ICP-MS) analysis. Each test treatment consisted of three replicate 2 L beakers containing six pairs of snails housed in clear polycarbonate tubes. Tubes were capped with 2 mm nylon mesh fastened with polyvinyl chloride circular clips. Each snail pair was provided with two discs of certified organic Cos lettuce, cut from the outer leaves. Test waters and lettuce were renewed daily and aeration was supplied for the duration of the test. On days 4, 9 and 14, snails were transferred to new tubes, capped with new mesh, so that egg counts could be performed. Eggs were counted after 4, 9 and 14 days using a stereo microscope.

In order to account for slight differences in control responses between individual tests, the data were transformed to percentage of control response, and pooled. Non-linear regression (3-parameter log-logistic) analyses were used to determine point estimates of Inhibitory

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[12] Hogan, A. C., R. A. van Dam, S. J. Markich and C. Camilleri (2005). "Chronic toxicity of uranium to a tropical green alga (Chlorella sp.) in natural waters and the influence of dissolved organic carbon." Aquatic Toxicology 75(4): 343-353.

Concentrations (ICs) that reduced endpoint responses by 10 and 50 percent (i.e. IC_{10} and IC_{50}, respectively) relative to the control responses.

4.4.3 Results and Discussion

This study successfully derived chronic U toxicity estimates for *A. cumingi* reproduction. However, there were no discernible differences in IC_{10} and IC_{50}s for the 4, 9 and 14 day endpoints (Figure 4.8; Table 4.4). This indicates that the 14 day duration is not required to derive a low toxicity estimate for *A. cumingi*. While this study showed that test duration of four days can produce a suitably low toxicity estimate for U, it would be cautious not to accept results from such short-duration tests as chronic toxicity estimates for other toxicants without first testing the validity of this. Therefore, we recommend 9 days should be a default duration to produce a chronic toxicity estimate for *A. cumingi*.

TABLE 4.4 TOXICITY OF URANIUM TO *AMERIANNA CUMINGI* IN MAGELA CREEK WATER

		Control response		U toxicity (µg L^{-1})	
	Day	Total eggs[a]	eggs/day[a]	IC_{10} (95% CL)[b]	IC_{50} (95% CL)[c]
Pooled data	4	175 (24)	44 (24)	60 (23 – 84)	158 (130 – 193)
	9	409 (13)	45 (13)	50 (27 – 68)	151 (127 – 180)
	14	615 (18)	44 (18)	46 (26 – 63)	153 (129 – 180)

[a] Mean (% coefficient of variation) *A. cumingi* eggs per pair in the controls.

[b] IC_{10}: the concentration that results in a 10% reduction in egg production relative to the controls

[c] IC_{50}: the concentration that results in a 50% reduction in egg production relative to the controls

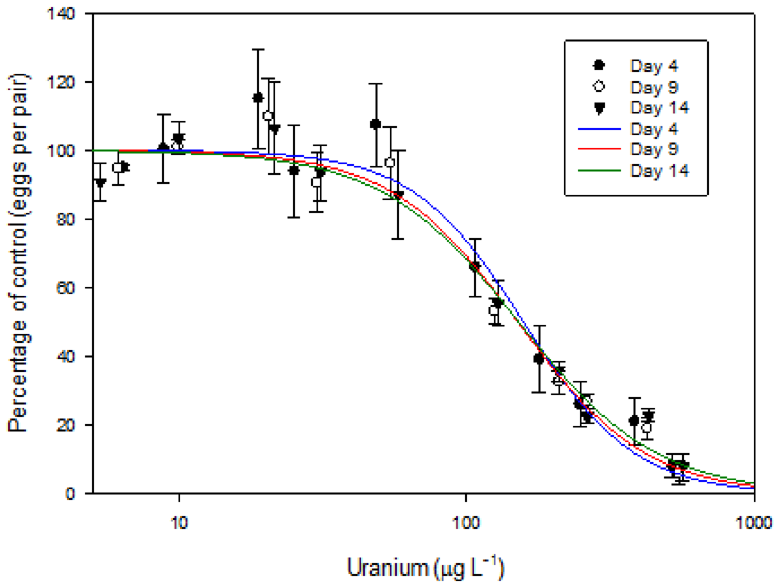

Figure 4.8 Response of *A. cumingi* egg production to uranium based on pooled data set after 4, 9 and 14 days. Data points represent the mean ± SE of triplicate samples. The fitted curve is a 3-parameter log-logistic model

In conclusion, the 14 day chronic test did not produce a lower U toxicity estimate for the snail compared to the four day acute. However, this is strong evidence for reducing the chronic duration of the *A. cumingi* egg production test when using U as a toxicant, and also forms an argument to reduce chronic duration when testing with other toxicants. These results have clarified that the application of an ACR, in this instance, would produce an over-conservative and unrealistic toxicity estimate, and it was more appropriate to collect the chronic data.

4.5 Toxicity of ammonia to local freshwater biota

4.5.1 Background

High concentrations of ammonia in Ranger process water (~1000 mg L^{-1} Total Ammonia Nitrogen, TAN) have not previously been considered an environmental risk, as process water is not discharged to the off-site environment. However, these risks may increase in the future, through (i) the presence of residual amounts of ammonia (~0.5 mg L^{-1} TAN) in treated process waters, which may be discharged to the environment, and (ii) potential seepage of ammonia from in-pit tailings post-closure.

Preliminary toxicity testing of ammonia with the green hydra, *Hydra viridissima*, found it to be highly sensitive to ammonia at pH 8. As pH increases, a greater percent of the ammonia is converted to the ammonium ion, which is more toxic than ammonia. Therefore, the toxicity of ammonia is highly affected by the pH of the water. Under the typical physico-chemical conditions of Magela Creek water, ammonia toxicity is likely to be lower than preliminary tests because its pH typically ranges from 6.0 to 6.5.

There is a need to understand ammonia toxicity under physical and chemical conditions relevant to the off-site surface water environment (Magela Creek) to a range of local freshwater species. Therefore, the aim of this research was to determine the effects of ammonia on local aquatic species under relevant conditions and, thus, to derive a site-specific Water Quality Guideline Value (WQGV) that could be used for both operational and post-rehabilitation purposes.

4.5.2 Methods

The toxicity of ammonia is currently being assessed using six local tropical freshwater species: the unicellular green alga (*Chlorella* sp.); the duckweed (*Lemna aequinoctialis*); the green hydra (*H. viridissima*); the cladoceran (*Moinodaphnia macleayi*); the aquatic snail (*Amerianna cumingi*) and the Northern trout gudgeon (*Mogurnda mogurnda*). To the end of 2014–15, ammonia toxicity testing had been completed for *H. viridissima, M. mogurnda* and *Chlorella* sp.

The diluent, Magela Creek Water (MCW), was spiked with ammonia using stock solutions of ammonium sulphate. Actual concentrations of ammonia in solution were checked before and after the test exposure, at ***eriss***, using spectrophotometry. A starting pH of 6.0 was the target for the toxicity tests and test solutions were kept within 0.3 units (based on daily pH measurements of the new test waters and tests waters which were 24h old) throughout the test. To control pH throughout testing, a bicarbonate buffering system was used where logistically and technically possible. This system involved conducting toxicity testing in air-tight chambers and increasing the atmospheric CO_2 concentration within the system. This system was used during ammonia toxicity testing on *H. viridissima*, *M. macleayi* and *M. mogurnda*. This method has the dual advantages of 1) being able to decrease the initial pH of the test solution to the desired pH and; 2) maintain pH throughout testing, without having a toxic effect on the test organism. The bicarbonate buffering system was not required for *Chlorella* sp. because the standardised protocol includes the use of 1 mM HEPES buffer, which adequately maintained pH during toxicity tests. Due to logistical or technical reasons, the bicarbonate buffering system was not able to be used during toxicity testing with *L. aequinoctialis* and *A. cumingi*. Consequently, toxicity test trials were conducted to determine the most appropriate organic buffer. MES (2-(*N*-morpholino) ethanesulfonic acid) was determined to be the most appropriate for use during *L. aequinoctialis* testing because it had no toxic effect on the test organism and was effective at stabilising the pH. It is yet to be confirmed which buffer will be used for *A. cumingi* testing.

4.5.3 Results and Discussion

The relationship between pH, temperature and ammonia toxicity has been extensively characterised by the USEPA (2013[13]). This information includes algorithms that allow adjustment of GVs for a specific pH and temperature. These algorithms have been used to derive an interim GV for ammonia (i.e. 0.7 mg TAN L^{-1} for 99 percent species protection) using a dataset consisting of international species. In this study, a site-specific GV for Magela Creek will be derived using toxicity tests with local species. The toxicity tests were kept within 0.3 pH units of the starting pH of approximately 6.0, which is the median pH in Magela Creek during the wet season.

Of the species tested, ammonia toxicity varied markedly (Table 4.5; Figure 4.8). *Hydra viridissima* was the most sensitive species followed by *M. mogurnda* and *Chlorella* sp. (Table 4.5; Figure 4.5.1). Preliminary results are available for *L. aequinoctialis* and *M. macleayi* but more testing is required for greater resolution of the toxicity estimates. Therefore, they are not presently reported. Ammonia toxicity testing is yet to commence for *A. cumingi.* Completed toxicity tests have yielded results consistent with the international literature in regards to species sensitivities, which are summarised in USEPA (2013)[1]. However, among this literature two species of unionid freshwater mussel are of particular note due to their high sensitivity to ammonia; *Lampsilis siliquoidea* had an EC20 of 3.2 mg TAN L^{-1} and *Lampsilis fasciola* of 1.4 mg TAN L^{-1} after normalisation to a pH of 7 and a temperature of 20°C (USEPA 2013[1]). As a result, investigations are underway at ***eriss*** to develop a freshwater mussel toxicity test using a native species, *Velesunio angasi,* which inhabits Magela Creek and is an important bush food for communities downstream of Ranger. Upon development of a successful toxicity test, results for the mussel will be included in future site-specific GV revisions for Magela Creek.

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[13] USEPA (2013). Aquatic life ambient water quality criteria for ammonia. EPA. Springfield, VA, United States, National Technical Information Service. 822-R-13-001.

TABLE 4.5 DETAILS OF THE AMMONIA CONCENTRATION-RESPONSE TESTS CONDUCTED.

Test ID	Date	Species name	Endpoint	Ammonia concentration range tested (mg L^{-1}) [a]	Comments
1382G 1394G	25/02/14 03/03/14	*Chlorella* sp.	Population growth	2.5 – 80 7.5 - 240	Lower nutrients/ lower density; 1 mM HEPES
1464L	25/05/15	*L. aequinoctialis*	Surface area growth rate	10 - 100	Modified design[b]; daily water renewals; 1 mM MES
1391B 1401B	07/04/14 28/04/14	*H. viridissima*	Population growth	1 – 32 1.5 – 24	Modified design[b]; Bicarbonate
1460D 1463D	27/04/15 15/05/15	*M. macleayi*	3 brood reproduction	3 – 48 30 - 120	As per protocol; Bicarbonate
1410E 1413E	14/06/14 23/08/14	*M. mogurnda*	Survival	10 – 320 15 - 60	Modified design[b]; Bicarbonate

[a] Nominal concentration range tested
[b] A modified design of less replicates and more treatments was used.

TABLE 4.6 PRELIMINARY AMMONIA TOXICITY ESTIMATES (± 95% CONFIDENCE LIMITS) TO 3 LOCAL FRESHWATER SPECIES IN MAGELA CREEK WATER

Species	IC10 (mg TAN L^{-1})[a]	IC50 (mg TAN L^{-1})[b]
Chlorella sp.	70 (45 – 85)	230 (200 - 260)
H. viridissima	1.5 (1 – 3)	8 (6 – 10)
	LC05 (mg TAN L^{-1})[c]	**LC50 (mg TAN L^{-1})[c]**
M. mogurnda	30 (1 – 35)	40 (40 – 44)

[a] IC_{10}: the concentration that results in a 10% reduction in growth rate relative to the controls
[b] IC_{50}: the concentration that results in a 50% reduction in growth rate relative to the controls
[c] Toxicity estimates for *M. mogurnda* are LC05 and LC50, that is the concentration that results in 10 and 50% reduction in the survival of the fish

In conclusion, ammonia toxicity testing has been successfully completed for three of the six local species. These species showed a wide range of sensitivities, with *H. viridissima* being the most sensitive and the second most sensitive species reported in the literature to date despite the low pH at which the tests were conducted. Toxicity testing is still required for three species: *L. aequinoctialis*, *M. macleayi* and *A. cumingi*. To control pH, the bicarbonate buffering system has been highly effective for some species, but was not suitable or practical for others. In these instances other biological pH buffers are being used.

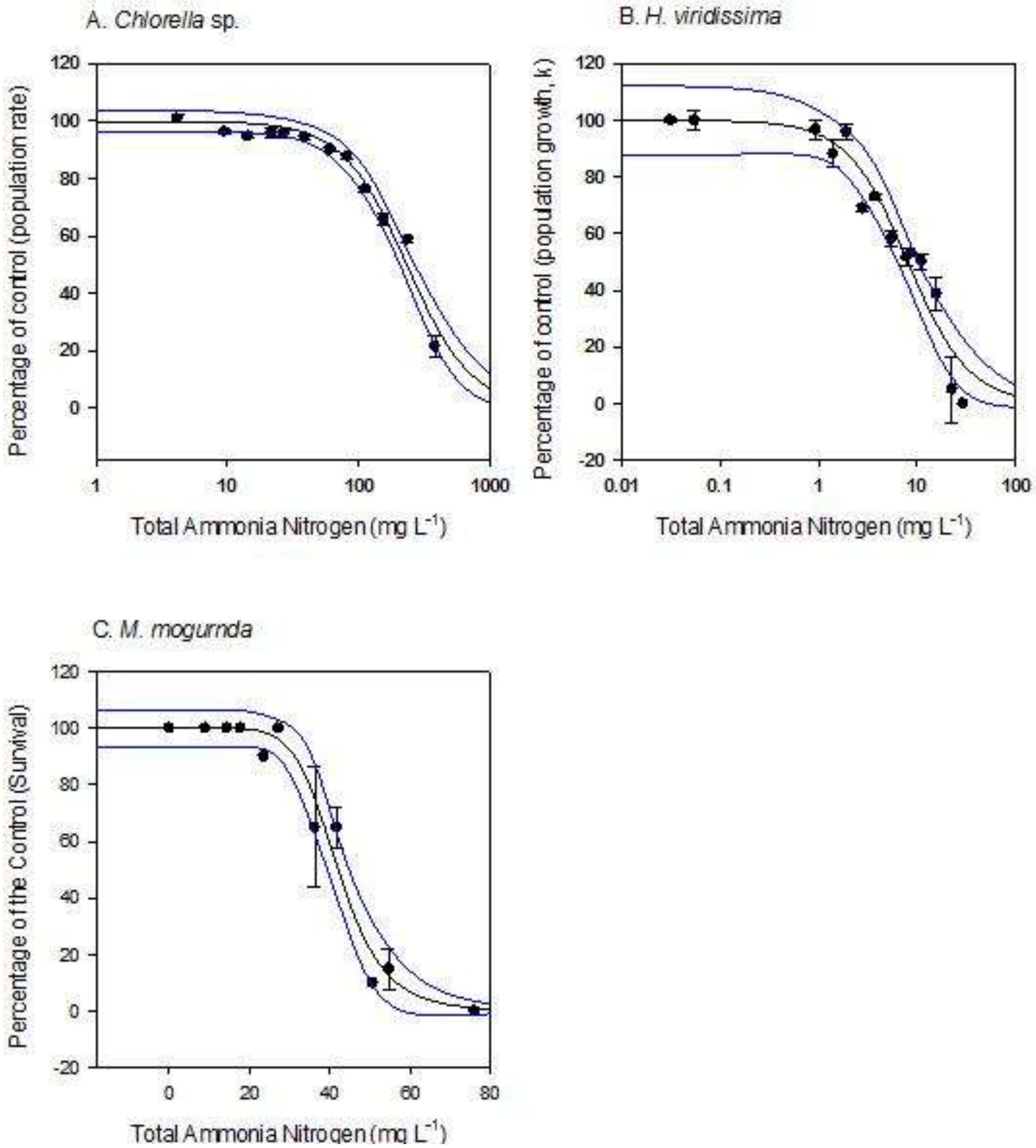

Figure 4.8 Effect of ammonia on A) *Chlorella* sp. growth rate B) *H. viridissima* population growth rate and; C) *M. mogurnda* survival. Data points represent the mean ± standard error of 2-3 replicates. 3-parameter logistic models were used to determine toxicity estimates for all species. Test were conducted at pH 6 ± 0.3 and temperatures of 27.5°C ± 1°C for *M. mogurnda* and *H. viridissima,* and 29°C ± 1°C for *Chlorella* sp.

