Australian Government

Department of the Environment and Energy

Supervising Scientist

SUPERVISING SCIENTIST

Annual Technical Report

2016-17

This report should be attributed as Supervising Scientist 2017. *Annual Technical Report 2016–17*, Commonwealth of Australia 2017.

Disclaimer

ISSN: 2207-7758 (Print)
ISSN: 2207-7766 (Online)

Supervising Scientist Branch is part of the Australian Government Department of the Environment and Energy.

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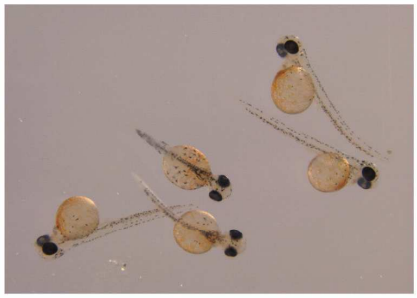
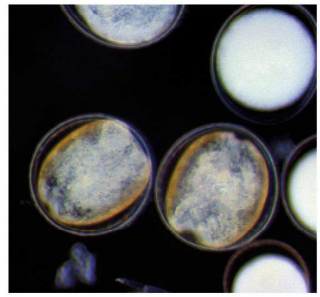
Our mission

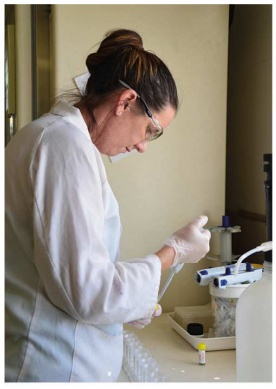
To protect and restore the environment of the Alligator Rivers Region from the effects of uranium mining

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

We pay our respects to the cultures of the Mirarr, Larrakia and Ngunnawal people, and to their elders both past and present.







Photos (from top left): *Mogurnda mogurnda* (Northern Trout Gudgeon) fry; staff in the field in an all-terrain vehicle; larval stage of freshwater mussels (*Velesunio angasi*) under the microscope; pH investigations on Coonjimba billabong; Ranger uranium mine from the air; in the lab; setting up for a fish sampling program; staff running the organisation's information stall at the 2016 Mahibilil Festival in Jabiru; launching the Swampfox X5 delta wing unmanned aerial system; Forest Kingfisher (*Todiramphus macleayii*) on the Ranger Project Area; helicopter used to access remote and inaccessible water sampling points.

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SUPERVISING SCIENTIST'S OVERVIEW

The 2016-17 reporting year was a significant one for the Supervising Scientist Branch (SSB); encompassing structural change, large assessment tasks and some significant milestone achievements.

In July 2017 SSB moved from the Department of the Environment and Energy's Science Division into its Heritage, Reef and Marine Division. At the same time the position of the Supervising Scientist was moved to the Assistant Secretary SSB, based in Darwin. The move aligns SSB with the Department's World Heritage responsibilities and provides significant synergies given the Supervising Scientist's core function of protecting the World Heritage attributes of the Kakadu National Park.

All monitoring and supervisory activities planned for 2016-17 were completed. The multiple lines of evidence gathered from these programs continued to show that the people and the environment of the Alligator Rivers Region remain protected from the effects of uranium mining, including from the Ranger uranium mine. Water quality in Gulungul Creek, to the west of Ranger, has continued to improve. Water quality in Magela Creek shows only minor influences from mining operations at Ranger. No exceedances of the statutory water quality objectives were recorded in either system.

Rehabilitation activities at Ranger continued through-out the reporting period, including the commencement of bulk backfill works in Pit 1, the deposition of tailing from both the mill and the tailings storage facility into Pit 3 and the submission of a mine closure plan by Energy Resources of Australia (ERA) in December 2016. ERA has recently commenced feasibility-level rehabilitation planning. This will provide a much greater level of detail in rehabilitation plans than has been available to date. We have been working with regulatory agencies and ERA to introduce a range of reporting metrics to monitor the progress of rehabilitation activities through the Ranger Minesite Technical Committee to provide visibility of ERA's progress in rehabilitation planning and implementation.

Coordination between SSB, the regulators, Traditional Owner representatives and ERA continues to increase. In order to ensure fit-for-purpose outcomes ERA now provide the opportunity to comment on the scope of key technical proposals, and to input at agreed milestones through the project development. This provides additional certainty for both ERA and the supervisory authorities that outputs will satisfy regulatory requirements and increases the speed of the assessment and approvals process.

In November 2016 the independent Alligator Rivers Region Technical Committee endorsed a revised set of Key Knowledge Needs (KKNs) for the rehabilitation of Ranger. The revision of the KKNs was a multi-year process underpinned by a detailed ecological risk assessment. A 10 year research program to address all of the revised KKNs has been developed, scheduled against the mine rehabilitation plan and costed. A process is being implemented to systematically close out the KKNs as new knowledge is acquired. An overview of the planning process, and its outcomes, will be published in 2017-18.

A review of ARRTC has been completed and the committee will be refreshed, with revised appointment and operating arrangements implemented, in early 2017-18.

Despite the large effort put into the KKN process and subsequent planning, significant research output was achieved. Additionally, good progress was made in the development of the Supervising Scientist's Rehabilitation Standards. The standards are advisory only, quantify the statutory rehabilitation objectives and summarise the science which informs them. The standards will form a key component of the Supervising Scientist's advice on rehabilitation activities at Ranger.

A number of large assessment tasks were undertaken during 2016-17. ERA's proposed final tailings level for Pit 1 was endorsed in February 2017, including the publication of a detailed assessment report which included a number of recommendations for further work.

A detailed assessment of the Ranger Mine Closure Plan was completed in July 2017 with an extensive assessment report provided to the Ranger Minesite Technical Committee members. Assessment of the Ranger Mine Closure Plan was a significant undertaking for SSB, with input from every part of the Branch and a number of external collaborators. The assessment report provides a pathway forward, linking the KKNs, rehabilitation related assessments and the rehabilitation works. An updated version of the assessment report will be published following ERA's public release of a revised version of the Plan in September 2017.

In March 2017 we advised ERA of our intention to engage a technical expert to review the deposition of tailings in Pit 3. This review has raised some issues with the methodology used to date. SSB will continue to engage with ERA and the regulator on a revised method of tailings deposition which provides for the highest possible level of environmental protection.

The considerable focus during 2016-17 on detailed planning, structural changes and improving and streamlining business processes sees SSB well placed to deliver the research, oversight and advice required to ensure the successful rehabilitation of the Ranger uranium mine, and the long term protection of the people and the environment of the Alligator Rivers Region.

Keith Tayler
Supervising Scientist

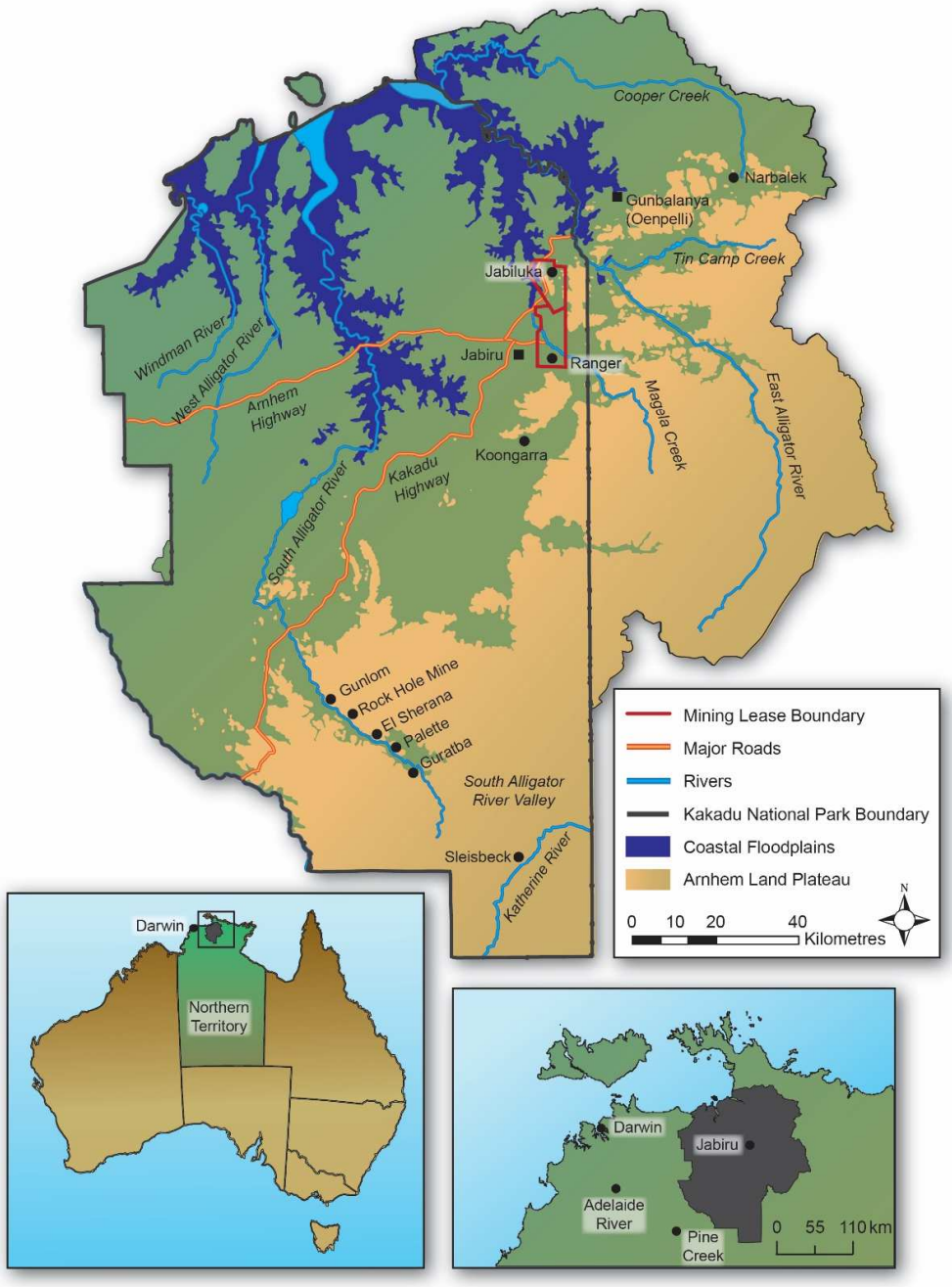

Figure 1 Alligator Rivers Region.