4.6 Initial results of simulations on landform up to 10 000 years

4.6.1 Introduction

Supervising Scientist Branch, in collaboration with research partners at the University of Hull (Professor T. Coulthard) and the University of Newcastle (Associate Professor G. Hancock), have carried out an initial assessment of the geomorphic stability of a conceptual rehabilitated landform of the Ranger mine for a simulated period of up to 10 000 years using the CAESAR-Lisflood landscape evolution model (LEM). CAESAR-Lisflood is an enhanced version of the CAESAR LEM that had previously been used to assess the geomorphic stability of the Ranger trial landform. For the purposes of this study, the digital elevation model (DEM) of the conceptual rehabilitated landform was divided into a series of subcatchments (Figure 4.9). To date, one catchment (Djalkmara) has been modelled for a simulated period of up to 10 000 years. The remaining catchments are currently being modelled for a similar period.

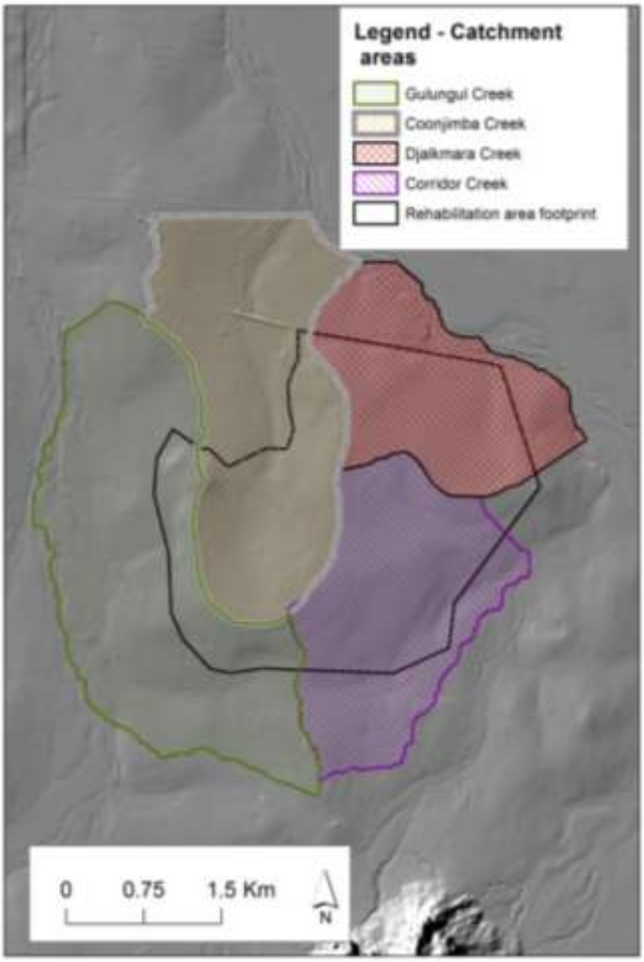

Figure 4.9 Catchment areas used for assessing the Ranger conceptual landform. This study focuses on Djalkmara catchment, on the upper right-hand side of the landform.

4.6.2 Methodology

The application of the CAESAR-Lisflood LEM requires the collation and integration of a range of data inputs. The key data inputs used by the model are a digital elevation model (DEM); rainfall data and surface particle size data.

A DEM representing a fully consolidated conceptual rehabilitated landform was supplied by ERA. The DEM was generated through the integration of two-metre contour interval data produced from a LiDAR survey of the mine in 2011, with a conceptual landform design developed for ERA by the University of New South Wales Water Resources Laboratory using one-metre contour interval data. These datasets were used to generate a grid surface with a horizontal spatial resolution of 10 m. Ten metres was determined to be the optimal resolution at which the CAESAR-Lisflood LEM could function within the spatial extent of the study catchments, and over the temporal periods modelled. The DEM was used to delineate the individual catchments which drained the landform (Figure 4.9).

Rainfall data collected at Jabiru airport over the period 1971–2006 were processed and used to produce a dataset containing 22 years of continuous rainfall data, recorded at hourly intervals. In addition, hourly rainfall data was recorded at Jabiru airport for an extreme rainfall event from March 2007. In the course of the latter event, 785 mm of rainfall was recorded in the three day period between 27 February and 2 March; rainfall intensity in this period exceeded a 1-in-100 year storm event. The 22-year rainfall dataset was looped twice to form a period of 44 years. The 2007 data was added to this dataset, to form a 45-year rainfall dataset. This 45-year dataset was looped multiple times to represent a simulated period of 10,000 years.

For modelling purposes, the Djalkmara catchment was assumed to be composed of two broad surface types – the natural, or Koolpinyah surface and a waste rock surface. The extent / distribution of these surface types within the catchment are shown in Figure 4.10. Consequently, the grain size data of these surface materials were used in the model simulations. Grain size data representing waste rock were obtained from the eight-hectare trial rehabilitated landform at Ranger in the 2009 dry season. Grain size data for the Koolpinyah surface (or natural, undisturbed material) were obtained from the catchment of Gulungul Creek. The grain size distributions from these two surfaces are shown in Figure 4.11. The sub–0.00063 m (i.e. 63 µm) fraction is treated as suspended sediment within CAESAR-Lisflood.

4.6.3 Results and discussion

Earlier studies have demonstrated that LEMs have developed to the stage where, if calibrated, they can reliably predict landform stability over periods of several years.

The initial CAESAR-Lisflood model results for the Djalkmara catchment, within the limitations described below, indicate the likely formation of multiple gullies of varying depth across the catchment. A potential concern is the prediction that gullies up to 7 m deep may form in the area currently occupied by Pit 3 within a simulated period of 10 000 years (Figure 4.12).

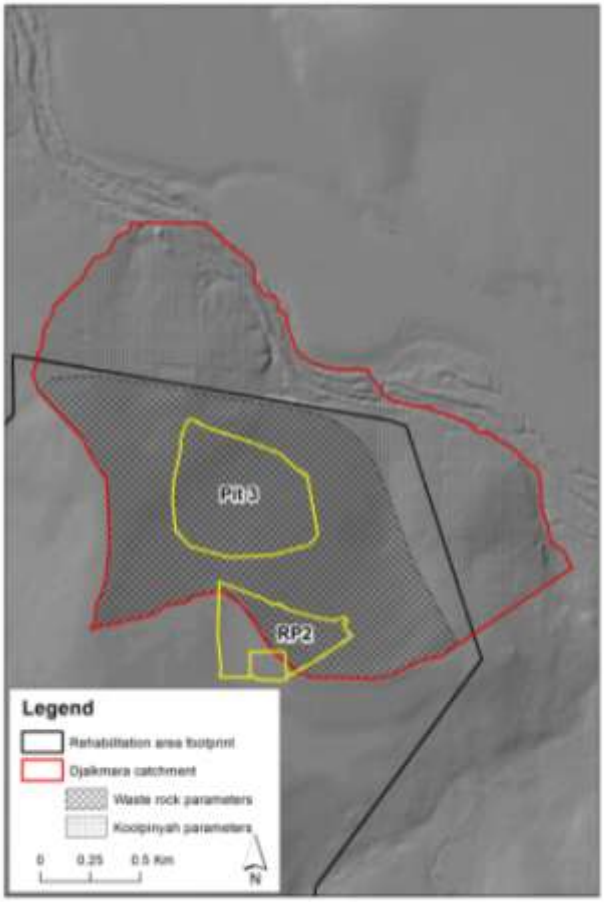

Figure 4.10 Distribution / extent of waste rock and Koolpinyah surfaces in the Djalkmara catchment. The location of existing mine features in the catchment are shown.

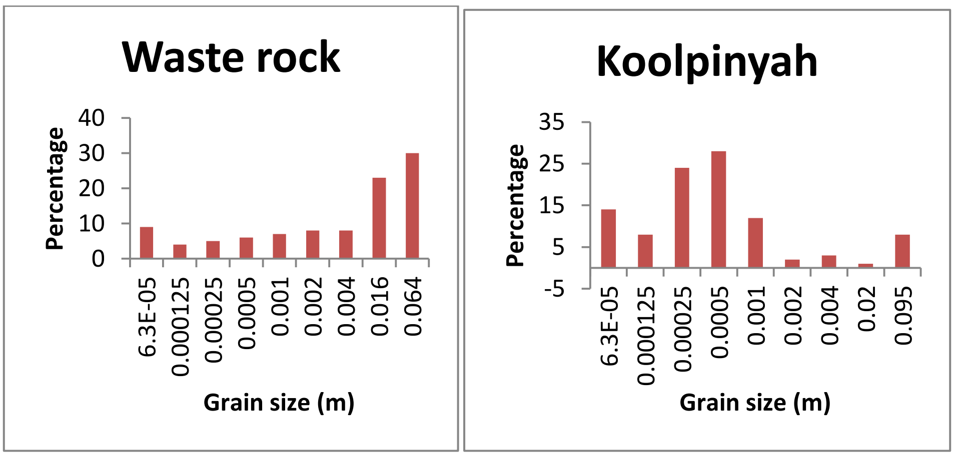

Figure 4.11 Grain size classes of waste rock and Koolpinyah surfaces used in CAESAR-Lisflood simulations.

The predicted average denudation rate (or rate of surface lowering) for the Djalkmara catchment is expected to be 0.02 mm/yr^{-1} which is well within the existing published denudation rates of the surrounding undisturbed landscape of 0.01 – 0.04 mm/yr^{-1}. However, two things should be noted: firstly, that in areas of gully incision the denudation rate will be orders of magnitude higher. Therefore the erosion rate at these points will be considerably elevated compared to that of the undisturbed surrounding environment. Secondly, the denudation rate is expected to be much higher for an initial period of up to 50 years after the landform has been constructed, when material is most available to be moved. After that period, the denudation rate is expected to decrease.

Importantly, the following caveats must be placed on these results:

- The simulations to date have utilised a limited rainfall dataset series to generate rainfall scenarios for this period. The 22-year dataset used to date is unlikely to be representative of the range and frequency of rainfall events that may be expected to occur over a 10,000 year period, particularly if the potential effects of climate change are included in the scenarios.
- The simulations have utilised a very simple vegetation parameter (the presence / absence of a grass cover at selected time intervals). Consequently, the effect of the growth and evolution of a multi-storey heterogenous vegetation community have not been incorporated into modelling to date. Similarly, the effects of fire on the landscape have not been modelled.
- The effect of weathering on the landscape over the simulated period has not been incorporated into the modelling.
- An analysis of uncertainty in model outputs has not been undertaken.
- Finally, the modelling assumed that there was no further human intervention or maintenance of the landform from the onset of the modelling period. Related to this, the landform did not incorporate any features such as sediment traps or rock-armoured drainage collection channels which may control erosion or sediment movement from the landform.

A number of the above-mentioned limitations are in the process of being addressed, as described in the following section.

It is important to note that model simulations to date have been largely based on parameters determined and calibrated from present surface conditions, which are the product of much longer-term geology-soil-climate-vegetation interactions. A significant issue for all models is accurate calibration and parameterisation, particularly for applied environments such as mine sites, where successful landscape rehabilitation is dependent on the short- and long-term erosional stability of the design landform.

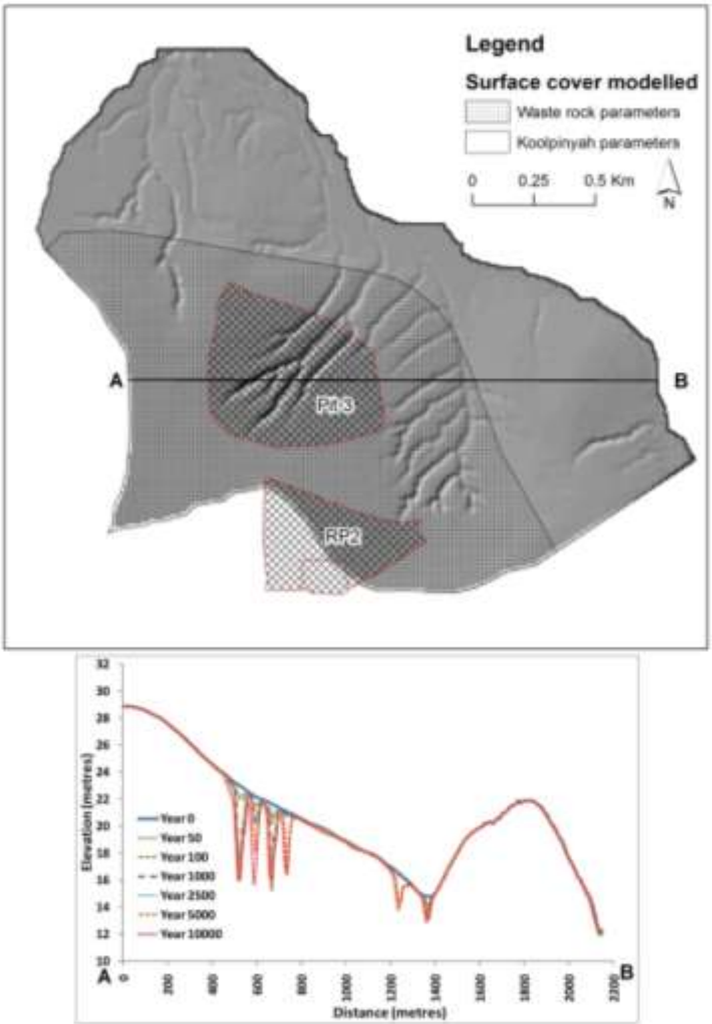

Figure 4.12 Predicted erosion in Djalkmara catchment after a simulated period of 10,000 years. Cross section A-B shows the development of gullies over time.