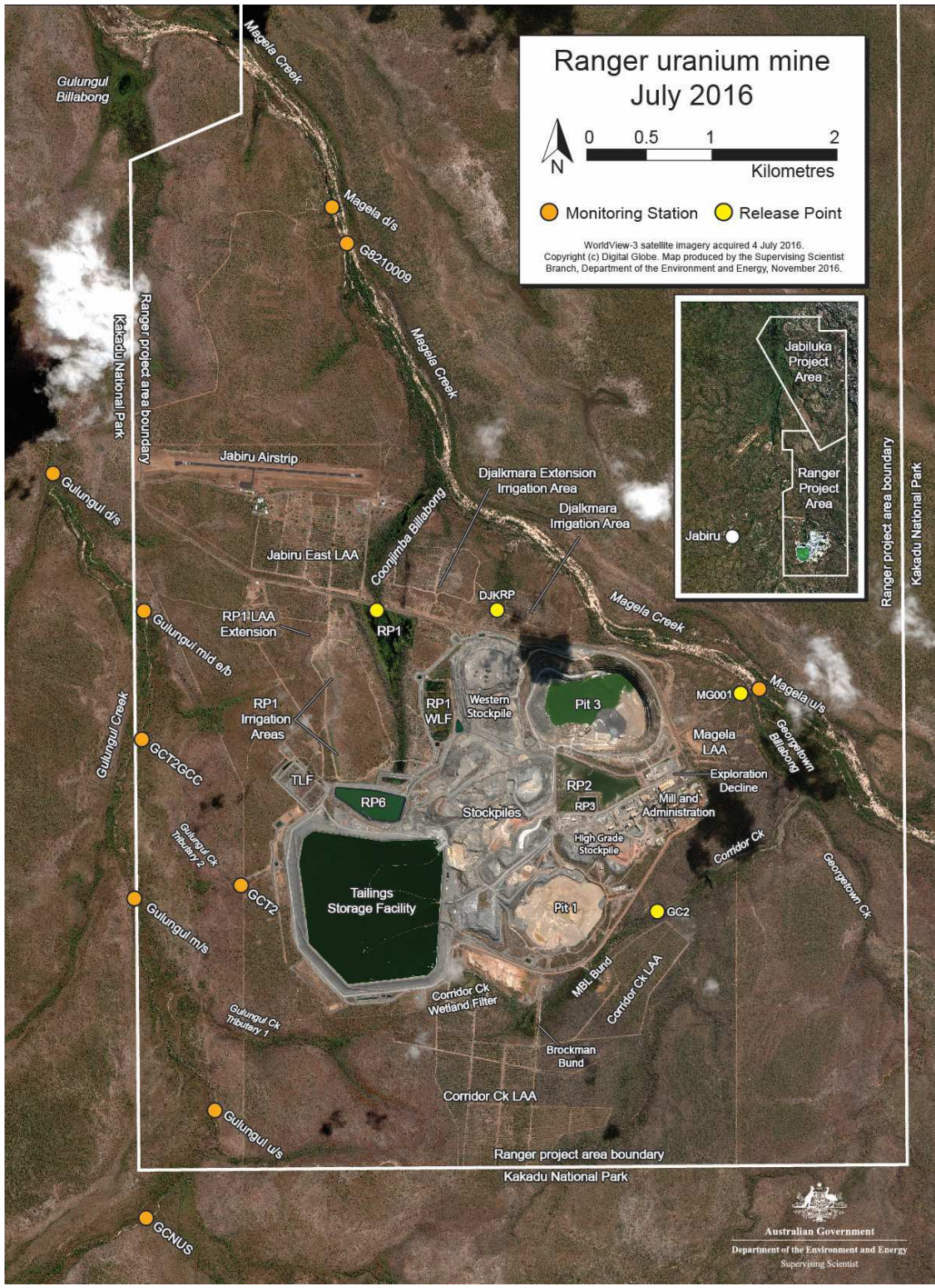

Figure 2 Ranger minesite.

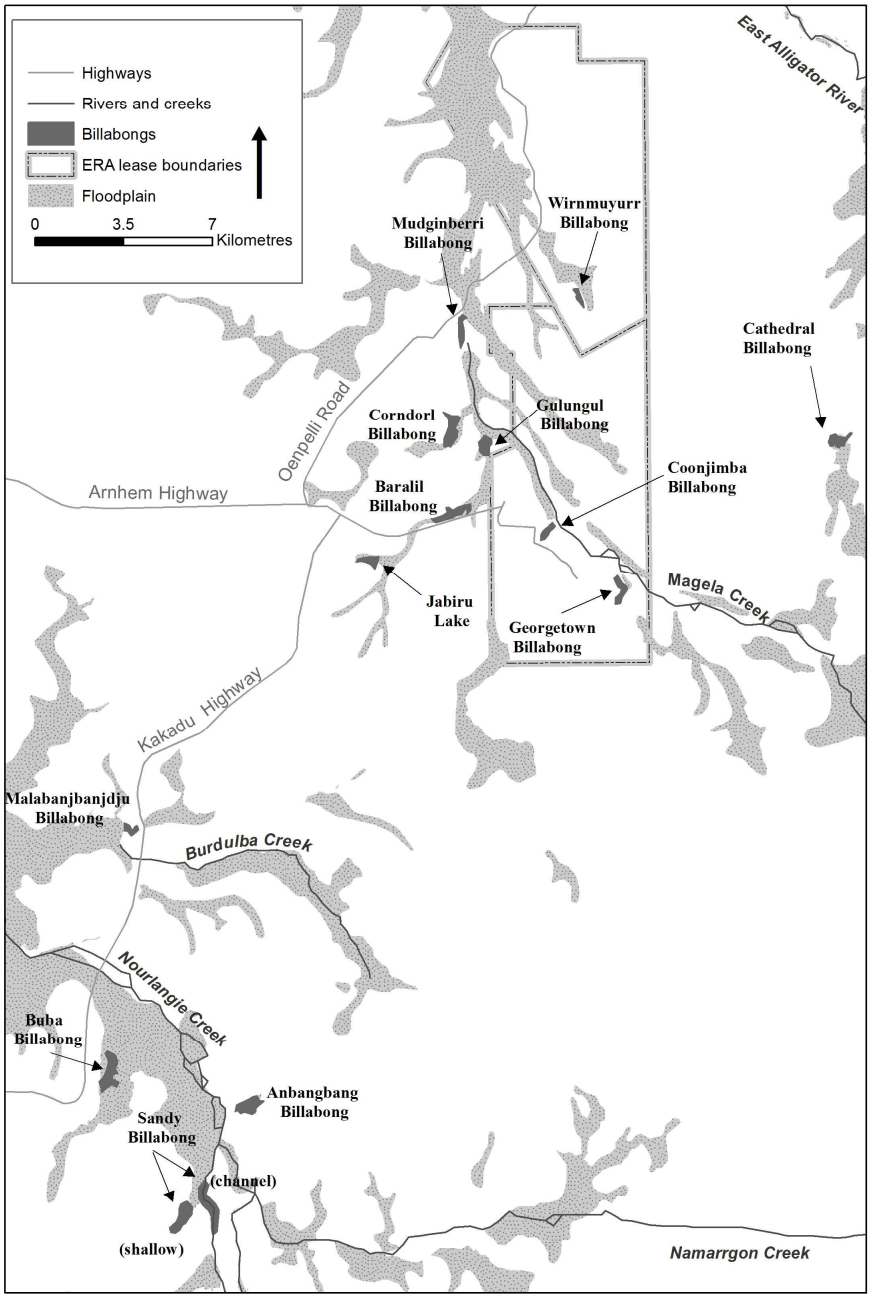

Figure 3 Location of waterbodies in the vicinity of Ranger mine, including those used as monitoring sites in Supervising Scientist Branch's research and biological monitoring programs.

1 INTRODUCTION

1.1 Role and function of the 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 Ranger Uranium Environmental Inquiry final report (also known as the Fox Report) in May 1977. The role of the Supervising Scientist is held by the Assistant Secretary of the Supervising Scientist Branch (SSB) in the Department of the Environment and Energy. The SSB is situated within the Heritage, Reef and Marine Division.

The Supervising Scientist has four key functions with respect to mining activities in the Alligator Rivers Region (ARR):

- Public Assurance and Advice
  - Ensure that the relevant Minister, regulators and stakeholders are informed of environmental risks related to mine operations and rehabilitation, and understand how relevant environmental standards ensure protection.
  - Advise relevant Ministers, regulators, stakeholders and the general public of the environmental monitoring program outcomes to provide assurance that people and the environment remain protected.
  - Communicate the science underpinning rehabilitation to stakeholders and the general public to provide assurance that the people and the environment of the ARR remain protected.
- Supervision
  - Supervise uranium mining operations, including oversight of the regulatory process, to ensure regulation is adequate, effective and consistent with Commonwealth requirements.
  - Assess rehabilitation planning and subsequent activities to ensure statutory requirements are achieved.
- Monitoring
  - Conduct a comprehensive and independent program of monitoring to detect effects of uranium mining on people and the environment.
  - Provide data to inform the Research and Supervision programs.
- Research
  - Provide a rigorous scientific basis for the development of environmental standards, and practices and procedures including monitoring programs that support the supervision program throughout mine operations and rehabilitation.