4.6.4 Conclusions and future work

Model simulations of the Djalkmara catchment during 2014–15 demonstrated that the CAESAR-Lisflood model is able to simulate landform evolution for periods of up to 10,000 years. The predicted formation of gullies up to 7 m deep over Pit 3 indicates further work is required on the landform design to prevent the formation of deep gullies, particularly around Pit 3.

A number of the limitations of the modelling work are currently being addressed to ensure model outputs are both plausible and scientifically defensible. These centre around three key areas:

1. *The development of a stochastic synthetic rainfall dataset, to generate a series of unique rainfall scenarios which may occur within a period of 10,000 years.* Importantly, utilising such a probabilistic approach also allows uncertainty in predictions to be better accounted for and provides a range or probability of likely outcomes, particularly if future climate change scenarios are incorporated. This is the only method at which millennial-scale quantitative assessments can be made within a risk framework.
2. *Enhancing the effect of vegetation community growth on landscape evolution within the landform model.* Vegetation has a major effect on the erosion potential of the landform surface. The vegetation parameter values used in the CAESAR-Lisflood model need to be better defined to better account for the effects of developing vegetation cover over the area of the Ranger mine site. Given its role in the northern Australian landscape, the role of fire, which may disrupt or prevent the development of specific vegetation communities, will also need to be considered. The integration of a dynamic vegetation model linking soil moisture to biomass growth, which could then be used to restrict surface erosion rates is currently being investigated.
3. *Implementing an effective weathering function into the model simulations, to reflect the natural rate of both physical and chemical weathering that occurs in a landscape.* This will ensure that the models do not prematurely predict sediment exhaustion from an environment. Work is currently underway to integrate data from existing and historical weathering studies in the region into model simulations.

The results of the simulations to date provide a guide for future enhancements both to the landform design and to the landform software model. Existing results combined with the proposed work will provide increased confidence that the CAESAR-Lisflood model will be able to correctly predict the potential paths for evolution of a rehabilitated landform once it has been constructed.

4.7 Sediment losses from the trial landform at Ranger mine

4.7.1 Introduction

Under current approvals mining at Ranger will cease in 2021, so there is a large focus on key aspects of rehabilitation on the mine-site. In order to meet legislated Environmental Requirements for closure, the final landform must resemble the surrounding landscape, be radiologically stable, exhibit erosion characteristics similar to the surrounding environment, and act as a functional containment structure for the mine tailings, which must be physically isolated from the environment for 10,000 years post-closure. It is important that the rehabilitated mine site does not become a significant source of elevated sediments and solutes to the surrounding environment.

eriss and ERA is collaboratively undertaking research to assist with the development of the final, rehabilitated landform for the Ranger mine. This work includes measurement of solute and sediment loads generated and transported from the landform during rainfall events. ***eriss*** is leading the erosion assessment component of the project, with ERA leading the vegetation component. The data generated from the project are also used for validation of predictive computer modelling of the long-term geomorphic behaviour of the proposed landform designs for the Ranger mine, which is also carried out by ***eriss***.

A trial landform (TLF) of approximately 8 ha was constructed in late 2008 and early 2009 adjacent to the north-western wall of the tailings storage facility (TSF) at Ranger mine (Figure 4.13). The trial landform was designed to assess:

1. two types of potential capping material: (i) waste rock only, and (ii) waste rock blended with approximately 30 percent fine-grained weathered horizon material (lateritic material)
2. two types of potential planting methods: i) direct seeding and ii) tube-stock.

The TLF was segmented into four main treatment areas and the surface was ripped on the contour before planting was carried out.

Since construction, measurements have been carried out to assess the generation and transport of sediments and solutes from the site, and the ability to achieve and sustain growth of plant species native to the region. Monitoring the trial landform during 2014–15 was reduced to measures of rainfall, runoff and bedload. This report provides an update on the hydrology and bedload yield, which have been reported in previous years.

4.7.2 Methods

Erosion plots were installed during the 2009 dry season on each of the four main treatment areas. These were achieved by physically isolating approximately 30 x 30 m areas (Figure 4.13) from the surrounding landform surface using raised damp course and concrete borders on three sides along with an open PVC drain on the down-slope side.

Each plot was instrumented with a range of sensors that were described in detail in previous years' annual reports. During 2014–15, the sensors on each of the plots included: a rectangular broad-crested (RBC) flume to accurately determine discharge; a tipping bucket rain gauge, a primary shaft encoder with a secondary pressure transducer to measure stage height; and a data logger with mobile phone telemetry connection.

Bedload samples were collected at weekly to monthly intervals during each wet season (monthly during 2014-15), depending on the magnitude of runoff events and staff availability. The samples were processed in the laboratory by weighing (after oven drying) as well as measuring the particle size distribution using the Wentworth size fractions of gravel (> 2 mm), sand (63 µm to 2 mm) and silt and clay (< 63 µm). Each sample was sieved to determine the sediment fractions.

4.7.3 Rainfall and runoff

4.7.3.1 Overview

Data are presented for a 'water-year', from September to August. Rainfall for all four plots and runoff from erosion Plots 1 & 2 are reported here for six wet seasons. We are currently investigating some issues with the runoff data from all plots (which mainly affect the larger runoff events), but have reported the current results here. Resolution of the issues will be reported later and will result in a slight change in the volume of water for each event but will not impact on the number of events.

4.7.3.2 Rainfall and runoff results and discussion

Mean annual rainfall at Jabiru Airport (Station No. 014198, located 2.3 km from the trial landform) is 1583 mm. The annual rainfall for the 2014–15 water year on the trial landform was the lowest for the six years of study, with 1083 mm (Table 4.7), and was 31.6 percent lower than the mean annual rainfall at Jabiru airport.

Surface runoff from the erosion plots occurs as a number of discrete events. Some of the smaller rainfall events result in water flow off the plots into the reservoir upstream of the flume, without water flow over the RBC flume. The runoff data for plots 1 (Table 4.7) and 2 (Table 4.9) are shown in different tables because of subtle differences in plot area. The topography created by the rips lines also differs, creating slightly different runoff characteristics. For the discussion below, only those flows over the RBC flume have been included.

The lowest number of discrete runoff events for both plots for the six wet seasons was for 2014–15, which had the lowest annual rainfall. The number of runoff events that produced discharge over the crest of the flume was lowest in the driest water year (2014–15), with 88 events on plot 1 and 92 events on plot 2, and was greatest in the wettest water year (2010–11), with 213 events on plot 1 and 221 events on plot 2.

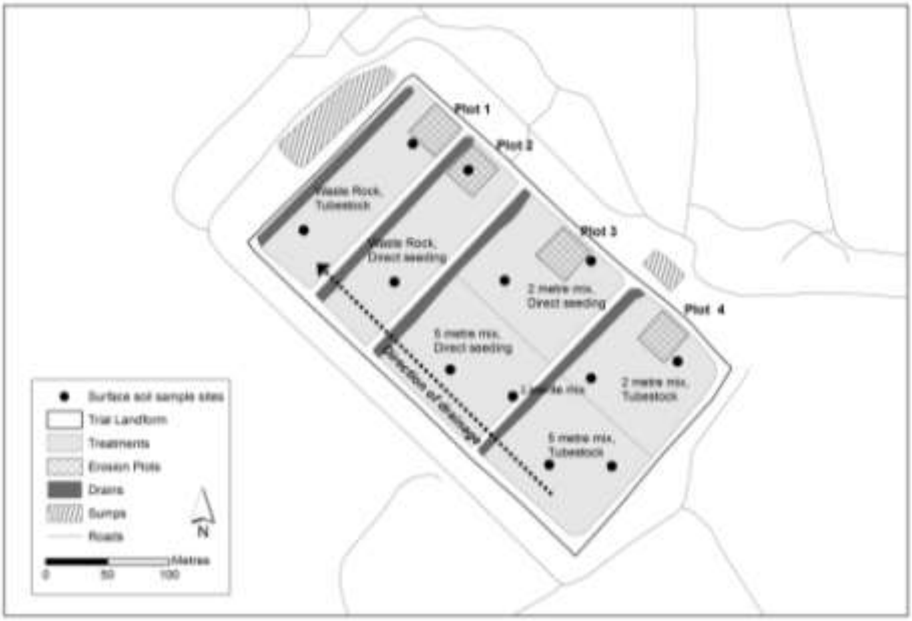

Figure 4.13 Layout of the erosion plots on the trial landform.

The annual runoff was lowest in the 2014–15 wet season (rainfall 31.6 percent below average) which is to be expected due to the very low wet season rainfall. Annual runoff on plot 1 was greatest in the wettest year (2010–11) when 13.5 percent rainfall was converted to runoff, and was least in 2014–15 when the trial landform experienced the lowest wet season rainfall (Table 4.7). On plot 2 annual runoff was always higher than for plot 1, with the wettest year (2010–11) having 14.8 percent of rainfall converted to runoff. Interestingly the 2012–13 wet season had the greatest runoff coefficient of 15.9 percent, a result that requires further investigation.

For plots 1 & 2, for each of the wet seasons there looks to be an exponential relationship between event rainfall and event runoff over the full range of rainfall. This has continued during the 2014–15 wet season on plot 1 (Figure 4.14). It is hypothesised that when event rainfall exceeds a value (in this case 30 mm) there is proportionally greater runoff than for smaller events (Figure 4.15). These smaller events do not totally infill the rip lines with water, and so runoff is only produced from a small part of the plot near the down slope border. Event rainfall greater than 30 mm can totally infill the surface storage, hence generating runoff from the whole plot surface.

TABLE 4.7 RAINFALL DATA FOR THE FOUR EROSION PLOTS ON THE TRIAL LANDFORM FOR THE SIX YEARS OF MEASUREMENT

Water year	Erosion Plot 1 Rainfall (mm)	Erosion Plot 2 Rainfall (mm)	Erosion Plot 3 Rainfall (mm)	Erosion Plot 4 Rainfall (mm)	Mean Annual Rainfall ± Standard Error (mm)
2009–10	1533	1531	1480	1528	1518 ± 13
2010–11	2227	2290	2205	2296	2255 ± 23
2011–12	1508	1531	1456	1489	1496 ± 16
2012–13	1283	1274	1260	1264	1274 ± 5
2013-14	1961	1962	1950	1991	1966 ± 5
2014-15	1051	1135	1109	1038	1083 ± 23

TABLE 4.8 RAINFALL AND RUNOFF DATA FOR EROSION PLOT 1 ON THE TRIAL LANDFORM FOR THE SIX YEARS OF MEASUREMENT

Water year	Maximum event rainfall (mm)	Number of runoff events over the flume	Runoff (L)	Runoff (mm)	Runoff coefficient (%)
2009–10	77	131	74886	81	5.3
2010–11	189	213	275650	300	13.5
2011–12	85	129	97366	106	7.0
2012–13	73	92	111603	121	8.1
2013–14	73	156	138228	150	7.7
2014–15	63	88	34804	38	3.6

4.7.4 Sediment results and discussion

4.7.4.1 Bedload

Sediment yields for major land disturbances, such as construction or landslides, are usually characterised by an initial pulse followed by a rapid decline This is true for the TLF annual bedload yield, which is characterised by an exponential decline in annual bedload yield over the six years since construction (Figure 4.15). The annual bedload yield for each plot has progressively declined as time since construction and vegetation cover have increased on the TLF (Table 4.10). Yields have declined on all plots, except for plot 2 for 2012–13 and 2013–14, where observations and photographs suggest this plot has the lowest amount of vegetation establishment and growth.

Previous research in the Alligator Rivers Region has shown that sediment yields decline progressively over at least the first three years following a major surface disturbance, as a result of initial washout of fine sediment and the subsequent formation of a gravel-armoured surface. Time since construction, rather than rainfall, is the dominant driver of bedload yield, as the greatest rainfall occurred in the second year (Table 4.7). Using the average rainfall per rain day as an index of rainfall intensity, the values for the six years were 13, 15, 11, 10, 15 and 10 mm d-1 for the each wet season from 2009–10 to 2014–15. The 2010–11 and the 2013–14 wet seasons were the wettest seasons and also had the most intense rainfall, further supporting the fact that rainfall is not a key driver for annual bedload yield on the trial landform.

The highest annual bedload yields were always generated from plot 2 (Table 4.7.4). While it is still not clear why this happens, shallower rip lines dominate the lower part of plot 2, resulting in direct connection of diffuse overland flow with the down slope plot drain and poorer vegetation establishment.

TABLE 4.9 RAINFALL AND RUNOFF DATA FOR EROSION PLOT 2 ON THE TRIAL LANDFORM FOR THE SIX YEARS OF MEASUREMENT

Water year	Maximum event rainfall (mm)	Number of runoff events over the flume	Runoff (L)	Runoff (mm)	Runoff coefficient (%)
2009–10	77	125	121794	139	9.1
2010–11	180	221	298294	341	14.8
2011–12	85	150	151853	173	11.3
2012–13	56	114	177534	203	15.9
2013–14	73	151	236416	270	12.5
2014–15	63	92	91794	105	9.2

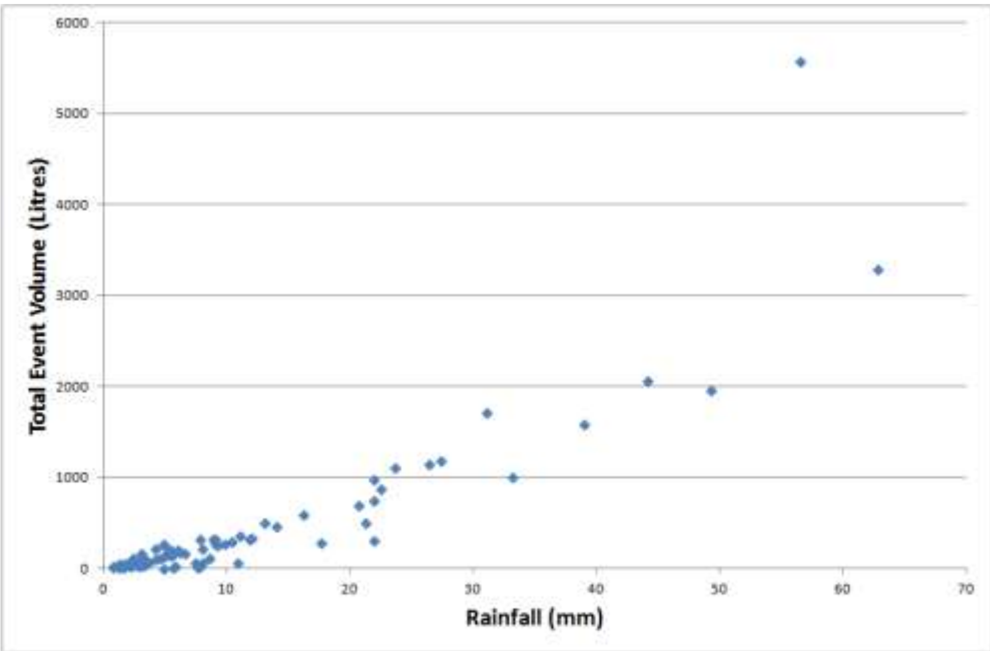

Figure 4.14 Relationship between total event rainfall and runoff for erosion plot 1 for 88 runoff events in the 2014–15 water-year.

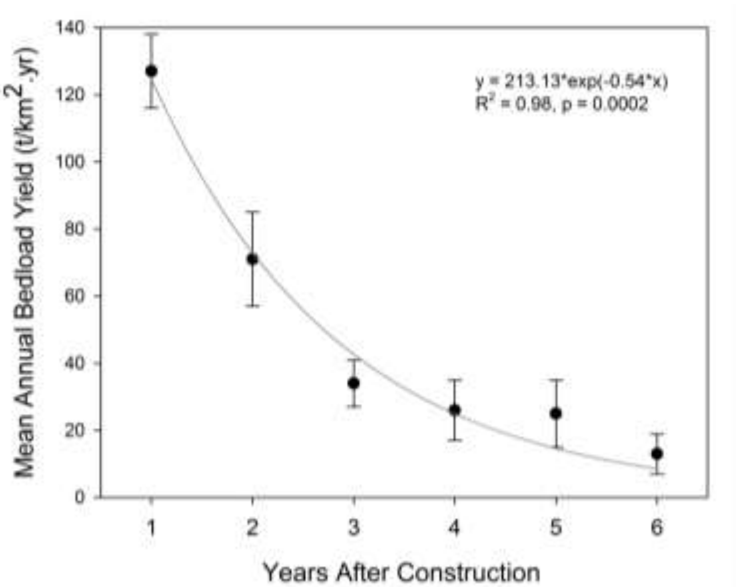

Figure 4.15 Exponential decrease in mean annual bedload yield with time since construction for the four plots on the trial landform. Data represent annual mean and standard error of estimate for all plots.

4.7.4.2 Bedload particle size analysis

For plots 1, 2 and 3, analysis of the bedload showed that the sand fraction has the highest percentage for all 6 wet season (all over 50 percent, Figure 4.16). On plot 4, the sand fraction was higher for years 2009–10 and 2012–13, and was essentially the same as the gravel fraction (around 50 percent) for the other four years. This indicates the importance of the sand fraction and shows that it is the main bedload erosion product in the early years after construction of a rehabilitated landform. The gravel fraction constitutes the next highest percentage with little silt and clay contained in the bedload. Surface armouring of coarse gravel has occurred by the washing out of silt and clay from the ground surface and the infilling of pore spaces in the surface layer.

4.7.5 Conclusions and future work

The priority for further work is to complete the calculation of runoff data from all plots, since the runoff must be determined before suspended sediment and solute loads can be derived. Correction of the runoff from all plots is progressing with plot 2 complete and plot 1 nearly complete. After five years the TLF project was to be reviewed with the results published as a series of Supervising Scientist Branch Reports. The data analysis for these report is currently under way.

Monitoring the TLF during the 2014–15 was heavily reduced to allow all efforts to be concentrated on processing and reporting the first five years of the project. Monitoring of the trial landform in its reduced capacity will enable further quantification of the effect of vegetation establishment on erosion rates, such that a higher level of confidence can be placed in the predictions from the landform evolution models that are being used to predict long-term erosion performance. Moreover, effects of fire on erosion rates will also be quantifiable in the event that the TLF is burnt as part of ERA’s revegetation trials. The runoff, sediment and solute loads that are being determined will also inform the design of sediment traps and wetland water quality polishing systems that will need to be incorporated into the rehabilitated mine footprint to manage the export of erosion products.

TABLE 4.10 ANNUAL BEDLOAD YIELDS (t/km^2.yr) FOR EACH PLOT FOR EACH YEAR OF MEASUREMENT

	Plot 1	Plot 2	Plot 3	Plot 4	Mean Annual Bedload Yield ± Standard Error
2009–10	106	147	111	143	127 ± 11
2010–11	59	113	54	56	70 ± 14
2011–12	34	48	38	15	34 ± 7
2012–13	28	50	14	14	26 ± 9
2013–14	24	53	11	13	25 ± 10
2014–15	11	29	6	6	13 ± 6

4.8 Critical groundwater research needs for Ranger mine

4.8.1 Background

The shape and nature of the landform at the Ranger Uranium Mine (Ranger) is gradually being altered as part of the rehabilitation of the minesite with the infilling of voids and the re-shaping of the landform. These important changes foreshadow the potential for significant changes in groundwater hydraulic behaviour. Clear conceptual site models, combined with robust data (historic, current and future) of groundwater levels, groundwater quality, landform topography and landform composition, will be essential to ensuring adequate protection of the environment from the off-site migration of contaminants via the groundwater pathway.

In recognition of the need for greater oversight of groundwater science in the Alligator Rivers Region, Supervising Scientist Branch acquired two hydrogeologists from Geoscience Australia, each on secondment for eight months during 2014–15. Key tasks for these placements were to review the status of groundwater knowledge and evaluate associated research needs.

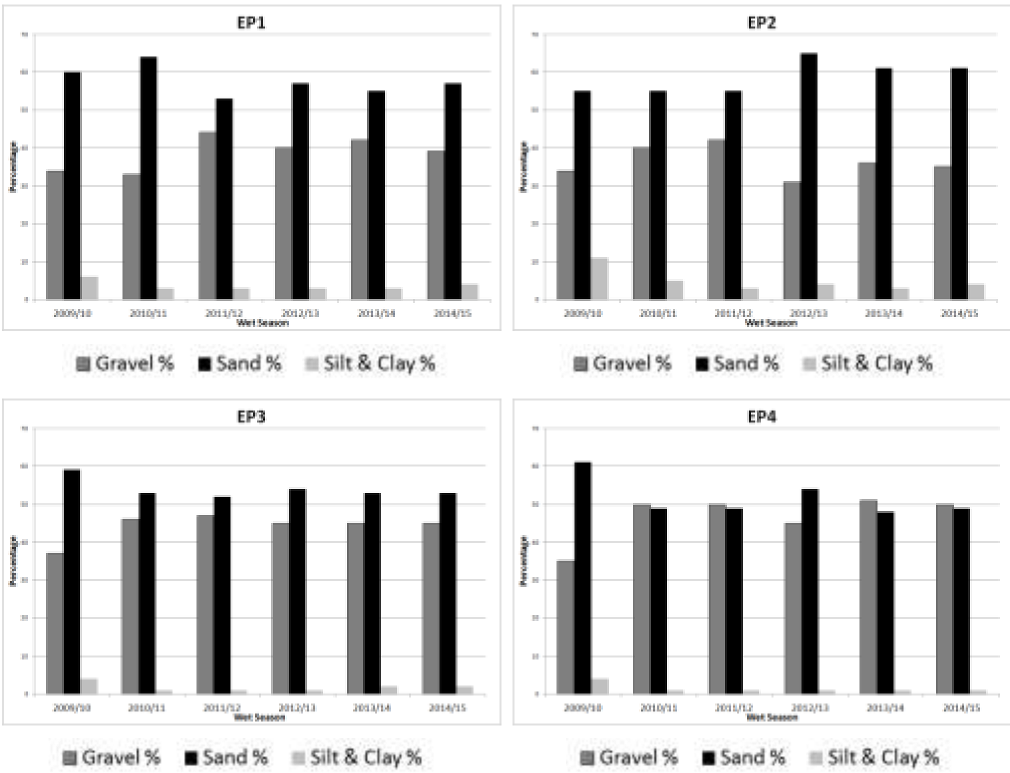

Figure 4.16 Annual yield of bedload fractions as a percentage of total bedload yield for all 4 plots.

4.8.2 Review process

Groundwater needs at Ranger were assessed for both arms of Supervising Scientist Branch: the Office of the Supervising Scientist (***oss***), which (amongst other roles) advises the regulator; and the Environmental Research Institute of the Supervising Scientist (***eriss***), which undertakes the research and monitoring to inform the regulation and provides assurance that the environment is protected from impacts of uranium mining.

This assessment was conducted by: reviewing documents submitted to Supervising Scientist Branch and regulator; participating in field investigations where groundwater is considered to have a critical role; and evaluating the research needs for groundwater. A significant part of this effort included the identification and collation of an extensive number of references (both published reports and grey literature) that relate to groundwater at Ranger, in either a regulatory or a research context.

Broad findings of the review are presented below.

4.8.3 Findings

4.8.3.1 Conceptual site models

A conceptual site model is an essential tool for the effective design of a groundwater monitoring programme. Monitoring results in turn are used to validate or challenge elements of the conceptual model and lead to new iterations of the model and enhancements to the monitoring programme.

Initial work at Ranger in the 1970s and 1980s focussed on developing an understanding of the different aquifers and how they interact with each other. The geology of the site is complex, which is why appropriate simplification of aquifer characteristics continues to be a major consideration, even today. A key element of groundwater conceptual models for Ranger is the water balance, which some investigators have attempted to develop.

Shallow groundwater is considered to follow site topography, draining directly towards the creeks and associated surface waterbodies around Ranger. Deeper groundwater is considered to follow regional topography and flows northwards towards the ocean, although movement of groundwater in the deeper strata is likely to be restricted to the fractures, which some authors consider to act as continuous, preferred pathways, particularly in fault zones. The regional extent of these features implies they may play a significant role in groundwater flow and contaminant transport. However, while this role has been demonstrated at a local scale on the minesite, it has not been confirmed at a regional scale.

Magela Creek is a primary focus of contaminant studies at Ranger. The creeks draining Ranger are tributaries of Magela Creek, and thus ultimately discharge into this primary channel. The degree of interaction between the different groundwater units and the surface water features is an important consideration in developing any conceptual model.

While the natural physical attributes are important in determining groundwater flow characteristics, of equal consideration at a minesite is the impact to groundwater flow and quality from infrastructure, such as impoundment structures for site water and tailings, as well as the mining and dewatering activities associated with the extraction of ore from the mining voids. Therefore, the conceptual groundwater model at a minesite is dynamic, and operational activities that are likely to influence groundwater quality and flow dynamics need to be incorporated into the conceptual model as they are created or removed.

Following the completion of extractive activities at the mine (December 2012), the subsequent infilling of the pits (not yet complete) and the creation of the final landform (to be achieved by 2026), ERA, operator of Ranger, indicates that groundwater hydraulic conditions will approximate pre-mining conditions. The timeframe in which this is predicted to occur is not specified, but the topography and constituent materials of the final landform will be of crucial importance to developing a new conceptual model that takes account of geochemical and hydraulic influences within the vadose (unsaturated) zone and below the water table at Ranger.

In summary, although a variety of conceptual models may have informed the development of the groundwater monitoring strategy since the commencement of mining at Ranger, evidence of the link between a conceptual model (in three physical dimensions and a temporal one) and the monitoring results has not been sighted.

4.8.3.2 Groundwater monitoring data

There is no single repository for groundwater data collected from the Ranger area; they are held by individual agencies in accordance with their respective obligations. This has resulted in data being held, uniquely or duplicated, by a variety of agencies and in a variety of different types of electronic media. Some data may exist solely as hardcopy or as scanned pdfs of hardcopy.

Groundwater monitoring at Ranger is conducted via two classes of monitoring bore: statutory bores and operational bores. Statutory bores are listed in the Ranger Authorisation (RA) and carry legally-enforceable monitoring, reporting and data retention obligations. Changes to these bores, or to the monitoring requirements, means a change to the RA, which can only be made by the Minister for the Northern Territory Department of Mines and Energy (DME).

In accordance with the RA in place since the commencement of mining, it has been a requirement that groundwater data (water level and water quality), are collected at specified intervals from statutory bores. In 2002, the number of statutory bores listed in the authorisation changed from 22 bores to 4 bores. At the same time, the requirements for groundwater monitoring from these bores changed: specific water quality measurements (at bimonthly to biannual intervals), and groundwater level measurements (a measurement in nine specific months of the year), were changed to a quarterly basis for both water quality and groundwater level measurements.

Part of the arrangements, linked to reducing the number of statutory monitoring bores in 2002, was the substitution of a complementary network of operational bores. These are listed in the ERA annual Water Management Plan and may be modified by agreement with the regulator and relevant stakeholders. Their number has grown over the years, and over 200 were listed in the most recent groundwater monitoring report. The full record of ERA groundwater quality data is held in a secure and searchable database, partially available to stakeholders via a web portal. Groundwater level data are not accessible by the same means, but on request to ERA, or via a nominated Northern Teritory official. This manner of accessing data is time-consuming and also delivers an incomplete or unsatisfactory dataset. There are indications, such as by inspection of data presented in recent ERA groundwater monitoring reports, that the full record of water quality and groundwater level data is not readily accessible, and that critical metadata (particularly those relating to the datum to which the water level is being measured) are not being used, thereby restricting the value of the dataset. Details of the timing of critical on-site infrastructure developments (such as the creation or infilling of mining voids and the construction of surface water impoundment structures) that can affect groundwater behaviour may be found by examining individual annual water management reports for the mine. However, a comprehensive timeline for infrastructure developments for the life of the mine (1980 to present) is not available. As indicated above, these structures and voids form an important part of the conceptual groundwater model, which in turn should be used in conjunction with an analysis of groundwater monitoring data, to guide the groundwater monitoring strategy.

ERA holds several additional datasets which may be of value to groundwater research, including a wealth of different geophysical data collected over the years. Such datasets will be most useful if supported by ground-truthing.

The DME conducts annual check monitoring of groundwater (groundwater level and quality) from statutory monitoring bores, and in selected observation bores, since 1980. DME also receives groundwater monitoring data from ERA, stored digitally from 1990 to present, with earlier data available in paper copy. Water level data prior to 2012 has not been observed in the digital dataset, and the water level data held since 2012 does not appear to be linked to a datum.

eriss has conducted selective groundwater quality sampling and/or water quality analyses of samples collected by others for over 30 years.