1.2 Uranium in the Alligator Rivers Region

The ARR is located 220 km east of Darwin and encompasses an area of approximately 28,000 km² (Figure). The ARR 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 ARR.

The Ranger and Jabiluka uranium deposits within the ARR 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 ARR. Mining at Ranger ceased in 2012, however processing of stockpiled ore is continuing. Mining ceased at Jabiluka in 1999 and the site remains 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 minesites 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.

This report provides an update on the current status of each of these sites and the activities undertaken by SSB throughout the 2015–16 reporting period.

1.3 The regulatory framework

The Authority to mine uranium at Ranger is issued under s 41 of the *Atomic Energy Act 1953*, which is administered by the Commonwealth Minister for Resources and Northern Australia. The Authority also provides the Commonwealth's environmental protection conditions, which are set out in the *Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine* (the Environmental Requirements). The Environmental Requirements outline key objectives and environmental standards for mining operations and rehabilitation. Under agreement, regulatory power over uranium mining in the Northern Territory is delegated to the Northern Territory Government and given effect under the *Mining Management Act 2015*, administered by the Northern Territory Department of Primary Industry and Resources (DPIR). The Supervising Scientist is appointed under the *Environment Protection (Alligator Rivers Region) Act 1978* to ensure protection of the ARR from the impacts of uranium mining, and does so by undertaking environmental research and developing standards and practices for environmental protection (see section 1.1). The Supervising Scientist provides advice to both the Commonwealth Minister for Resources and Northern Australia, and the Northern Territory Minister for Primary Industry and Resources.

2 PUBLIC ASSURANCE AND ADVICE

The SSB communicates the outcomes of the Branch's supervisory, research and monitoring activities to various stakeholders using a range of consultative activities. These activities provide the SSB with the opportunity to identify, understand and address the broad range of stakeholder concerns and sensitivities related to uranium mining in the ARR.

2.1 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (ARRAC) comprises an independent Chair and representatives of various regulatory and stakeholder organisations from the community and government sectors. The committee provides a valuable forum for community liaison and engagement regarding the protection of the ARR from the effects of uranium mining.

The 46th ARRAC meeting was held in Jabiru in September 2016, and the 47th ARRAC meeting was held in Darwin in April 2017. At both these meeting, the Committee was advised of the SSB's current activities in the Alligator Rivers Region, which included updates on SSB's, monitoring and research programs associated with the water quality of Gulungul and Magela Creeks. Energy Resources of Australia Ltd (ERA) presented overviews of mine closure planning activities and the DPIR reported on their water quality check monitoring program. Reports were also presented by Committee members including the Northern Land Council, Cameco Australia Pty Ltd, Northern Territory Department of Health, The Australian Radiation Protection and Nuclear Safety Agency.

The minutes of ARRAC meetings are available on the ARRAC website at: environment.gov.au/node/23143

2.2 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) advises the Minister for the Environment and Energy on the adequacy and appropriateness of the scientific research conducted by the SSB, ERA and other stakeholders. ARRTC also reviews the quality and adequacy of the science underpinning regulatory assessments and approvals of uranium mining related applications and proposals in the ARR.

ARRTC comprises a Chairperson and a number of independent scientific members, whose combined knowledge and expertise cover the breadth of scientific disciplines necessary to inform the closure and rehabilitation of Ranger.

The 36th ARRTC meeting was held in Darwin in August 2016. At this meeting, the Committee endorsed the SSB's proposed 2016–17 research program and was provided with an update on the rehabilitation of Ranger mine. The Committee provided positive feedback on the enhanced level of alignment between the SSB research program and the rehabilitation of Ranger mine, enabling the Committee to assess the program in a cohesive and transparent manner. The 37th and 38th ARRTC meetings were held in Darwin in November 2016 and May 2017 respectively. Meeting 37 marked a significant milestone as the ARRTC formally endorsed the revised Key Knowledge

Needs (KKNs), which articulate the knowledge required to mitigate and manage key environmental risks arising from operations, rehabilitation and closure of Ranger mine. At its 38th meeting, the ARRTC endorsed the Supervising Scientist's proposed 2017–18 research program.

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

2.3 Communication with other stakeholders

The primary focus of the SSB's communication team during 2016–17 was to provide stakeholders and the general public with information on the work conducted by the SSB, including the Branch's input to the rehabilitation process for Ranger mine. This was achieved using different communication media to engage with a range of stakeholders and interested parties, including various reports as well as providing presentations to the wider national and international community (Table 1).

TABLE 1 PRESENTATIONS AT NATIONAL AND INTERNATIONAL CONFERENCES 1 JULY 2016 TO 31 JUNE 2017

Conference	Place/date (no. Papers)
Climate Adaptation Conference	Adelaide, Australia, 5–7 July 2016 (1 Presentation)
The 14th Biennial Conference of the South Pacific Environmental Radioactivity Association	Sanur, Indonesia, 7–9 September 2016 (3 presentations)
The 20th Australasian Weeds Conference	Perth, Australia, 11–15 September 2016 (1 Presentation)
GEOBIA 2016: 6th International Conference on Geographic Object-based Image Analysis	Enschede, Netherlands, 14–16 September 2016 (1 presentation)
Uranium Mine Remediation Exchange Group Meeting	Colorado, USA, 26–30 September 2016 (1 presentation)
Life of Mine Conference 2016	Brisbane, Australia, 28–30 September 2016 (3 presentations)
The 4th Society of Environmental Toxicology And Chemistry – Australasia Conference	Hobart, Australia, 4–7 October 2016 (4 presentations)
The AusIMM International Uranium Conference 2017	Adelaide, Australia, 6-7 June 2017 (1 presentation)
Interim meeting of Working Group 1 of the International Atomic Energy (IAEA) Agency Modelling and Data for Radiological Impact Assessments (MODARIA II) scientific programme	Brussels, Belgium, 26–30 June 2017 (working group participation)

The SSB has participated in a number of community activities throughout 2016–17, including the 2016 Mahbilil festival in September 2016, and World Wetlands Day in February 2017. The SSB provided information stalls for these events, enabling the SSB's staff to engage with attendees, discussing scientific posters on display and offering hands-on scientific activities related to environmental monitoring and protection. These local events provide important opportunities to engage with the local communities and exchange information and knowledge. The SSB information stalls attract people, both local and visitors to the area, who are keen to hear about the work undertaken by the SSB.

The SSB employs local Aboriginal people to assist with fieldwork for a number of environmental monitoring programs, such as the collection of freshwater mussels in October 2016, for use in the radiological monitoring program. This facilitates the transfer of both cultural and environmental knowledge and information between the traditional custodians of the land and the SSB staff.

Figure 4 A SSB staff member assists a young student to view local water macroinvertebrates through a microscope.

As part of Science Week, in September 2016 and March 2017, staff from the SSB visited the Jabiru Area School and assisted children from years two to four to participate in activities related to wetland ecology and wet season water quality in Kakadu National Park. The lessons enabled children to handle and look at a number of aquatic macroinvertebrates through microscopes and to hear how these creatures help us understand and measure the health of the local freshwater environment (Figure 4).

3 SUPERVISION

The SSB provides regulatory oversight of uranium mining and exploration activities in the ARR including assessment of mining and rehabilitation plans, reports and applications made by ERA under the Northern Territory *Mining Management Act 2015*. Through this assessment process, SSB and other stakeholders are able to ensure that ERA's activities remain in compliance with the relevant Environmental Requirements.

SSB also carries out a program of minesite routine periodic inspections (RPIs) and environmental audits. These processes allow stakeholders to review environmental incidents and associated investigations, assess the adequacy of systems in place to manage critical on-site risks and to ensure effective maintenance and upkeep of mine infrastructure. Minesite Technical Committees (MTCs) have been established for Ranger, Jabiluka and Nabarlek to provide a forum for the mining operator, regulators and key stakeholders to discuss environmental management and regulatory issues.

3.1 Ranger

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 (RPA) and is adjacent to Magela Creek, a tributary of the East Alligator River.

Ranger is an open cut mine, producing uranium oxide (U_3O_8) via acid leach extraction since 1981. Mining at Ranger ceased in 2012 and under current approvals, stockpiled ore can continue to be processed until 2021. Rehabilitation planning for the minesite has been underway for a number of years, with ERA submitting a draft Mine Closure Plan at the end of 2016. Rehabilitation activities have already commenced, and all rehabilitation works must be complete by 2026.

Orebody No 1 was exhausted in late 1994 and the pit, known as Pit 1, is now used as a tailings repository. Excavation of Orebody No 3 began in 1997 and mining in the pit, known as Pit 3, ceased in 2012. Tailings deposition in Pit 3 commenced in February 2015 and will continue until all tailings have been relocated from the Tailings Storage Facility (TSF) to the pit.

The majority of data presented in this section are reported to SSB by ERA throughout the year.

3.1.1 Operations

3.1.1.1 Water management

All water on-site is managed in accordance with the current approved Water Management Plan. It is updated annually and assessed by the MTC prior to approval. The plan describes the systems for routine and contingency management of the three water classes on site. These are classified based on quality using electrical conductivity (EC) as the key indicator, as shown in Table 2.

TABLE 2 WATER CLASSES AT RANGER MINE

Water class	Indicative EC range (µS/cm)
Release water	193–476
Pond water	1220–2380
Process water	18,800–34,900

The rainfall recorded at Jabiru Airport for the 2016–17 wet season was 1701 mm. This was above the annual average of 1550 mm and well above the rainfall for the 2015–16 wet season, which was 921 mm (Figure 5).

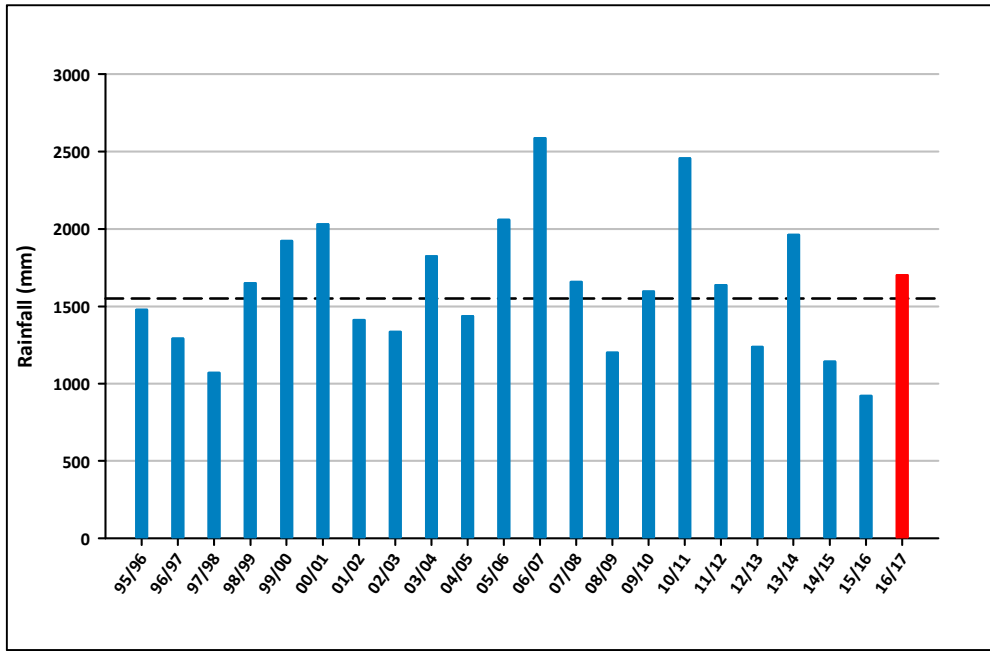

Figure 5 Wet season rainfall (vertical axis) measured at Jabiru Airport from 1995 to 2017 (horizontal axis). Black dotted line indicates the average annual rainfall of 1550 mm.

Process water

'Process water' is water that has been in direct contact with the extraction circuit and must be retained on site due to its very poor quality. Process water is currently stored in the above-ground TSF, Pit 3 and parts of the Pit 1 catchment area (Figure 2) As part of the strategy to manage and reduce the process water inventory on site, ERA constructed a brine concentrator treatment plant in 2013, producing a very high quality distillate that can be released off-site. Details of water treatment using the brine concentrator are shown in Table 3.

TABLE 3 ANNUAL PROCESS WATER TREATMENT VOLUMES

Date	Annual operating period (days)	Distillate produced (ML)
2013–14	181	470
2014–15	328	1031
2015–16	309	1124
2016–17	321	1474

The brine concentrator distillate is discharged at various locations around the site, ultimately reporting to Magela Creek during the wet season or being irrigated on Land Application Areas (LAAs) during the dry season. The brine concentrator has a nominal capacity to treat 1830 ML of process water per year and forms an integral part of ERA's rehabilitation strategy. ERA is currently exploring options to increase the capacity of the brine concentrator by up to 25% by 2018.

Additional process water treatment strategies such as the recommissioning of the High Density Sludge (HDS) treatment plant are also being investigated by ERA.

A number of initiatives for reducing the inputs into the process water inventory by up to 3 ML/day were implemented during 2016-17.

Pond water

'Pond water' is 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. Pond water is stored in Retention Pond 2 (RP2), Retention Pond 3 (RP3), Retention Pond 6 (RP6) and parts of the Pit 1 catchment area (Figure 2). ERA has previously committed to not releasing pond water without prior treatment to improve its quality. Pond water is currently treated via three microfiltration/reverse osmosis water treatment plants, with a combined treatment capacity of 25 ML/day. Table 4 shows the annual total volumes of pond water treated and resulting permeate produced.

TABLE 4 ANNUAL POND WATER TREATMENT VOLUMES

Date	Volume treated (ML)	Permeate produced (ML)
2011–12	7097	4873
2012–13	842	589
2013–14	4782	3311
2014–15	3028	2025
2015–16	634	440
2016–17	3890	2621

Permeate is discharged at various locations around the site, including the Corridor Creek Wetland Filter, ultimately reporting to Magela Creek during the wet season, or is irrigated on LAAs during

the dry season. Active discharge of pond quality water from the minesite may occur from specific on-site locations in accordance with regulatory approvals.

Release water

Rainfall runoff from certain locations of the Ranger site such as Retention Pond 1 (RP1) and the Ranger access road culverts, is referred to as 'release water'. It does not require capture or treatment on site and is either discharge actively or allowed to discharge passively during the wet season. Major release pathways include the Coonjimba Creek system and the Corridor Creek system (Figure 2).

The volume of water released actively during wet season generally depends on the amount of rainfall in a particular season, and the water management strategies in place at the time. Table 5 shows the total volume of water actively released from the site since 2013–14 (noting that water released passively is not quantified).

TABLE 5 ANNUAL ACTIVE RELEASE WATER VOLUMES

Location	Volume (ML)
2013–14	1674
2014–15	772
2015–16	117
2016–17	1573

3.1.1.2 Tailings and waste management

Table 6 summarises the management of tailings from the processing mill over time. As part of the site rehabilitation process, ERA is focussed on the deposition of tailings into Pit 3 for permanent storage. Tailings deposition in Pit 1 was completed in 2008 and final backfill commenced in Q2 2017. Tailings deposition in Pit 3 commenced in 2015, with the pit currently receiving tailings from both the processing mill and from the TSF (via dredging).

TABLE 6 MILL TAILINGS HISTORY

Activity	Year
Construction of the TSF approved	1979
Tailings deposition in TSF	1980–96
Tailings deposition in Pit 1	1996 –08
Tailings deposition in TSF	2008–15
Tailings deposition in Pit 3 from mill commences	2015
Tailings transfer from TSF to Pit 3 commences	2016

The primary mechanisms for disposal of hazardous wastes include disposal in the mine pits, incineration and off-site disposal. Non-hazardous wastes are disposed of either through disposal to on-site landfill or off-site recycling. In 2016, an application to construct a temporary hazardous

waste disposal site adjacent to Pit 3 was approved. This new site replaces the former waste disposal site in the north-west section of Pit 1.

3.1.2 Rehabilitation

3.1.2.1 Rehabilitation Objectives

The primary rehabilitation objective for Ranger, as set out in the Environmental Requirements, is to rehabilitate the site to a standard that, in the opinion of the Minister for Resources and Northern Australia, with the advice of the Supervising Scientist, enables it to be incorporated into the surrounding World Heritage-listed Kakadu National Park.

Concurrently, with the development of closure criteria by ERA, SSB are developing a suite of 'Rehabilitation Standards' for release in 2017. These rehabilitation standards are being developed in accordance with section 5c of the *Environment Protection (Alligator Rivers Region) Act 1978*, covering key environmental themes: water and sediment, landform, flora and fauna, radiation and soils. The rehabilitation standards reflect the Environmental Requirements and provide quantitative values, based on the best available science, against which the achievement of the rehabilitation objectives can be assessed. The rehabilitation standards also reflect the highest level of ecosystem protection and may be updated in the future, as additional relevant knowledge becomes available. Further information on the rehabilitation standards is provided in chapter 5.2.1.

3.1.2.2 Ranger Mine Closure Plan

ERA is required to submit a Mine Closure Plan for approval, under both the Commonwealth and Northern Territory legislation. The Mine Closure Plan must detail ERA's approach for planning and implementation of minesite rehabilitation activities, and demonstrate how these activities will achieve the Environmental Requirements. The plan requires approval by the respective Commonwealth and Northern Territory Ministers, with advice from the Supervising Scientist.

A draft Ranger Mine Closure Plan (RMCP) was submitted by ERA to stakeholders for review in December 2016. SSB undertook a detailed technical review of the draft RMCP, with feedback provided to ERA in July 2017. ERA advised that an updated RMCP will be released publicly in September 2017, addressing feedback provided on the draft document by SSB and other stakeholders. SSB will review the updated RMCP and intends to publish an Assessment Report, detailing whether:

- environmental risks associated with rehabilitation have been adequately identified and assessed, and mitigation measures identified/implemented
- proposed closure criteria appropriately quantify the Ranger Environmental Requirements such they will allow the future determination of their achievement
- proposed rehabilitation strategies are based on the best-available scientific information
- proposed rehabilitation activities will result in the achievement of the relevant Ranger Environmental Requirements.

It is envisaged that the RMCP will be updated periodically during the rehabilitation process and some of the less complex rehabilitation activities may be detailed sufficiently within the RMCP and may be approved within it (for example, the mill deconstruction). Other more technically-

complex activities will likely require an application and approval process external to the RMCP, which would require the submission of a stand-alone application that included all relevant information (for example, the rehabilitation of Pit 3 and the Tailings Storage Facility).

The Department of Industry, Innovation and Science is currently coordinating a consultation process with key stakeholders to develop a Rehabilitation and Closure Approvals Framework, including specification of which activities will be approved as part of the RMCP and which will be assessed and approved as stand-alone applications. The Framework will ensure that ERA, regulators and stakeholders have a common understanding of the regulatory process, and that there is clear accountability and governance for decision-making.

3.1.2.3 Current status of rehabilitation

Approved rehabilitation works have already commenced on site, such as tailings deposition into the mined-out pits, as stipulated in the Environmental Requirements. Table 7 shows the performance metrics as of June 2017 for major rehabilitation activities currently occurring on site. These are discussed in the following sections. Table 8 summarises the approvals related to rehabilitation and Table 9 summarises the rehabilitation works that have been carried out to date.