Data collected on sediment depth profiles across surface water channels are provided within numerous reports on the geomorphology of these features, and are likely to be useful in understanding the groundwater flow characteristics of these alluvial aquifers, particularly when combined with the results of geophysical surveys already conducted across, and within, the same strata.

The Water Resources Division of the Northern Territory Department of Land Resource Management (DLRM) conduct regional groundwater monitoring (level and quality) for the whole of the Northern Territory through a network of monitoring bores, and data are retained by that agency as well as by the Bureau of Meteorology in accordance with the requirements of the *Water Act 2007*. DLRM holds any available pre-mining and early mining groundwater data (level and water quality) and associated geophysics reports for the region until approximately the mid 1980s.

ERA is responsible for water quality testing of the Jabiru water supply. However, when considering groundwater at Ranger within the regional context, such as in consideration of off-site water quality, agencies within the Northern Territory Government have ongoing responsibility for the collection of groundwater quality data where groundwater is the source of a community water supply.

The ability of the monitoring infrastructure within the Ranger Project Area to adequately capture data in accordance with objectives (such as might be contained in a conceptual model) is uncertain and difficult to evaluate without clear objectives linking the monitoring intentions to the conceptual model. Many of the monitoring bores (statutory or operational) span multiple aquifers and might be assumed to be receiving inflow from multiple discrete seeps in the vertical sense. Thus, both level and quality information may represent influences from more than one groundwater horizon.

In summary, the disparate locations and manner of storing groundwater data, as well as the requirement to conduct quality assurance on the data, add challenges to the task of collating these datasets prior to conducting an analysis with confidence.

4.8.3.3 Groundwater monitoring reporting

Annual regulatory reports that relate to groundwater are submitted by ERA to the Ranger Minesite Technical Committee (MTC) for review by its members and subsequent formal acceptance, with amendments if required. These reports are the principal means by which the status of on-site groundwater behaviour at Ranger is established. A review of some recent reports indicates that the level of analysis can be of a superficial nature. Supervising Scientist Branch continues to work with ERA to improve the depth of analysis provided in these reports.

DME groundwater check monitoring is reported to the Alligator Rivers Region Advisory Committee (ARRAC). Comparative data plots, presented by DME, indicate that the ERA and DME results for groundwater are not well aligned. This may indicate natural variation within the groundwater (where even the vertical placement of the sampling pump may influence the results) and/or indicate discrepancies in data collection and sample analysis between the two organisations.

Results of surface water monitoring activities are provided to the Alligator Rivers Region Technical Committee (ARRTC). Reference may be made to groundwater if it is implicated in surface water or sediment quality and where associated groundwater monitoring is conducted by others (e.g. by ERA, such as in the case of recent investigations in the Gulungul Creek catchment). ***eriss*** does not currently have a groundwater programme and so does not routinely report on groundwater, although ad hoc groundwater work is reported to ARRTC. Supervising Scientist Branch publicly provides formal reports of investigations and advice made in response to incidents.

Reporting activities associated with groundwater monitoring at Ranger, as indicated above, are distributed across different committees which may result in an incomplete shared understanding of the status of groundwater at any one time.

4.8.3.4 Groundwater research

Numerous groundwater research projects have been conducted at Ranger over the years. In the early years (1970s and 1980s) these were mostly undertaken by representatives of the Northern Territory Government. Although not necessarily focussed specifically on groundwater, relevant work was also conducted by Supervising Scientist Branch. Amongst this collection of reports, of particular interest are those reporting on the many aspects of the characteristics of the creeks surrounding the Ranger Project Area, including sediment characterisation, geophysical surveys, groundwater flow characteristics, surface water flow characteristics and water quality investigations.

A significant body of multi-disciplinary groundwater research has been supported by ERA, including the results of many collaborative projects with CSIRO. Other important work, such as the hydrogeochemistry of the waste rock, is understood to be available. Although acid mine drainage potential at the site has been evaluated, reference to techniques, such as are outlined in international literature, or utilised by Rio Tinto at sites around the world, has not been sighted. Much of this research work has been presented to meetings of individual committees (ARRTC and MTC), or to separate workshops, with the content tailored to the purpose of the meeting and to a very limited audience. While the existence of such reports can be found by investigating the archives of individual meetings, reports stored in such a manner are not easily discoverable. Their accessibility may also be limited if they are not referenced or published in a more public forum.

eriss has produced several reports on groundwater quality which serve to highlight important research needs. Importantly, ***eriss*** holds only a small proportion of all the groundwater quality analyses conducted over the last 30 years. A complete analysis of water quality datasets from each agency is warranted, and should be conducted in the context of the hydraulic and geochemical behaviour of the host strata. This would facilitate an appropriate evaluation of the groundwater monitoring programme to ensure that it accounts for the lag time in groundwater responses that will arise from changes in landform with Ranger rehabilitation.

In summary, much detailed research relating to groundwater at Ranger has been conducted over the years, and has been used to guide specific activities at the site. The value of this work is reduced by the poor quality of data storage and fragmented nature of the studies. The development of a whole of site conceptual model, linked to the regional context, would be of great assistance in drawing this previous work together and greatly increasing understanding of groundwater systems at Ranger

4.8.4 Conclusions

A significant body of work on groundwater at Ranger has been conducted by ERA, Supervising Scientist Branch and the Northern Territory Government since the late 1970s. Groundwater is a cross-cutting feature yet intermittent lapses in interdisciplinary and inter-organisational linkages, combined with significant changes in technology over the last 35 years, have resulted in unintentionally impeding the accessibility and integration of relevant information.

Limited observation of available groundwater data and its presentation in recent reports or meeting documents, indicate that the management of groundwater data remains suboptimal.

Distinguishing ‘Statutory’ from ‘Operational’ bores may have resulted in discrepancies in the rigour of monitoring these bores.

Conceptualisation of groundwater for the whole of the Ranger site appears incomplete and not linked to the groundwater monitoring strategy. As the surface of the site at Ranger is re-engineered prior to closure, it is inevitable that many of the operational bores will be destroyed. A new plan for groundwater monitoring at the site, during and after rehabilitation activities, will be required in advance of their destruction and in anticipation of the intended landform shape and materials of the final landform.

While groundwater conditions across the site are not fully understood, and the lag times of potential impacts not fully accounted for, the challenge of ensuring the protection of the environment around Ranger will be intensified as site operations change.

4.8.5 Recommendations

In the light of the above findings, and of the changes in landform currently in train at Ranger, now is a critical period in the history of groundwater research at Ranger. Because there is a wealth of background information, much of the effort is in collating and interpreting existing material prior to launching new research, as indicated in the following recommendations:

1. Improved and integrated management of groundwater data, particularly with respect to groundwater levels.
2. Comprehensive groundwater data and literature review spanning the last four decades, including: data from all sources; grey literature; relevant national and international guidelines.
3. Development of a comprehensive conceptual site model (CSM) for the whole of the site under current operations, including natural and operational elements and an associated water balance. In combination with the data review above, this should include a site-wide review of contaminant movement in groundwater to inform groundwater monitoring strategy for the next decade.
4. Development of a whole of site conceptual model following closure of the Ranger site in consideration of:
    a. The final site contours (Digital Elevation Model) to which the site will be engineered.
    b. The nature and placement of different types of waste materials around the site, particularly waste rock and tailings.
    c. The potential geochemical and dynamic behaviour of groundwater in the different layers of the final landform at Ranger, including the vadose zone, and their interaction with adjacent groundwater and surface water bodies.
5. Review of the suitability of the number, location and nature of statutory bores, including their instrumentation and monitoring schedule, for the next decade of activities at Ranger.
6. Targeted groundwater research:
    a. Research linked to projects proposed by others (opportunistic approach), such as the investigations in Magela Creek and Gulungul Creek catchments currently proposed by ERA.

b Establishment of groundwater head and quality testing, and associated monitoring, to verify contaminant movement and identify trajectories of geochemical reactions.

A longer version of this report is currently in preparation as a Supervising Scientist Branch Internal Report (IR641), to be complete by the end of July 2015.

4.9 Rehabilitation and closure ecological risk assessment for Ranger mine

4.9.1 Background

ERA is required to rehabilitate Ranger uranium mine by 2026. A large number of research and assessment projects are underway by both Supervising Scientist Branch and ERA to ensure the necessary knowledge is available to inform the rehabilitation and closure strategy. Supervising Scientist Branch 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 Supervising Scientist Annual Report 2012–13 were finalised in late 2013 and have been published as Internal Report 624, and are available on Supervising Scientist Branch's website. The initial risk screening focussed on the post-decommissioning phase (the period from 2026 until monitoring has demonstrated that closure criteria have been achieved) was reported in the Supervising Scientist Annual Report 2013–14 and is currently being incorporated in a consolidated internal report on the ecological risk assessment. The work reported in 2013–14 on ecological processes has been completed and is being reported in an internal report. This paper summarises work undertaken to identify and screen the ecological risks identified for decommissioning at Ranger. Decommissioning of the site has commenced with the backfilling of Pit 1 and Pit 3 and this periods will continue through until 2026.

4.9.2 Risk screening

The risk screening process was summarised in the Supervising Scientist Annual Report 2013–14 when reporting on the results for the post-decommissioning risk screening. This risk screening process was focussed on unmitigated risk which is the initial step in the risk assessment method being undertaken. Further screening processes will be undertaken to determine risk scores after mitigation and uncertainty are applied to the unmitigated risk scores. The risk screening process undertaken for the decommissioning phase was slightly different to that undertaken for the post-decommissioning phase. Survey questions were derived from the conceptual models and the existing likelihood and consequence statements from the post-decommissioning survey. Additionally, risk assessments undertaken by ERA (i.e. Tailings and brine Management, Integrated Tailings and Water closure Strategy, and

Best Practicable Technology) were cross-checked to ensure all risks were captured in the decommissioning survey. A total of 45 questions were provided to 21 experts across the key stakeholder groups (i.e. ***eriss***, ERA, Gundjeihmi Aboriginal Corporation and the Northern Land Council. A workshop was considered unnecessary to reach consensus on responses, as participants were familiar with the process having participated in the post-decommissioning risk screening. The responses for the likelihood and consequence statements were used to populate a Bayesian Belief Network, which was used to produce a ranking for all the risks and hazards.

Table 4.11 summarises the ten hazards with the highest scores. The critical hazards are: increased sediment runoff; elevated solutes (e.g. dissolved salts, nutrients) via surficial and groundwater flows; weeds; and solute (major ions) concentrations via groundwater flow.

Table 4.12 summarises the ten risks (likelihood and consequence statements) with the highest risk scores. The critical risks, defined as ‘stressor’ → ‘effect’, are:

1. weeds → terrestrial habitat diversity and ecosystem function
2. elevated solutes (e.g. dissolved salts, nutrients) via groundwater and surficial water flows → terrestrial habitat diversity and ecosystem function
3. solute (major ions) concentrations via groundwater flow → off-site water quality
4. increased sediment runoff → terrestrial habitat diversity and ecosystem function.

4.9.3 Future work

Further work is being undertaken to filter the risks for mitigation, address high uncertainty, and determine those risks that require further detail and quantitative analysis. This process also has to be applied for the post-decommissioning risk screening. These processes will provide us with a consolidated list of key risks for the time period from now until mine closure. A synthesis of the ecological risk assessment and the risk knowledge base for Ranger uranium mine is also being compiled. These activities will provide the basis for a review of the Key Knowledge Needs, which will take place in the latter part of 2015.

TABLE 4.11 THE HIGHEST RANKED HAZARDS FOR THE DECOMMISSIONING PHASE

Likelihood	Consequence	Risk score	Risk rank
What is the likelihood of increased sediment runoff from the RPA?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.744	1
What is the likelihood of increased sediment runoff from the RPA?	What would be the consequence to aesthetic values of the landscape meeting the expectations of stakeholders (additional to the consequences from the existing problem)?	0.744	1
What is the likelihood of elevated solutes (e.g. dissolved salts, nutrients) in soil or water originating from the RPA via surficial water flow?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.728	3
What is the likelihood of elevated solutes (e.g. dissolved salts, nutrients) in soil or water originating from the RPA via surficial water flow?	What would be the consequence to aesthetic values of the landscape meeting the expectations of stakeholders (additional to the consequences from the existing problem)?	0.728	3
What is the likelihood of elevated solutes (e.g. dissolved salts, nutrients) in soil or water originating from the RPA via groundwater flow?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.641	5
What is the likelihood of elevated solutes (e.g. dissolved salts, nutrients) in soil or water originating from the RPA via groundwater flow?	What would be the consequence to aesthetic values of the landscape meeting the expectations of stakeholders (additional to the consequences from the existing problem)?	0.641	5
Given human and non-human vectors, what is the likelihood of weeds sourced from the RPA causing an increase in the magnitude of the existing problem in KNP?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.518	7

TABLE 4.11 THE HIGHEST RANKED HAZARDS FOR THE DECOMMISSIONING PHASE

Given human and non-human vectors, what is the likelihood of weeds sourced from the RPA causing an increase in the magnitude of the existing problem in KNP?	What would be the consequence to aesthetic values of the landscape meeting the expectations of stakeholders (additional to the consequences from the existing problem)?	0.518	7
What is the likelihood that solute (major ions) concentrations in the KNP will exceed guidelines due to soil or water originating from the RPA via groundwater flow?	What would be the consequence to off-site water quality?	0.517	9
What is the likelihood that solute (major ions) concentrations in the KNP will exceed guidelines due to soil or water originating from the RPA via groundwater flow?	What would be the consequence to aquatic habitat diversity of off-site aquatic ecosystems?	0.517	9

TABLE 4.12 THE HIGHEST RANKED RISKS FOR THE DECOMMISSIONING PHASE

Likelihood	Consequence	Risk score	Risk rank
Given human and non-human vectors, what is the likelihood of weeds sourced from the RPA causing an increase in the magnitude of the existing problem in KNP?	What would be the consequence to terrestrial habitat diversity and ecosystem function (additional to the consequences from the existing problem)?	0.914	1
What is the likelihood of elevated solutes (e.g. dissolved salts, nutrients) in soil or water originating from the RPA via groundwater flow?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.895	2
What is the likelihood of elevated solutes (e.g. dissolved salts, nutrients) in soil or water originating from the RPA via surficial water flow?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.802	3
What is the likelihood that solute (major ions) concentrations in the KNP will exceed guidelines due to soil or water orginating from the RPA via groundwater flow?	What would be the consequence to off-site water quality?	0.786	4

TABLE 4.12 THE HIGHEST RANKED RISKS FOR THE DECOMMISSIONING PHASE

What is the likelihood of increased sediment runoff from the RPA?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.764	5
What is the likelihood of fire originating on the RPA being at a frequency and/or intensity greater than the existing fire regime in KNP to the extent that it impacts vegetation?	What would be the consequence to aesthetic values of the landscape meeting the expectations of stakeholders (additional to the consequences from the existing problem)?	0.764	6
Given human and non-human vectors, what is the likelihood of weeds sourced from the RPA causing an increase in the magnitude of the existing problem in KNP?	What would be the consequence to aesthetic values of the landscape meeting the expectations of stakeholders (additional to the consequences from the existing problem)?	0.752	7
What is the likelihood that solute (major ions) concentrations in the KNP will exceed guidelines due to soil or water orginating from the RPA via groundwater flow?	What would be the consequence to aquatic habitat diversity of off-site aquatic ecosystems?	0.748	8
What is the likelihood of increased sediment runoff from the RPA?	What would be the consequence to terrestrial habitat diversity and ecosystem function(additional to the consequences from the existing problem)?	0.700	9
Given human and non-human vectors, what is the likelihood of weeds sourced from the RPA causing an increase in the magnitude of the existing problem in KNP?	What would be the consequence to aquatic habitat diversity of off-site aquatic ecosystems?	0.696	10

5 OTHER SCIENCE AND TECHNICAL ACTIVITIES

5.1 Introduction

In addition to research and monitoring on the impacts of uranium mining in the Alligator Rivers Region, Supervising Scientist Branch 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 of the Environment with Environment Protection and Biodiversity Conservation Act (EPBC) related approvals and other significant projects, assisting the International Atomic Energy Agency (IAEA) with best practice in 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 2014–15 is provided below.