TABLE 7 KEY REHABILITATION METRICS

Activity	Completed	ERA Target	Remaining
Dredging of TSF tailings	4.5 Mt	5.9 Mt	18.6 Mt
Pit 1 Backfill	0.73 Mt	0.96 Mt	11.6 Mt
Brine concentrator distillate production 2017	708 ML	781 ML	NA
Brine Injection	Currently offline	Online	NA

TABLE 8 REHABILITATION RELATED ASSESSMENT ACTIVITIES

Activity	Year of approval
Pit 3	
Deposition of tailings in Pit 3	2007
Notification of intent to deposit tailings in Pit 3	2015
Assessment of environmental impacts from deposition of tailings in Pit 3	Still under assessment
Notification of change to Pit 3 operation	Still under assessment
Pit 1	
Relocate 1 Mm^3 from TSF to Pit 1	1997
Interim storage of tailings in Pit 1 to -12 mRL	2007
Interim storage of process water to -15 mRL	2010
Placement of 2.5 m layer of waste rock	2013
Final storage of tailings to -12 mRL	2017
Pit 1 Backfill design	2017

TABLE 9 REHABILITATION WORKS

Activity	Year
Pit 1	
Deposition of tailings commenced	1996
Deposition of tailings completed	2008
Preload capping with waste rock	2014
Laterite cover – conversion to pond water catchment	2016
Waste rock backfill – preparation works and commencement of bulk backfill	2017
Pit 3	
Waste rock backfill to -100 mRL	2014
Construction of under-bed drainage and brine injection infrastructure	2014
Deposition of mill tailings commenced	2015
Deposition of TSF tailings commenced	2016
Brines injection commenced (currently suspended)	2016
TSF	
Tailings dredging commenced	2016

3.1.2.4 Pit 1

Mining in Pit 1 ceased in 1995 and tailings transfer to the pit commenced in 1996 and was completed in 2008. During 2014, a 2.5 m thick layer of waste rock was placed over the tailings within Pit 1 to accelerate the dewatering of the tailings, via a system of vertical 'wick' drains. The placement of a low-permeability cap (i.e. compacted laterite waste rock material) on top of the waste rock was completed in 2016, to enable conversion of the Pit 1 footprint from a process water catchment to a pond water catchment. Incident rainfall and runoff from surrounding areas that report to the capped section of Pit 1 are managed as pond water, provided the EC remains below 4000 µS/cm.

On 17 March 2016, ERA submitted an application for a final tailings level in Pit 1. SSB undertook a comprehensive assessment of the application that included independent review by subject matter experts (e.g. geochemistry, hydrogeology). Additionally, SSB hosted a groundwater workshop in September 2016, attended by these experts, ERA and other relevant stakeholders. The application demonstrated that the risk to Kakadu National Park from tailings stored in Pit 1 is low, compared to the cumulative risk associated with the whole rehabilitated minesite, and that reducing the amount of tailings stored in Pit 1 would not further reduce this risk.

On 1 February 2017, SSB publicly released an assessment report supporting the proposed final tailings level, including recommendations for additional whole-of-site investigations, modelling and monitoring that will be required for ERA to demonstrate its ability to achieve the rehabilitation objectives. This report also included a recommendation related to the Pit 1 bulk backfill plan, which was submitted by ERA for review in early February 2017 and was subsequently assessed and supported by SSB.

The NT Minister for Primary Industry and Resources approved the Pit 1 final tailings level on 27 March 2017 and the Minister for Resources and Northern Australia approved the Pit 1 final tailings level (subject to ERA addressing the Supervising Scientist's recommendations) on

5 April 2017. ERA commenced bulk backfill works in April 2017. Table 7 shows that at the start of June 2017, Pit 1 backfill was behind schedule. In June 2017 approximately 490,000 tonnes of backfill was placed compared to a target of 240,000 tonnes, bringing Pit 1 backfill back on schedule. As of 30 June 2017, 1.2 million tonnes of waste rock and laterite backfill had been placed within Pit 1 with backfill of 2's material on schedule to be completed by the middle of 2018.

The Supervising Scientist Assessment Report for the Pit 1 Final Tailings Deposition Level to +7mRL can be found on the website at: http://www.environment.gov.au/resource/assessment-report-ranger-pit-1-final-tailings-deposition-level-7-mrl

3.1.2.5 Pit 3

Mining in Pit 3 was completed in November 2012 and preparation of the pit to receive tailings was completed in December 2014. This included backfilling the lower section of the pit with 31.2 million tonnes of waste rock, establishing brine injection bores into the waste rock backfill and constructing an under-bed drainage system which will enable removal and treatment of water displaced upwards by brine injection and allow tailings pore water to express downwards and be recovered.

A geotechnical failure occurred on the north wall of Pit 3 in March 2016. A subsequent investigation by ERA revealed several possible causes for the failure, including the presence of faults in the underlying weathered basement rock and ponded water at the surface. To reduce the risk of further failures, ERA installed two dewatering pumps to reduce groundwater pressure in the area and modified surface water drainage to direct water away from the pit crest. Additional continuous monitoring equipment has also been installed around the failure zone and there are no further indications of continuation of the failure.

A number of projects are underway to transfer mine waste into Pit 3 for permanent storage. This includes diversion of mill tailings previously reporting to the TSF to Pit 3 and transfer of TSF tailings to Pit 3, using a custom-built dredge. Brine injection into the waste rock underfill commenced in September 2015. The brines injection process has been temporarily suspended due to failure of the decant bore used to extract water from the under-bed drain. ERA is investigating options to repair or replace the decant bore. In the interim, brines produced from process water treatment are being recirculated within the process water system. ERA is monitoring the process water quality to ensure that brine recirculation does not impact on future water treatment capability.

The process water level in Pit 3 is currently being managed in a closed circuit with the TSF, enabling maintenance of water levels in the TSF that are optimal for ongoing dredging of tailings. ERA recently advised the MTC that, in order to continue dredging in the TSF, a significant volume of water will need to be returned to Pit 3, which may result in flooding the existing tailings beach that has formed in the south-east region of the pit. It is possible that the tailings beach will be submerged indefinitely and ERA have commenced investigating methods for sub-aqueous tailings deposition.

In April 2017, SSB engaged a geotechnical consultant to undertake a detailed independent review of the current Pit 3 tailings deposition strategy, to ensure that the consolidation outcomes are adequate for protecting the surrounding environment and meeting statutory rehabilitation

timeframes. The consultant conducted a two day site inspection in May 2017 and subsequent review of relevant tailings data and information. A draft report was provided to the SSB on 30 June 2017, which raised a number of issues related to the current status of tailings in Pit 3 and with regard to the tailings deposition strategy. The SSB has discussed these with ERA and the regulatory agencies, and will keep key stakeholders informed via the MTC process. Based upon the findings of this report, the SSB will make recommendations on the current tailings deposition and management strategy. Any revisions made to the Pit 3 tailings deposition strategy in the future will be assessed by the SSB, regulatory agencies and key stakeholders.

3.1.2.6 Tailings Storage Facility

As indicated above, the tailings currently stored in the TSF are being transferred to Pit 3. As of June 2017, 4.5 million tonnes of tailings had been transferred from the TSF to Pit 3, with approximately 18.6 million tonnes of tailings remaining in the TSF. The transfer of tailings from the TSF to Pit 3 is scheduled for completion in Q1 2021. The process is currently behind schedule due to sub-optimal dredge performance.

3.1.3 Assessment activities

3.1.3.1 Assessments and approvals

SSB assesses various documents submitted by ERA in accordance with the Environmental Requirements and the Ranger mine Authorisation, and provides advice to the regulators, the mining operator and key stakeholders through the Ranger MTC, which met four times during 2016–17. Significant agenda items discussed at the meetings included the following:

- Pit 1 groundwater inflow reduction trials and bulk backfill strategy
- Pit 3 water quality monitoring, flood protection, brine injection and tailings deposition
- hazardous waste management
- process water treatment initiatives and inventory forecasting
- effectiveness of management and monitoring strategies for high EC events in Gulungul Creek
- process safety implementation status and future oversight activities
- progressive rehabilitation performance tracking for TSF dredging, brines injection, Pit 1 backfilling and process water treatment.

3.1.3.2 Audits and inspections

The annual environmental audit was conducted from 14-17 June 2016. The audit assessed 75 environmental commitments and actions drawn from the approved Ranger Mining Management Plan 2014-2018, and supporting environmental management plans including the Ranger Operational Performance Plan 2014–2015 and the five year Fire Management Plan 2012–2016. The audit identified two Category 2 non-conformances associated with ERA's change management process in relation to the introduction of fire management initiatives, and the completeness of waste disposal permits. Fourteen conditional findings and a number of observations were provided to assist ERA in improving elements of the mine management systems. As of June 2017, the identified deficiencies had been satisfactorily addressed.

The 2017 environmental audit was conducted from 30 July– 4 August 2017 and focussed on ERA's operational monitoring and management of rehabilitation and closure activities.

RPIs were carried out as scheduled during the 2016–17 reporting year. Table 10 shows the focus areas for each of the RPIs.

TABLE 10 RANGER ROUTINE PERIODIC INSPECTIONS 2016–17

Month	Primary focus
July 2016	Pit 1 water management, Pit 3 tailings deposition and brines injection and process water treatment.
August	TSF annual inspection and southern boundary track repairs.
September	Hydrocarbon storage and distribution, acid spill (26/08/2016) and Gamba grass at Jabiru airport (07/07/2016).
October	Water management and release systems, Pit 1 surface water management, site wide pipe labelling, hazardous waste lay down area, Pit 3 wall slump.
November	TSF dry season remediation works, weed management, process water leak (02/10/2016).
December	Crushing, grinding and processing circuit, laterite plant slurry spill (02/11/2016), product on road (16/11/2016), process liquor spill (25/11/2016), process water booster pump leak (26/11/2016).
January 2017	Radiation monitoring and management, leaks from tailings line pump A (16/12/2016) and pump B (28/12/2016)
February	Surface and groundwater monitoring, SAQP implementation, MB-L pump testing.
March	Weed and land use management.
April	TSF 6 monthly inspection, TSF dredging and Pit 3 tailings deposition and process water storage.
May	Process and pond water treatment, brines management, Pit 1 backfill, tailings leak (13/05/2017), diesel spill (08/05/2017), process liquor leaks (12/05/2016 and 18/05/2016)
June	2017 Fire management program, exploration rehabilitation, southern boundary track repairs follow up, waste liquor spill (02/06/2017)

The 2017 Ranger and Jabiluka RPI and audit program was agreed by stakeholders in December 2016. Each RPI in the program has a specific theme, aligned with relevant activities on site (Table 11).