5.2 National initiatives for radiation protection of the environment

In April 2015, Dr Andreas Bollhöfer and Dr Che Doering took part in an Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) coordinated workshop on radiation protection of the environment. The workshop was attended by representatives from Government, Industry and Academia. During the workshop new developments for the ERICA tool and CROMERICA were presented, with updates also provided on the activities of Committee 5 of the International Commission on Radiological Protection (ICRP) and on the progress and current status of the national Safety Guide for Radiation Protection of the Environment. Dr Doering has been a member of the Radiation Health Committee Working Group for development of the safety guide. Discussions were held with all participants on how this group of experts could take a more nationally-coordinated approach to support international activities, such as the ERICA consortium, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and ICRP, so that the best outcomes for Australia could be achieved. Dr Doering presented on Supervising Scientist Branch's international involvement through participation in the EMRAS II (Environmental Modelling for Radiation Safety) and MODARIA (Modelling and Data for Radiological Impact Assessments) programmes of the IAEA, and Dr Bollhöfer presented current activities and initiatives through the South Pacific Environmental Radioactivity Association (SPERA).

5.3 The 13th South Pacific Environmental Radioactivity Association (SPERA) conference

The 13th biennial SPERA conference was held at Charles Darwin University from 1-3 September 2014, followed by an excursion to the Ranger mine and two technical workshops at ***eriss*** on 4–5 September 2014. The conference and workshops were organised by members of the ***eriss*** Environmental Radioactivity group in collaboration with Charles

Darwin University, the Northern Territory Government and Energy Resources of Australia Ltd.

The primary objective of SPERA is to encourage and facilitate communication among scientists working in the South Pacific region in the field of environmental radioactivity. This involves the study of the occurrence, behaviour and impact of radioactive species present in the environment naturally or due to human activities. More than 50 delegates from seven countries attended the conference, and selected papers will be published in a Special Issue of the Journal of Environmental Radioactivity in 2015.

5.4 The IAEA's MODARIA programme

The IAEA four-year programme on MODARIA was launched in November 2012, to continue some of the work of the EMRAS and EMRAS II programmes in the field of radioecological modelling (see Supervising Scientist Annual Report 2012–13). Supervising Scientist Branch continued its involvement with working groups 4 and 8 of the MODARIA programme in 2014–15, 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. Dr Che Doering attended the third MODARIA Technical Meeting in Vienna in November 2014, and Drs Andreas Bollhöfer and Doering attended the Interim Technical Meetings of working groups 4 and 8, and a joint Strategy for Allied Radioecology (STAR)/MODARIA workshop in Vienna in April 2015.

5.5 Revision of Australian and New Zealand 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. Supervising Scientist Branch continued to support the Water Division in the Department of the Environment with revision activities, primarily through the technical coordinator roles of ***eriss*** research scientists, Dr Rick van Dam and Dr Chris Humphrey. Key activities of the ***eriss*** personnel during 2014–15 included: provision of technical guidance for: (i) the development of the new website structure; (ii) procurements for projects on (a) ecoregional water quality and ecological information and guidance, and (b) derivation of guideline values for toxicants; and (iii) other ongoing projects. In addition, Supervising Scientist Branch's Science Knowledge and Communications group developed initial concept logos and theming for the products of the final guidelines. Finally, Supervising Scientist Branch hosted a secondee to the Department's Water Division from the Northern Territory Department of Mines and Energy, in May and June 2015, tasked with progressing aspects of the website development.

5.6 Developing toxicity testing methods for tropical marine species

This three year project aimed to develop a suite of tropical marine toxicity test methods and will come to completion at the end of 2015. Funding for this project has been provided by Rio Tinto Alumina and aluminium operations, the Northern Territory Research and Innovation Board and the Northern Australian Marine Research Alliance. ***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford, participate on the steering committee for the project, and Dr Melanie Trenfield is one of the post-doctoral fellows conducting the research. The project has been conducted in collaboration with scientists from the Australian Institute of Marine Science, Charles Darwin University and Rio Tinto.

The key outcomes in the final year of the project included the development of toxicity tests for five marine species: a microalga *Isochrysis galbana*, snail larva *Nassarius dorsatus*, barnacle larva *Amphibalanus amphitrite*, hermit crab larva *Coenobita variabilis* and sea anemone *Aiptasia pulchella*. Toxicity testing with the metals aluminium (Al), copper (Cu), gallium (Ga) and molybdenum (Mo) has been completed for the first four species and is currently underway for *A. pulchella*. The toxicity data from these species will contribute to providing a more reliable water quality guideline value for Al, Ga and Mo in seawater.

Particular achievements were: (i) a publication of the toxicity test for the microalga *I. galbana* (Trenfield et al 2015); (ii) a publication submitted describing the toxicity test and results for the marine snail (*N. dorsatus*); (iii) presentation of the barnacle, hermit crab and snail tests and results at the 3rd Society of Environmental Toxicology and Chemistry (SETAC)-AU conference (1419 September 2014, Adelaide); and (iv) presentation accepted to communicate the snail toxicity test and results at the SETAC-Australasia conference (25-28 August 2015, Nelson, NZ).

5.7 Effect of nickel on *Hydra viridissima* under varying calcium and magnesium concentrations and implications for NiBLM predictions

The application of generic water quality criteria in Europe and the North America has resulted in jurisdictions that are unable to meet obligations because the background concentrations exceed the water quality criteria. Consequently, a model was created by Nickel Producers Environmental Research Association (NiPERA) to predict the toxicity of nickel to aquatic organisms in waters with varying chemical conditions. This model, called the Nickel Biotic Ligand Model (NiBLM), was developed using toxicity data from Northern Hemisphere species, but did not predict nickel toxicity in Australian tests to the desired accuracy, especially for species that inhabit soft waters of Australia. The extremely soft waters that are found in some regions of Australia are lower than the range of water conditions for which the NiBLM was calibrated, i.e. <2 mg L^{-1} of calcium. The two water parameters that notably differed between Australia and the Northern Hemisphere waters were the hardness (i.e. the concentration of calcium and magnesium) and the ratio of calcium to magnesium concentration in the waters. This highlighted a need to explore the calcium and magnesium binding constants within the NiBLM model. Hence, NiPERA contracted the ***eriss*** Ecotoxicology group to further explore this issue.

The aim of this project was to improve the predictive ability of the model for Australian ecosystems. The ratios of calcium and magnesium in test waters were varied to determine the effect of hardness and the ratio of calcium to magnesium on nickel toxicity. *Hydra viridissima*, a tropical freshwater cnidarian, was used to assess the chronic toxicity of nickel in eight different waters with varying calcium and magnesium concentrations. The hardness of the water ranged between 1.1 and 53 mg L^{-1} $CaCO_3$, which represented hardness concentrations observed in both Australian and European freshwaters. Five of the hardness concentrations tested had calcium concentrations that were below the lower validation limit of the European NiBLM of 2 mg L^{-1} Ca, and would not be tolerated by many standard test species. As expected, *H. viridissima* was markedly more sensitive to nickel in the softest waters. When the dataset was divided into softer and harder waters, a greater ameliorating effect of increasing hardness was observed in the soft waters compared to the hard waters. Compared to the effect of hardness, the calcium to magnesium ratio appeared not to play an important role in nickel toxicity, which indicated that calcium and magnesium provide a similar protective effect. As such, increasing the competitive binding of both calcium and magnesium in the model by the same amount improved the predictions of nickel toxicity to *H. viridissima*. The findings of this study have broadened of the use of the NiBLM model by improving predictions of nickel toxicity in Australian softwaters and waters with similar chemical conditions in other regions of the world.

5.8 New diagnostics for multiply-stressed marine and freshwater ecosystems

In September 2014, a group of marine and freshwater specialists, including Dr Chris Humphrey from ***eriss***, were invited to attend a workshop at the Sydney Institute of Marine Sciences to review and explore recent advances in key environmental areas, including ecological modelling, biomonitoring science, ecogenomics and earth observation technologies. With ground-breaking developments in these disciplines, significant new opportunities are now available for the study of complex stress regimes. The workshop explored the potential offered by these new approaches to characterise stressor regimes, to explore stressor-response relationships among biota, to design better early-warning systems and to develop smart tools to support sustainable management of human activities through more efficient regulation. A key focus of the workshop was to more closely integrate diverse approaches developed by aquatic scientists working on marine and freshwater systems. Three per-reviewed papers were written from the workshop proceedings and are appearing in the journal, *Marine and Freshwater Research.*

5.9 Science Division activities

5.9.1 Essential Environmental Measures Programme

The Science Division's Environmental Resources Information Network (ERIN) Branch is developing the Essential Environmental Measures programme, which aims to improve the capacity to track trends in the state of the environment by delivering meaningful information and reusable open-access data on a set of Essential Environmental Measures.

In June 2014, a group of water quality experts from around Australia, including Dr Chris Humphrey from ***eriss***, was invited to the first Essential Environmental Measures workshop in Canberra, focussing on water quality. This workshop made significant progress on:

- identifying 16 candidate Essential Environmental Measures for water quality;
- identifying practical, deliverable opportunities and ideas for improving water quality measurement and data; and
- considering how to move forward with improvements to water quality measurement and data in the future.

Workshop outcomes have been summarised in a paper prepared by ERIN.

5.9.2 National Environmental Science Programme

The National Environmental Science Programme (NESP) is coordinated by the Science Division's Science Partnerships Section. The programme is focussed on six research hubs which were announced in 2014. The NESP Research Priorities Horizon Working Group was established in October 2014 to provide the opportunity for all areas of the Department to contribute in determining the research that will be conducted under NESP.

Dr Renee Bartolo and Dr Chris Humphrey contributed to the working group focussed on the Northern Australia Environmental Resources Hub (NAER) with Dr Bartolo undertaking the role of focal point for the working group. The NAER hub is supporting the sustainable development of Australia's northern landscapes. As well as determining the research priorities across the department, the working group assessed the initial research plans and provided feedback on the projects proposed under the plans.

Given the link between the NAER and the Threatened Species Recovery hub, Dr Bartolo attended a two day threatened species forum held in Kakadu in February 2015. The focus of the forum was on implementing Kakadu's threatened Species Strategy and was also the first meeting of the Kakadu Threatened Species Network.

5.9.3 UAV Demonstration for ERIN

In October 2014, Dr Renee Bartolo and Dr Tim Whiteside demonstrated the use of unmanned aerial vehicles (UAVs) for capturing hyperspatial image data at Owen Springs (central Australia) for the Landscape Analysis Section in ERIN. The demonstration coincided with the Terrestrial Ecosystem Research Network's AusPlots field method training. The Department has a research investment in field data collection through a project with AusPlots to enhance the site survey approach in building information about 'condition'.

The UAV flights undertaken at Owen Springs were to trial the linkage between field data and hyperspatial remote sensing data acquired by a UAV, collected at the same time.

5.10 Other contributions

Research staff within Supervising Scientist Branch undertook other activities within and outside of Australia not identified in earlier chapters, as summarised below.

Dr Wayne Erskine undertook work for the Goulburn-Broken Catchment Management Authority (Victoria) on the River Reaches, Historical Channel Changes and Recommended Methods to Improve Macquarie Perch Habitat on Hughes Creek, Victoria.

Mr John Lowry from ***eriss*** undertook a review of landform modelling work performed by URS Pty Ltd for a mine site in Western Australia.

6 COMMUNICATION ACTIVITIES

6.1 Overview

In 2014–15 Supervising Scientist Branch undertook a range of communication activities to ensure its stakeholders (local residents including traditional owners, government and non-government organisations, mining companies and the science community) remained informed about the possible environmental effects of uranium mining in the Alligator Rivers Region.

Communication about Supervising Scientist Branch's supervision, assessment, research and monitoring activities occurs through various forms of consultation, presentations, reporting and statutory committees, as well as face-to-face discussions. In the reporting period, these activities provided Supervising Scientist Branch with the opportunity to identify, understand and address the broad range of stakeholder concerns that accompany the sensitive issue of uranium mining.

The Science Knowledge & Communication unit — part of the Office of the Supervising Scientist — oversees general communication activities, including with Indigenous stakeholders and the Alligator Rivers Region community. Many of these activities are undertaken in partnership with the Jabiru-based Indigenous Communication Officer. Science Knowledge & Communication unit also promotes the research outputs of Supervising Scientist Branch to the broader scientific community.

6.2 Communication with the local community including traditional owners

Supervising Scientist Branch has an obligation to facilitate awareness of its research and monitoring activities among the local community, including traditional owners and other Indigenous communities in the area. Additionally our targeted strategy for communicating to the local Indigenous communities contributes to the Department of the Environment's overarching commitment to 'Closing the Gap'.

Findings from the monitoring and research projects carried out in the region are made available to traditional owners and other Indigenous residents of the Alligator Rivers Region, by the Indigenous Communication Officer and the Science Knowledge and Communications unit. During the reporting period, the Science Knowledge & Communication unit developed developed a series of informative videos narrated in Kunwinjku language with English subtitles, which can be used by the Indigenous Communication Officer when visiting local communities to help explain the methods and results of Supervising Scientist Branch's work in the region. The videos are also available on Youtube and from the Department's website.

The Indigenous Communications Officer maintains regular informal contact with the Mirarr people – the traditional owners of the land on which Ranger and Jabiluka lie, in order to keep the local people informed and up-to-date about our monitoring and research programmes and to receive feedback on specific concerns and expectations of the Mirrar.