TABLE 11 2017 ROUTINE PERIODIC INSPECTIONS

Month	Theme
January	Radiation (completed)
February	Surface and groundwater monitoring (completed)
March	Weed and land use management (completed)
April	TSF 6 monthly inspection, tailings and process water transfer (completed)
May	Brine concentrator, water treatment plants and brines management (completed)
June	Fire management (completed)
July	Annual stakeholder environmental audit (completed)
August	TSF annual inspection (completed)
September	Hydrocarbon, hazardous chemical management and SX plant
October	Wetland filters, retention ponds and water management
November	Rehabilitation activities
December	Crushing circuit, mill and processing area

3.1.3.3 Environmental incidents

During the reporting period, 17 environmental incidents were reported to stakeholders, as detailed in Table 12. Most of these incidents related to minor process water and waste liquor spills within the processing area, or minor tailings line leaks within the tailings line corridors between the processing facilities and the TSF or Pit 3. The number of reported incidents during this reporting period is comparable to the previous reporting period (2015-16) when 16 environmental incidents were reported to stakeholders.

All incidents were investigated by SSB through the RPI process and were considered to have been resolved satisfactorily, with no off site impacts attributable to these incidents detected through SSB's routine monitoring program.

TABLE 12 ENVIRONMENTAL INCIDENTS 2016–17 AT RANGER MINE

	ADU	Hydrocarbon	Tailings	Process water	Weeds	Other	Total
Processing	1	1	1	9	-	1*	**13**
RPA	-	-	-	-	1	-	**1**
Tailings Circuit	-	1	2	-	-	-	**3**
Total	**1**	**2**	**3**	**9**	**1**	**1**	**17**

* 350 L – 500 L acid spill in the distribution line.

An annual comparison of incidents reported over the past five years is shown in Figure 6. The reduction in reported incidents between 2013–14 and 2014–15 is attributed in part to the cessation of mining activities in 2012, and a general reduction in waste rock haulage since 2014.

Figure 7 shows that hydrocarbon-related incidents decreased from 25 in 2013–14 to seven in 2014-15, which is likely to relate to the decrease in mobile plant on site. The number of process water, hydrocarbon and tailings-related incidents reported during 2016–17 are similar to the number reported in 2015–16.

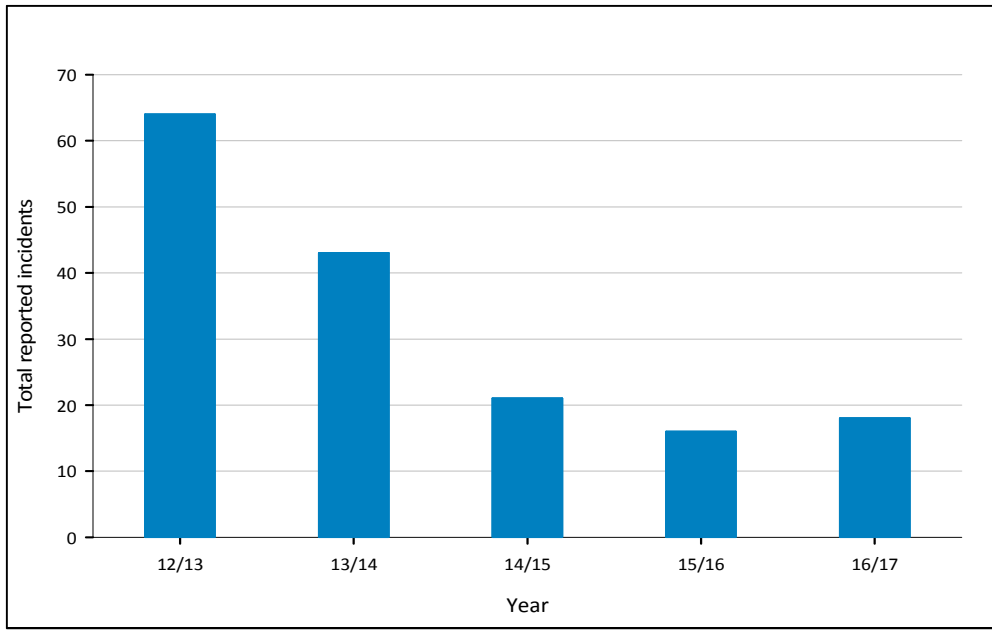

Figure 6 Ranger mine reported environmental incidents by year.

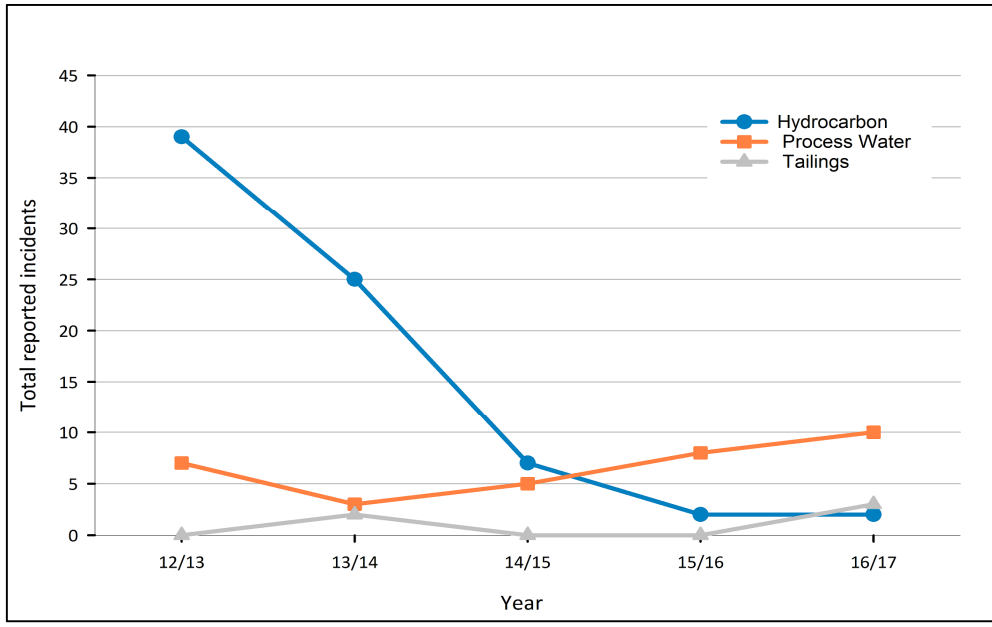

Figure 7 Hydrocarbon, process water and tailings incidents by year.

3.1.3.4 Significant incidents

No incidents requiring formal investigation by the SSB were reported during 2016–17. One notable incident, pertaining to the identification of a small patch of Gamba grass at the Jabiru Airport, was reported on 7 July 2016. Through the RPI process, stakeholders were satisfied with ERA's containment actions and planned monitoring program. A follow up inspection by stakeholders in March 2017 found no evidence of further infestation of Gamba grass.

Table 13 provides a summary of the significant incidents that have occurred since 2013.

TABLE 13 SUMMARY OF SIGNIFICANT INCIDENTS

Year	Incident	Outcome
2013	**Leach tank failure** December 2013 Leach Tank No. 1 at the ERA Ranger uranium mine collapsed, spilling approximately 1,400 m^3 of slurry containing ground uranium ore, water and sulphuric acid into the processing area.	In February 2016 DPIR finalised their investigation and concluded they would not be proceeding to prosecution. Noetic Solutions Ltd continued to monitor the implementation of recommendations related to process safety via a series of quarterly inspections. Noetic Solutions were retained by ERA to assist with ongoing process safety management.
2014	**Product packing stack emission** In November 2014 ERA reported that uranium emissions from the product packing stack at Ranger mine exceeded the authorised rate of 1.5 kg of uranium per day.	Subsequent investigations by ERA, SSB and DPIR concluded the limit was not actually exceeded, but the initial notification from ERA was the result of human error in the calculation of uranium emissions. Improvements in how uranium emissions are calculated and verified have been implemented by ERA. As part of the RPI process, a review of these improvements and confirmation that ERA tests relevant alarms and interlocks in accordance with statutory requirements was undertaken in January 2017
2015	**Uncontrolled fire in Kakadu** On 1 October 2015 a weed management burn by ERA resulted in an uncontrolled fire in Kakadu National Park, which burnt into culturally and environmentally sensitive areas.	The Department of Environment and Energy's Compliance and Enforcement Branch determined the fire was unlikely to have resulted in a significant impact on matters of national environmental significance. As such, the Department does not intend to pursue this matter further under the *Environment Protection Biodiversity and Conservation Act 1999*. SSB and NT Government identified deficiencies in ERA's fire management system, which was subsequently audited in 2016.

3.2 Jabiluka

The ERA-owned Jabiluka mineral lease abuts the northern boundary of the Ranger Project Area, with the former Jabiluka minesite situated 20 km north of the Ranger minesite. Jabiluka is in the East Alligator River catchment, adjacent to Ngarradj (Swift Creek), which flows into the Magela floodplains to the north. 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 it was agreed that the Jabiluka site would not be mined and the site was placed in long-term care and maintenance. Whilst in long-term care and maintenance, revegetation activities have been undertaken by ERA, however, final closure of the site is not anticipated in the short-term given that lease expiry will not occur until August 2024. There are possible extension options under the Northern Territory *Mineral Titles Act*.

3.2.1 Rehabilitation

3.2.1.1 Revegetation, weed and fire management

Revegetation of the disturbed parts of the Jabiluka mineral lease aims to recreate a vegetation community of local native plant species of similar density and abundance to that existing in undisturbed, adjacent areas.

Between 2006 and 2014 approximately 15,500 seedlings were planted across the Jabiluka mineral lease, including the former Jabiluka mine footprint and the former Djarr Djarr exploration camp site. Hot fires originating off the lease have burnt through the revegetated areas of the Djarr Djarr exploration camp site in 2007, 2008 and 2010, resulting in significant vegetation mortality.

The results of revegetation surveys carried out by ERA during October 2015 are expected to be published in 2017, including information on the current status of revegetation of the Djarr Djarr camp site. The SSB will continue to oversee the progress of revegetation at Jabiluka.

ERA uses herbicide to actively manage weeds at the Jabiluika mineral lease. ERA spent a total of 245 person hours on weed control activites at Jabiluka during 2016-17. This represents a 24% decrease in time spent on weed control, compared to 321 hours in 2015-16. This decrease was primarily attributed to wet season access issues. ERA is looking to optimise the effectiveness of future weed control by ensuring equipment is available on site during the wet season.

ERA undertakes annual fuel-reduction burning around the Djarr Djarr and Jabiluka sites to reduce the effects of wildfires on the revegetated areas, with the most recent burns conducted in June 2017.

3.2.1.2 Water management and monitoring

The Interim Water Management Pond (IWMP) was removed in 2013 and the area was recontoured and revegetated. Groundwater and surface water quality is currently monitored in accordance with the Jabiluka Authorisation. ERA continues to monitor water quality upstream and downstream of the Jabiluka site, in both the northern and central tributaries of Ngarradj Creek that flow from the site. Given the low environmental risk posed by the site, SSB ceased water quality monitoring prior to the 2015–16 wet season.

Monitoring of downgradient bores is conducted by ERA quarterly in accordance with the Jabiluka Authorisation. This includes field determinations of physico-chemical parameters (in-situ pH, EC and

temperature) and laboratory analysis of inorganic N (nitrate and ammonia), common ions (calcium, magnesium, sodium, potassium, hydrogen carbonate, chloride and sulfate) and filtered uranium (<0.45 µm). A filtered sample from each bore is also analysed annually for filterable ^{226}Ra. Groundwater monitoring conducted during 2016–17 concluded the majority of key water quality parameters for downgradient bores remained within the historical trend observed since 1997. A spike in filtered nitrate was observed for bore JDGB1, located to the South West of the Jabiluka site, however results returned to historical levels in the following grab sample. During 2016–17, ERA commenced consultation with GAC in regards to sampling the Mine Valley Bores located to the west of Jabiluka. Sampling of these deep bores will inform the future groundwater monitoing program.

Jabiluka lies to the west of the Ngarradj Creek and is in the headwaters of three sub-catchments. These sub-catchments are termed by the southern, central and northern tributaries of Ngarradj Creek. The upstream (JCUS) and downstream (JCS) surface water sampling sites in Ngarradj Creek, the North Tributary and Central Tributary are sampled monthly by ERA each wet season until flow ceases at the Ngarradj Creek downstream site (JSC). Flow at JSC commenced on 22 January 2017 and ceased on 16 June 2017.

Creek monitoring conducted by ERA during 2016–17 concluded that in-situ EC at the JSC and JCUS monitoring sites were comparable and both remained below the EC Limit for the duration of the wet season. Filtered magnesium results also remained below the Limit value at both JSC and JCUS. Overall, results reported at JSC during the 2016-17 wet season remained comparable and within the historical range of results reported in previous wet seasons.

ERA continues to assess erosion at the Jabiluka site and has installed a number of sediment traps to reduce the transport of fine material in surface flows.

3.2.2 Supervision and assessment activities

SSB assesses various documents submitted by ERA in accordance with the requirements of the Jabiluka Authorisation and provides advice to key stakeholders through the Jabiluka MTC. The Jabiluka MTC met four times during 2016–17 and focussed on the ongoing progress of revegetation and weed management.

Due to the low environmental risk posed by the site the SSB has ceased annual audits of the Jabiluka site. Pre and post-wet season RPIs will continue to be undertaken, to assess any emerging issues (e.g. erosion, weeds) and to continue to monitor the effectiveness of revegetation.

The 2016 pre-wet season site inspection was conducted on 17 November 2016 and focussed on the progress of rehabilitation and general vegetation health. No outstanding wet season preparative actions were identified during the inspection. The post-wet season site inspection was conducted on 25 May 2017 and no emerging issues or management activities outside of the routine weed and fire management activities were identified.

There were no environmental incidents reported for Jabiluka during 2016–17.

3.3 Nabarlek

The former Nabarlek mine, located 280 kilometres east of Darwin, was initially owned by Queensland Mines Pty Ltd. The Nabarlek ore body was mined during the dry season of 1979 and

milling continued until 1988, producing around 11,000 tonnes of uranium concentrate (U_3O_8). The mine was decommissioned in 1995 and the site underwent rehabilitation. In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd, thereby acquiring the Nabarlek lease.

Since 2008, UEL has undertaken extensive exploration on the Nabarlek lease and has assumed responsibility for management of the rehabilitated areas of the site. This includes undertaking a range of programs for weed control, revegetation, fire management and other rehabilitation works, as required. The exploration activities and the performance of the ongoing rehabilitation and revegetation program continues to be monitored and assessed by the SSB, the regulator and key stakeholders.

3.3.1 Rehabilitation

3.3.1.1 Revegetation, weed and fire management

The survival rate of tube stock seedlings planted in 2013 was reviewed by UEL in August 2016 using photo-monitoring. The results showed variable survival rates, ranging from >90% survival on the runoff pond area, through to <5% survival on the waste rock dump and former camp areas. UEL is planning to plant approximately 500 tube stock seedlings during 2017. A review of tube stock planting techniques prior to these 2017 planting activities will be undertaken by UEL to identify more effective methods to increase survival rates.

UEL completed the annual weed spraying and controlled burn programs during March 2016, in accordance with the approved Mining Management Plan. Weed mapping was undertaken in conjunction with the 2016 annual weed spraying. This weed mapping measured weed composition and density at 145 sample locations across the lease and indicated that buffalo grass, Stylo, and passionfruit vine occurred in high densities across many of the sample locations. Hyptis, para grass, and mission grass also occur within the lease area. Ongoing temporal assessment of weed density and distribution across the lease through regular weed mapping activities will help to demonstrate the effectiveness of UEL's weed management program. Observations on the ground continue to indicate a reduction in the overall density of weeds across the site, including a reduction in para grass density and the apparent elimination of mission grass from the former evaporation pond region.

Weed spraying scheduled for early 2017 was not undertaken, due to difficulties in accessing the site at the end of the 2016-17 west season. Further weed spraying is scheduled for early 2018.

Annual fire management activities are undertaken in conjunction with the local Demed Rangers from Oenpelli, as recommended during the 2015 audit.

3.3.1.2 Water management and monitoring

Statutory surface and groundwater monitoring is conducted by the Northern Territory Government and UEL. Monitoring results are reported in the six-monthly Northern Territory Supervising Authorities Environmental Surveillance Monitoring in the ARR reports.

In August 2016, UEL collected water samples from 11 bores and from surface water sites along Cooper Creek. Results from the sampling were consistent with previous years monitoring results, with elevated sulfate and uranium concentrations down gradient from the former mine pit and elevated sulfate concentrations and low pH values for bores down gradient of the former

irrigation and evaporation pond areas. Sulfate results have remained elevated but stable since 1988, while uranium concentrations downgradient of the mine pit have shown an increasing trend since 2003. At the beginning of the 2016-17 wet season, SSB deployed two continuous EC sensors, one in Kadjirrikamarnda Creek downstream of the former minesite, and two in Cooper Creek at sites upstream and downstream of the former minesite. The sensors were retrieved at the end of the wet season and data is currently being assessed.

3.3.1.3 The Radiologically Anomalous Area

The 0.4 ha Radiologically Anomalous Area (RAA) 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).

In August 2015, UEL undertook a program of shallow drilling in the RAA to further characterise the area's radioactivity profile. Analysis of soil composites suggest that the majority of the radioactive material is confined to a small section of the RAA, mostly present in the upper 3 m of the soil profile. UEL has committed to using this information to develop a work program for rehabilitating the area, although no specific works have been proposed for the 2017 field season.

3.3.2 Exploration

A Mining Management Plan detailing the 2016 dry season exploration works was submitted to the Northern Territory Government in June 2016. SSB reviewed the plan and provided comments on 26 July 2016.

From August to October 2016, UEL completed an exploration campaign comprising ground gravity and radon-in-soil surveys. A follow-up campaign was completed in November 2016, with reconnaissance rock chip sampling and scintillometer surveys at anomalous radon-in-soil locations.

The MMP for the 2017 dry season works was submitted by UEL on 28 June 2017 and is currently undergoing assessment by SSB. UEL is planning to undertake further exploration activities from August to October 2017. This exploration program will comprise further ground gravity and radon-in-soil surveys, with the potential to include drilling and induced polarisation surveying. The 2017 stakeholder environmental audit will be scheduled to coincide with these exploration activities.

3.3.3 Supervision and assessment activities

Stakeholders inspected Nabarlek on 13 September 2016, primarily to assess the progress of rehabilitation activities carried out after the 2016 drilling program, and to follow up on the findings of the 2015 audit of the Mining Management Plan. The site inspection identified no significant environmental risks; however two of the conditional findings from the 2015 audit, related to hydrocarbon management and storage, were escalated to Category 2 non-compliances. Neither of the initial findings had been adequately addressed since the time of the audit and UEL has committed to addressing these matters during the proposed 2017 exploration program. All other outstanding matters from the audit had been appropriately resolved.