Information exchanges occur on Mirrar country and use digital technology to illustrate and enhance the message and understandings. These activities nurture trust and strengthen Supervising Scientist Branch's relationship with the local Indigenous stakeholders.

Supervising Scientist Branch held a stall at the Mahbilil festival in Jabiru township in September 2014, promoting the research and monitoring that Supervising Scientist Branch conducts. Supervising Scientist Branch uses its presence at the Mahbilil event to hear and respond to general local community concerns that might not be raised in more formal settings. The stall featured interactive aquatic macroinvertebrate displays to provide a hands-on educational experience for visitors.

In February 2015, Supervising Scientist Branch ran an information stall in Jabiru for World Wetlands Day, to inform the local community of the work of Supervising Scientist Branch in protecting the wetlands of the Alligator Rivers Region from the potential effects of uranium mining. The stall was of particular interest to local school children who enjoyed the interactive features such as microscopes and live aquatic creatures. The stall also featured information on the ways in which research by Supervising Scientist Branch contributes to wetland preservation around the world.

Figure 6.1 Stills from the Kunjwinku language videos developed for traditional owners and Indigenous communities in the Alligator Rivers Region

Figure 6.2 Jabiru Field Station staff at Mahbilil festival 2014

As well as direct liaison with local Indigenous communities, the Indigenous Communications Officer liaises with other important stakeholders located in Alligator Rivers Region, including Energy Resources of Australia Ltd community relations staff, Joint Management Branch Parks Australia staff, local Indigenous corporations and the Northern Land Council to ensure there is a continuous two-way flow of information on current and proposed Supervising Scientist Branch activities. Consultation occurs with Kakadu residents to explain Supervising Scientist Branch projects and seek permission to carry out research on Indigenous land.

Employment of Indigenous people for activities such as field research provides our staff the opportunity to work alongside Indigenous landowners on their own country, sharing knowledge and gaining greater insight into traditional cultural values and understandings of the land. Through these activities, local Indigenous people gain valuable technical skills and insight into how Supervising Scientist Branch carries out work. Regular contact between our Indigenous Communication Officer and the Gundjeihmi Aboriginal Corporation facilitates this interaction.

The publications produced by Supervising Scientist Branch focus on research and monitoring-related information and are pitched at varying levels of scientific detail and complexity, depending on the intended audience. This approach aims to ensure that all stakeholders are catered to with publications that convey accessible, directly-relevant aspects of the organisation’s work.

The Science Knowledge and Communication unit produces and distributes several scientific report series, described below in section 6.6, all of which record and showcase the work of Supervising Scientist Branch. Additionally, during the reporting period, the Science Knowledge & Communication unit developed a number of new communication products, targeting Alligator Rivers Region residents, including traditional owners. These include a new seasonal newsletter called ‘The Monitor’, which was developed with the aim of keeping residents of the Alligator Rivers Region informed about the status of the environment surrounding Ranger uranium mine, as monitored by Supervising Scientist Branch.

Figure 6.3 Jabiru Field Station staff with students from West Arnhem College at World Wetlands Day 2015

Figure 6.4 2014 popnetting crew

6.3 Communication with other external stakeholders

Supervising Scientist Branch staff engage with a range of external stakeholders to promote awareness of the research and monitoring activities of the organisation and our role in protecting the Alligator Rivers Region. In 2014–15 Supervising Scientist Branch's two specialised statutory committees, the Alligator Rivers Region Technical Committee (ARRTC) and the Alligator Rivers Region Advisory Committee (ARRAC), facilitate discussion and information exchange between Supervising Scientist Branch and its primary stakeholders (which include uranium mining companies, scientists, environmental non-government organisations, Indigenous associations, and state and Australian government agencies). These committees are an important means of ensuring transparency and scientific rigour, as well as fostering trust between the various stakeholder organisations. Consultation through these committees ensures the research programme of Supervising Scientist Branch is endorsed by key stakeholders. Details are in chapter 2.

Supervising Scientist Branch website is an important tool in raising community awareness and providing free public access to scientific data and reports. Supervising Scientist Branch research results and environmental monitoring programmes are continually updated on Supervising Scientist Branch website.

The Science Knowledge & Communication unit also co-ordinates the Supervising Scientist Branch's contribution to the Department's annual report and produces the Supervising Scientist annual report.

These publications are particularly useful for informing Supervising Scientist Branch's technical advisors of the results of environmental monitoring and research by Supervising Scientist Branch staff and by external authors.

6.4 Research protocols for Kakadu National Park

Details of the proposed 2014–15 Supervising Scientist Branch research and monitoring activities within Kakadu National Park were submitted to Parks Australia and the Northern

Land Council in April 2015 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 Supervising Scientist Branch and Parks Australia staff, the Kakadu Board of Management and traditional owners in relation to Supervising Scientist Branch research and monitoring activities within Kakadu National Park.

6.5 Internal communications

Supervising Scientist Branch actively supports open exchange of information amongst staff within the Supervising Scientist Branch, the Science Division and across the Department.

Supervising Scientist Branch maintains effective internal communication between staff of all levels through regular team, programme and general staff meetings. Subject-specific working groups are convened as required to address strategic business issues within Supervising Scientist Branch, and staff participate in a range of business-related and technical working groups across the Portfolio. Our internal bulletin board facility allows staff to post work and professional-development related notices for all staff to see.

Supervising Scientist Branch staff familiarity of scientific research activities across and outside the organisation is fostered 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, innovation and synergies across the scientific programme areas of ***eriss***.

Supervising Scientist Branch intranet is regularly updated with a range of new information and features to assist staff in their daily work.

With the integration of Supervising Scientist Branch into the Department’s new Science Division during the reporting period, a number of new communication activities were initiated by the Science Knowledge & Communication unit with the goal of facilitating scientific information flow throughout the Division and the broader Department. One example is the Supervising Scientist Branch’s Research Update Forum, which showcases vignettes of Supervising Scientist Branch research work, was extended to the rest of the Science Division.

The theme of enhancing communication systems with IT solutions underpinned a number of internal communication innovations. In 2014–15 the EndNote system of electronic libraries was upgraded to better accommodate the needs of Supervising Scientist Branch in regard to storage, access and reporting on its scientific information resource.

6.6 Science communication

Strategic communication with academic and research organisations was prioritised in the reporting period, to position Supervising Scientist Branch at the forefront of research in its relevant fields, and as a desirable research partner. It took the form of publication by Supervising Scientist Branch researchers in a range of scientific journals and periodicals (detailed in Appendix 2). Additionally, a number of Supervising Scientist Branch staff contributed to and collaborated with external scientific, technical and other professional organisations during the reporting period, including editorial boards and panels.

Supervising Scientist Branch hosted numerous researchers and visitors from other organisations to undertake collaborative funded projects, for sabbatical periods, or to present seminars or training workshops during the reporting period as detailed in Table 6.1.

In April 2015, Supervising Scientist Branch hosted and presented a continuing professional development technical seminar for the Surveying and Spatial Sciences institute, on unmanned aerial vehicles (UAVs). The seminar covered the application of UAV technology to the environmental monitoring programme of Supervising Scientist Branch and was well attended by representatives of the surveying industry, various government sectors as well as academics and researchers.

Participation in international events during 2014–15 allowed Supervising Scientist Branch staff to share their knowledge and expertise with peers and maintain awareness of international best practice in relevant areas. Participation is important in ensuring Supervising Scientist Branch maintains its profile as a respected part of the broader scientific and technical community. Supervising Scientist Branch staff presented papers at a number of national and international conferences during the reporting period as described in Table 6.2.

The results of research and investigations undertaken by Supervising Scientist Branch staff are made available to stakeholders and interested members of the public, as well as to the scientific and wider community through publications on the Department's website, in journals and conference proceedings, and in a range of internal and publicly distributed publications. In 2014–15 Supervising Scientist Branch posted continuous, event-based and routine water monitoring results on its website for public viewing. Water monitoring data were updated fortnightly while the creeks around Ranger mine were flowing. Biological and radon monitoring data were also posted online for public viewing.

In-house productions included three new Supervising Scientist Branch Reports and eight additions to Supervising Scientist Branch 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.

Supervising Scientist Branch continued to minimise hard copy production of its publications, defaulting to electronic distribution wherever possible, as a means to reduce our carbon footprint and also to reduce costs and administrative burden. Complete series of Supervising Scientist Branch publications are available in PDF format on the Department's website and are also provided by email on request.

Other activities undertaken in the reporting period included staff participation in National Science Week, conferences and presentations for professional development. Supervising Scientist Branch also hosted visits by interstate and international delegates during 2014–15 (see Table 6.1).

A full list of papers and reports published during 2014–15 is provided in Appendix 2. Papers presented at national and international conferences are listed in Appendix 3.

TABLE 6.1 RESEARCHERS AND OTHER VISITORS, 2014–15

Activity	Visitor/ organisation	Date
Provision of support/ advice and discussion on (1) model reliability of CAESAR-Lisflood, (2) the implementation of a weathering function, and (3) development of a vegetation growth function into the CAESAR-Lisflood model, with all three points focussing on its use for assessing geomorphic stability of Ranger landform for up to 10,000 years	Professor Tom Coulthard, University of Hull, United Kingdom	20–27 May 2015
Initial team meeting / progress update – development of a synthetic rainfall dataset for long-term (10 000 year) modelling of the stability of the Ranger rehabilitated landform. Presentation to Supervising Scientist Branch staff and external stakeholders on project aims, methodology and results to date	Dr Danielle Verdon-Kidd and Associate Professor Greg Hancock, University of Newcastle, Australia	20–22 May 2015
Unmanned aerial system (UAS) operations in Kakadu	Lew Woods, Skycam New Zealand	21–24 April 2015
Visit of Darwin laboratories and collection of dust samples using DustScan sampling disks around Ranger mine	Emma Owens, University of Portsmouth, UK	4–11 June 2015

Supervising Scientist Branch's website continued to be redeveloped in keeping with structural changes across the Department and also to enhance visit numbers and user movement through the website.

In 2014–15, ***eriss*** staff supervised one post-graduate research project on the effect of uranium on the structure and function of sediment bacteria communities (PhD, Macquarie University, to be completed January 2017)

In the same period, ***eriss*** staff supervised an honours student from Charles Darwin University, to investigate water turbidity monitoring of tropical billabongs of the Alligator Rivers Regions (NT) through Unmanned Aerial System (UAS) Imagery, project to be completed by July 2016 and another honours student investigating Sediment accretion and carbon burial in the mangroves of Darwin Harbour, completed in June 2015.

In 2014–15, ***eriss*** staff hosted and supervised a number of Charles Darwin Univeristy professional placements for their SID300 Professional Practice in Science Unit. Students contributed to:

- Supervising Scientist Branch's stream chemistry and biological monitoring programmes for the Ranger Uranium Mine, conducted in the 2014–15 wet season
- Preliminary Ground Water Dependent Ecosystem (GDE) Mapping for the Ranger Project Area
- Using UAV imagery to map erosion in the South Alligator Valley

TABLE 6.2 CONFERENCE PRESENTATIONS 2014–15

Conference	Place/date (no. Papers)
Joint Congress of the Australian Society of Fish Biology and the Australian Society for Limnology	Darwin, Australia 30 June–3 July 2014
Life-of-Mine 2014 Conference	Brisbane, Australia 16–18 July 2014 (1 presentation)
7th Australian Stream Management Conference	Townsville, Australia 28–30 July 2014 (3 presentations)
SPERA 2014, 13th South Pacific Environmental Radioactivity Association Conference	Darwin, Australia 1–3 September 2014 (6 presentations)
Society of Environmental Toxicology & Chemistry – Asia Pacific Conference	Adelaide, Australia 15–18 September 2014 (6 presentations)
ARPS 2014, 39th Annual Conference of the Australasian Radiation Protection Society	Hobart, Australia 26–29 October 2014 (3 presentations)
Workshop on ‘Protection of the Environment and the ERICA Tool’	Hobart, Australia 26 October 2014 (1 presentation)
3rd Technical Meeting of the International Atomic Energy Agency (IAEA) programme on Modelling and Data for Radiological Impact Assessment (MODARIA)	Vienna, Austria 10–14 November 2014 (2 presentations)
Sediment Dynamics - From the Summit to the Sea : International Association of Hydrological Sciences (IAHS) Symposium	New Orleans, United States, 11–14 December 2014 (1 presentation)
STAR-MODARIA Workshop on ‘Making data available’	Vienna, Austria 20–21 April 2015 (1 presentation)
Workshop on ‘Protection of the Environment and International Engagement’	Yallambie, Australia 8 April 2015 (2 presentations)
10th International Mine Closure Conference	Vancouver, Canada, 1–3 June 2015 (1 presentation)

7 Administrative arrangements

7.1 Human resource management

7.1.1 Supervising Scientist

The Supervising Scientist is a statutory position established under the Commonwealth *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 April 2013.

7.1.2 Structure

The Supervising Scientist Branch consists of two sections, the Office of the Supervising Scientist (***oss***) and the Environmental Research Institute of the Supervising Scientist (***eriss***).

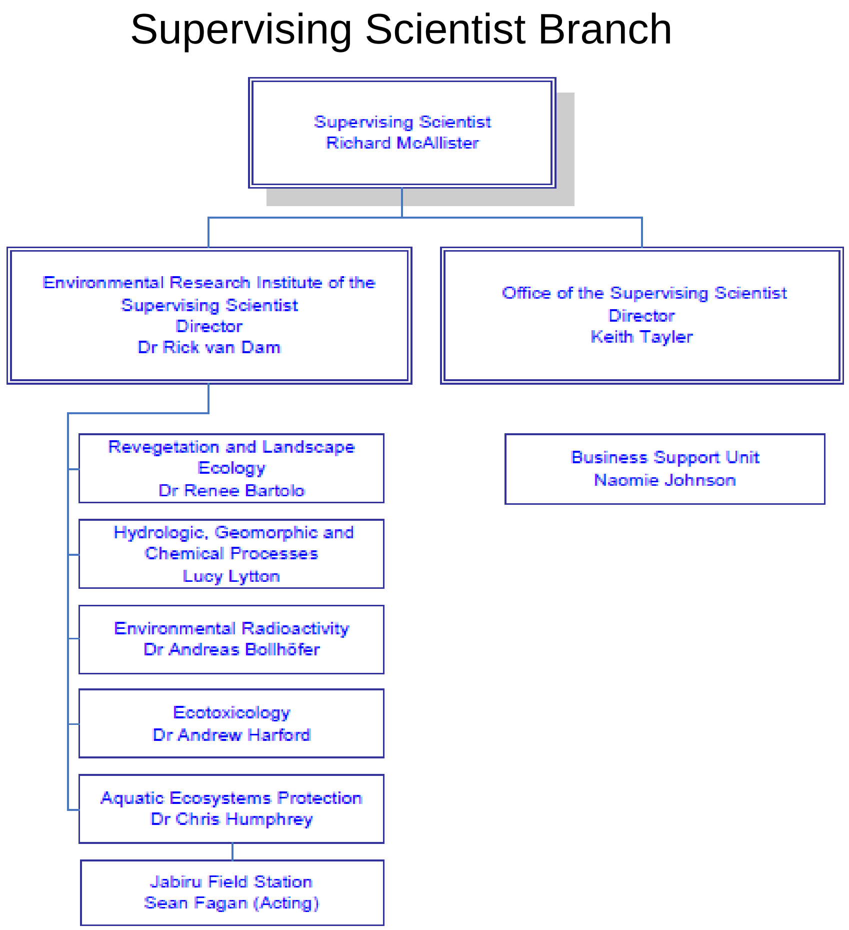

Figure 7.1 Organisational structure of Supervising Scientist Branch (as at 30 June 2015).

The ***oss*** is responsible for supervision, assessment, policy, information management and corporate support activities. ***eriss*** is responsible for scientific research and monitoring activities. Dr Rick Van Dam assumed the Director role of ***eriss*** in September 2014. Supervising Scientist became part of the Department of the Environment's newly-established Science Division on 1 July 2014. There were no changes in functions or annual reporting.

Average staffing numbers for 2013–14 and 2014–15 are given in Table 7.1

7.1.3 Workforce management

In line with the Department's policies and practices, the Supervising Scientist Branch 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 Supervising Scientist Branch 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 Branch's succession plan. Through the Department's 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. Supervising Scientist staff have access to Canberra-based seminars and information sessions. Locally-hosted seminars, in addition to Supervising Scientist internal seminar series, provide staff with a range of topics relevant to Supervising Scientist business activities.

During 2014–15 the health and wellbeing programme offered staff access to vaccinations for influenza and a team pedometer challenge.

7.2 Work Health and Safety

Supervising Scientist Branch continued to maintain a strong commitment to Work Health and Safety (WHS) during 2014–15. No workers compensation claims were submitted and no Comcare reportable incidents were reported.

TABLE 7.1 STAFFING NUMBERS [1] AND LOCATIONS

	2013–14	2014–15
Darwin	39.8	38.3
Jabiru	8.0	7.0
Canberra	0.0	1.0
Total	47.8	46.3

1 Actual Full Time Equivalent (FTE) at June 2014 and 2015

In April 2015 Supervising Scientist Branch recruited a full-time WHS and Facilities Manager. The focus for this position is to improve the structure and performance of the Safety Management System across Supervising Scientist Branch, whilst ensuring alignment with the Science Division and departmental system.

In response to a Comcare report into quad bike incidents in 2013, Supervising Scientist Branch phased out the quad bike fleet located at Jabiru Field Station and replaced the bikes with new all terrain vehicles (ATVs), which provide workers with a much higher level of safety. Due to reliability and robustness issues; especially under body protection; identified during use in the field, replacement ATV's were sourced and the fleet will be available in the 2015–16.

The Department of the Environment Darwin and Jabiru 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 quarterly WHS site inspections. The number of hazards identified has significantly reduced as a result of improved maintenance systems, reporting and further maturing of the safety culture in Supervising Scientist Branch.

In 2014–15, safety education for staff focused on the operational environment and included:

- influenza vaccinations
- crocodile safety
- field work safety
- 4WD training in the use of new ATVs
- 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 Supervising Scientist Branch's general control, safety and management plans of ionising and non-ionising source holdings.

7.3 Finance

Full financial statements for Supervising Scientist Branch are contained in the Department's annual report, available at: **environment**.gov.au/about/publications/annual-report/index.html.

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

7.4 Facilities

7.4.1 Darwin facility

The majority of Supervising Scientist Branch staff are located at the Department's Darwin facility adjacent to the Darwin International Airport. This facility consists of office accommodation and laboratories. The office space and amenities are shared with Parks Australia, which is also part of the Department.

The Darwin facility experienced two significant events during 2014–15 which impacted on the usability of the facility. There were no injures caused by these incidents, showing that the incident response strategies the Branch has in place are effective. These were:

- Total loss of power to the Darwin International Airport precinct which resulted in the installation and connection of a generator for a period of ten days.
- Partial ceiling collapse in the laboratory wing due to excessive water build-up from a blocked air-conditioning drain.

7.4.2 Jabiru Field Station

The primary function of the Jabiru Field Station (JFS) is to support the activities of Supervising Scientist in the Alligator Rivers Region. The 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 2014–15 there were a number of upgrades to facilities and equipment including the construction of a large shelter over the loading zone at the rear of the main building (refer to Figure 7.2), the replacement of two Toyota Landcruiser trayback field vehicles, the replacement of three Polaris ATVs, the purchase of a 360° Hummingbird sonar unit for crocodile safety, and the replacement of a laboratory dishwasher.

7.5 Information management

Staff in Supervising Scientist Branch use the Department's electronic document and records management system, SPIRE. This enables staff to store and preserve most records digitally, instead of on paper.

TABLE 7.2 SUMMARY OF DIRECT PROGRAMME EXPENSES

Portfolio Budget Statement (PBS) Outcome 1	2013–14	2014–15
Programme 1.5 – Environmental Regulation *	$8 721 840	$9 284 358
Total*	$8 721 840	$9 284 358

* Excludes departmental corporate overheads.

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 2014–15.

7.7 Ministerial directions

There were no Ministerial Directions issued to Supervising Scientist Branch under Section 7 of the *Environment Protection (Alligator Rivers Region) Act 1978* during 2014–15.

7.8 Animal experimentation ethics approvals

eriss seeks the approval of Charles Darwin University's Animal Ethics Committee 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 Animal Ethics Committee 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 the Animal Ethics Committee and approved on 8 October 2014. A final report will be submitted in September 2016. Individual permits for new ***eriss*** staff conducting research with fish were also granted during this time. This project is due for renewal on 1 October 2016 and the individual permits are valid for two years. The number of fish used in toxicity tests at ***eriss*** was reported in July 2015 to the Northern Territory Government, as part of our licence requirements permitting the use of animals for research purposes.

Figure 7.2 The new shelter at the rear of the JFS building.

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 Animal Ethics Committee on 9 March 2015. The progress report for A11034 was approved on 29 March 2015. The progress report for A12007 was re-submitted on 16 June 2015 for the Committee's next meeting on 15 July 2015. A final report for both projects is due in March 2016.

On 8 September 2014, a new project, 'Baseline Studies for Biological Assessment in the Alligator Rivers Region (A14010)', was submitted to the Animal Ethics Committee for approval. Approval was received on 1 December 2014 and allows Supervising Scientist Branch to collect aquatic organisms at locations associated with mining exploration in Arnhem Land (outside of Kakadu National Park), as part of baseline studies, in anticipation of any future mining. This project relates to Key Knowledge Need 5.3.1 (Appendix 1).

Table 7.3 provides information on new applications, renewals of approvals and approval expiries for projects during 2014–15.

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	1 Oct 2014	1 Oct 2016
Monitoring mining impact using the structure of fish communities in shallow billabongs	A12007 (previously A09001)	25 Sept 2000	15 July 2015	15 July 2016
Fish community sampling in channel billabongs around Ranger mine using boat visual census	A11034	22 Feb 2012	09 Mar 2015	05 Mar 2016
Baselines Studies for Biological Assessment in the Alligator Rivers Region	A14010	8 Sept 2014	01 Dec 2014	01 Dec 2017

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 Alligator Rivers Region 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, the Alligator Rivers Region Technical Committee (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 Northern Territory 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.
- A 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 (ERs). Similar standards would be expected for any future mining development at Jabiluka or Koongarra.

Specifically, under the Ranger 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 Supervising Scientist Branch , 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 Key Knowledge Needs (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, 140 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 Alligator Rivers Region. 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 to Pit 3) methods and geochemical and geotechnical assessment of potential barrier materials. Strategies and technologies must also be devised 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 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 (such as permeabilities, aquifer connectivity), 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 Alligator Rivers Region, 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 Ranger Project Area. 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

Supervising Scientist Branch conducts regular assessments of the status of mine sites in the South Alligator River 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 Key Knowledge Need will need to be revisited pending the possible re-incorporation of the area into Kakadu National Park.

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APPENDIX 3 PRESENTATIONS TO CONFERENCES AND SYMPOSIA, 2014–15[14]

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Doering C, Bollhöfer A 2014. Relative importance of 238U-series radionuclides to ingestion dose from terrestrial bush foods in the north Australian uranium mining context. Paper presented at the third Technical Meeting of the International Atomic Energy Agency (IAEA) Modelling and Data for Radiological Impact Assessments (MODARIA) Working Group 4 'Analysis of Radioecological Data', 10 November 2014, Vienna, Austria.

Doering C, Bollhöfer A 2014. EMCLs for terrestrial wildlife in the Australian U-mining context and important radionuclides. Paper presented at the third Technical Meeting of the International Atomic Energy Agency (IAEA) Modelling and Data for Radiological Impact Assessments (MODARIA) Working Group 4 'Analysis of Radioecological Data', 10 November 2014, Vienna, Austria.

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Whiteside T & Bartolo R 2015. Monitoring vegetation success of a rehabilitated mine site using multispectral UAV imagery. Paper presented at NT Spatial: New Positioning Technologies and Spatial Techniques Forum, 29 May 2015, Darwin, Australia.

APPENDIX 4 LIST OF ERISS RESEARCH PROJECTS, 2014–15

Project Code	Project Title	Work group*
Completed		
RES-2006-004	Impact of Cyclone Monica on Gulungul Creek catchment, Ranger mine site and Nabarlek area	HGCP
RES-2007-004	Landslips in the Upper Magela catchment	HGCP
COR-2009-001	Point Source data management review/implementation	RLE
RES-2010-006	Model Geomorphic stability of Pit 1 landform	HGCP
RES-2012-001	Effect of manganese on tropical freshwater species	Ecotox
RES-2013-010	Aquatic ecosystem knowledge assessment and evaluation	AEP
RES-2013-013	Toxicity of distillate from the fully commissioned brine concentrator plant	Ecotox
EXT-2015-001	Effect of nickel on *Hydra viridissima* under varying calcium and magnesium concentrations	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-2005-005	Development of catchment geomorphic characteristics of Gulungul Creek	HGCP
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-2007-005	Development of a spectral library for mine site rehabilitation assessment-vegetation components (Re-activated after being suspended)	RLE
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

Project Code	Project Title	Work group*
RES-2009-004	Radon exhalation from the Ranger uranium mine trial landform	EnRad
COR-2009-010	Development of a reference toxicant test protocol and a test endpoint based on plant surface area for the Lemna aequinoctialis 96-h plant growth test	Ecotox
RES-2009-011	Ranger trial landform research	HGCP
RES-2010-007	Assessing the geomorphic stability of the Ranger trial landform	HGCP
RES-2010-012	Re-analysis of existing uranium freshwater chronic toxicity data to revise the site-specific and national U trigger values	Ecotox
RES-2012-002	Dose rates to non-human biota	EnRad
RES-2012-003	Toxicity of ammonia in Magela Creek water	Ecotox
RES-2012-005	Model the geomorphic stability of proposed landform for up to 10,000 years	HGCP
RES-2012-008	Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine	EnRad
EXT-2012-010	Developing new ecotoxological methods to protect Australian tropical marine ecosystems	Ecotox
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
RES-2013-002	Analysis of landscape change on the Ranger site pre-mining using historical aerial photography	RLE
RES-2013-009	Radionuclide fluxes from the trial landform	EnRad
RES-2014-001	Effects of uranium on the structure and function bacterial sediment communities	Ecotox
RES-2014-006	East Alligator Slackwater Deposits	HGCP
Commenced		
RES-2012-006	Aquatic plant communities of shallow lowland waterbodies of the ARR	AEP
RES-2013-016	Videographic techniques for monitoring fish	AEP
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-2014-007	Monitoring billabong turbidity using a UAS	RLE
RES-2014-008	Traditional knowledge of plants in Kakadu National Park	EnRad

Project Code	Project Title	Work group*
RES-2014-009	Spectral investigation of Ranger salts	RLE
RES-2015-010	Mapping of groundwater dependent ecosystems (GDEs) on the Ranger Lease	RLE
RES-2015-012	Critical groundwater research needs for Ranger mine and the Alligator Rivers Region	HGCP
RES-2015-013	Development of a model for radium-226 uptake in Velesunio Angasi	EnRad
RES-2015-014	Environmental fate and transport of Ac-227 and Pa-231	EnRad
RES-2015-015	Characterising and mapping salt effloresences using remotely sensed data	RLE
RES-2015-019	Molecular genetics methods for species-level macroinvertebrate determinations	AEP

* AEP: Aquatic Ecosystems Protection; Ecotox: Ecotoxicology; EnRad: Environmental Radioactivity; HGCP: Hydrologic, Geomorphic and Chemical Processes; RLE: Revegetation and Landscape Ecology.

GLOSSARY OF TERMS, ABBREVIATIONS AND ACRONYMS

ANOVA	ANalysis of VAriance testing
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 2008* (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.
BACIP	Before-After Control-Impact Paired design
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.
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).
CR	concentration ratio
CCWG	Closure Criteria Working Group
CDU	Charles Darwin University
DME	Northern Territory Department of Mines and Energy (formerly Northern Territory Department of Resources)

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.
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.
EIS	Environmental Impact Statement
EMRAS	Environmental Modelling for Radiation Safety
ERA	Energy Resources of Australia Ltd
eriss	Environmental Research Institute of the Supervising Scientist
ERs	Environmental Requirements
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)
GCT2	Gulungul Creek Tributary 2
GCUS	Gulungul Creek Upstream (upstream monitoring site)
GDEs	groundwater dependent ecosystems
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.
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.
in situ	a Latin phrase that translates to 'on site'
ISWWG	Independent Surface Water Working Group
IT	Information Technology
ITWC	Integrated Tailings, Water and Closure project
IWMP	Interim Water Management Pond
JFS	Jabiru Field Station
KKN	Key Knowledge Needs
KNP	Kakadu National Park
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
MODARIA	Modelling and Data for Radiological Impact Assessment
MOL	Maximum Operating Level. The maximum level at which a liquid containing impoundment can be operated.
mRL	Reduced Level metres
MTC	Minesite Technical Committee
near Infrared	0.7 to 1.3 µm
NGO	Non-government Organisation
NLC	Northern Land Council
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

PERMANOVA	PERmutational Multivariate Analysis Of Variance testing
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
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
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

Supervising Scientist Branch	A Branch of the Science Division, Department of the Environment, which incorporates the Environmental Research Institute of the Supervising Scientist (***eriss***)and Office of the Supervising Scientist (***oss***).
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
TBM	Tailings and Brine Management
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
WQGV	Water Quality Guideline Value

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