There were no environmental incidents reported for Nabarlek during 2016–17.

A Nabarlek MTC meeting was held on 25 January 2017 and focussed on the ongoing progress of revegetation and weed management.

3.4 Other activities in the Alligator Rivers Region

3.4.1 Uranium rehabilitation projects

3.4.1.1 South Alligator Valley uranium 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 ARR. The majority of these sites are now the responsibility of the Australian Government Director of National Parks. In May 2006, the Australian Government provided funding over four years for their rehabilitation. A containment facility was constructed in 2009 at the old El Sherana airstrip for the final disposal of historic uranium mining waste recovered from several sites throughout the South Alligator River Valley. Further background on the remediation of historic uranium mining sites in the South Alligator Valley was provided in the 2008–09 Supervising Scientist Annual Report.

An audit of the containment facility was conducted by the Australian Radiation Protection and Nuclear Safety Agency on 10 September 2015. In June 2016, a review of the monitoring data for the containment facility commissioned by Parks Australia recommended minor improvements to annual management activities, monitoring data reporting and minor earthworks to restrict pooling of water on the surface of the facility.

SSB staff carried out an inspection of the containment facility on 8 June 2017. The need to repair surface cracks on the containment and ongoing management of annual mission grass were the main findings from this inspection. Bushfires had been through the area in late 2016, impacting on revegetation in some areas of the containment facility; however monitoring equipment was not damaged. Continuation of a program of late wet season/early dry season low intensity burns to reduce fuel load and protect monitoring equipment was recommended.

3.4.2 Uranium exploration projects

3.4.2.1 Cameco Arnhem Project and Wellington Range – King River Joint Venture Projects

Stakeholders inspected the Cameco Arnhem Project and Wellington Range – King River Joint Venture Project Area on 12–13 September 2016, with a focus on the 2016 exploration drilling sites and reviewing the progress of rehabilitation of the 2015 exploration sites. No significant environmental risks were identified during the inspection; however some recommendations were made regarding drill sample and core management, hydrocarbon storage, radiation protection and artesian bore monitoring and remediation.

During this inspection, the two conditional findings from the 2015 Mining Management Plan compliance audit, relating to drill sump linings and rehabilitation plan development, were determined to be adequately addressed and were closed out.

No further exploration activity has been proposed by Cameco in the ARR during 2017, with dry season activities focused on the rehabilitation and closure of former exploration areas. On 16

December 2016, a Closure Report was submitted to the Northern Territory Government by Cameco for the historic Myra Kukalak and Cadell Project exploration areas, located in north-west Arnhem Land.

A closure audit of the Myra, Kukalak and Cadell Project and the Arnhem Projects, to assess compliance with their relevant closure reports, is scheduled to be undertaken in September 2017

3.4.2.2 UEL West Arnhem Joint Venture

The 2016 inspection of UEL West Arnhem joint venture was undertaken in conjunction with the Nabarlek site inspection on 13 September 2016. As discussed in Section 3.3, two of the conditional findings pertaining to hydrocarbon management and storage were escalated to Category 2 non-compliances, as they had not been adequately addressed since the time of the audit.

The MMP for the 2017 dry season works was submitted by UEL on 20 July 2017. The exploration program proposed for 2017 will comprise ground gravity and radon-in-soil surveys to be conducted from August to October 2017.

3.4.2.3 Alligator Energy Arnhem Projects

The 2015 audit of Alligator Energy Arnhem Projects identified two conditional findings, related to safety signage and the plugging of boreholes. No exploration activities were carried out at this site during 2016, so SSB did not undertake any site inspections or audits during the 2016–17 reporting period.

On 8 June 2017, Alligator Energy submitted a Mining Management Plan for the Tin Camp Creek and Beatrice Projects. No major ground disturbance is proposed during 2017, with exploration limited to a two week program in August 2017 for the collection of rock chip samples from outcrops within the tenements.

3.4.2.4 UXA Resources Nabarlek Group Project

No exploration activities were proposed or carried out at this site during 2016, so SSB did not undertake any site inspections or audits during the 2016–17 reporting period.

4 MONITORING

4.1 Ranger mine environmental monitoring

In order to ensure protection of the environment and the people of the ARR, ERA is required to achieve specific water quality objectives (WQOs) for both Magela and Gulungul creeks (Figure 2). Because these WQOs are largely based on site-specific biological effects data, their achievement provides confidence that the environment has been protected. The WQOs for Magela Creek were originally established by the Supervising Scientist in 2004 and were updated in 2016. The WQOs are designed around a tiered management response consisting of:

- Focus Trigger Values – watching brief
- Action Trigger Values – data assessment
- Investigation, Guideline and Limit Trigger Values – full investigation and management response.

In addition to ERA's statutory monitoring program, SSB conducts an independent surface water quality monitoring program that uses a multiple lines-of-evidence approach for undertaking environmental impact assessment. All monitoring undertaken by SSB to date, including during the 2016–17 wet season, indicates that there have been no observed environmental impacts from operations at Ranger mine in the offsite environment.

The dates of wet season flow commencement and cessation, since the 2009–10 wet season, are shown in Table 14.

TABLE 14 WET SEASON CREEK FLOW SUMMARY

Wet season	Magela Creek			Gulungul Creek		
	Flow commencement	Flow cessation	Flow Duration (days)	Flow commencement	Flow cessation	Flow Duration (days)
2009–10	2 Dec 2009	27 Jul 2010	237	30 Dec 2009	24 Jun 2010	176
2010–11	24 Nov 2010	15 Aug 2011	264	14 Dec 2010	7 Jul 2011	205
2011–12	23 Nov 2011	7 Aug 2012	258	2 Nov 2011	21 Jun 2012	232
2012–13	7 Jan 2013	1 Jul 2013	175	23 Dec 2012	18 Jun 2013	177
2013–14	28 Nov 2013	21 Jul 2014	235	4 Dec 2013	23 Jun 2014	201
2014–15	27 Dec 2014	15 Jun 2015	170	2 Jan 2015	1 May 2015	119
2015–16	25 Dec 2015	6 Jun 2016	163	31 Jan 2016	23 May 2016	99
2016–17	20 Sep 2016	25 Oct 2016	35	22 Sep 2016	3 Oct 2016	11
	16 Nov 2016	17 Jul 2017	244	05 Oct 2016	11 Oct 2016	6
				16 Nov 2016	17 Nov 2016	1
				23 Nov 2016	13 Jun 2017	203

Within the multiple lines of evidence approach, SSB uses two broad approaches to assess possible environmental impacts from mine water input to receiving surface waters around the minesite: (1) early detection, and (2) assessment of long-term ecosystem-level responses.

Early detection methods include:

(i) continuous and event-based monitoring of chemical and physical indicators
(ii) *in situ* toxicity monitoring using freshwater snail reproduction
(iii) bioaccumulation monitoring using freshwater mussels.

To assess long-term 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 mining.

4.1.1 Early detection monitoring in Magela Creek

Monitoring undertaken in Magela Creek during the 2016–17 wet season indicates that there have been no observed environmental impacts from operations at Ranger uranium mine in the offsite environment.

Chemical and physical monitoring

Magela Creek flows to the north-west of the Ranger minesite and receives mine waters from Retention Pond 1, the former Djalkmara Billabong and Georgetown Creek (Figure 2).

The electrical conductivity (EC) data measured in Magela Creek upstream and downstream of these mine inputs were comparable to the 2015 – 16 wet season (Figure 8).

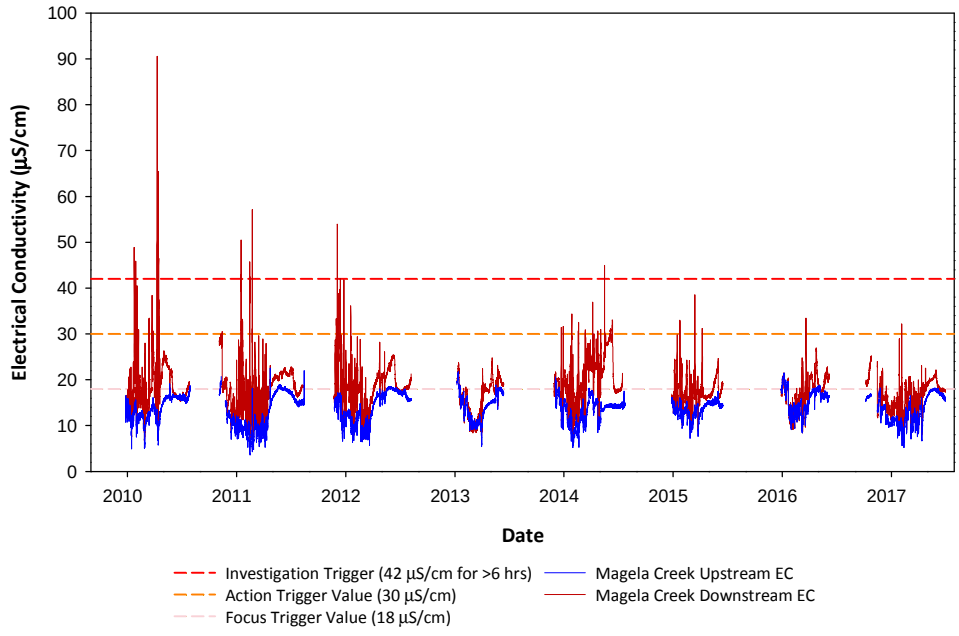

Figure 8 Magela Creek electrical conductivity (EC) data measured during the wet season 2009–17.

The EC Action trigger value was exceeded on one occasion during the 2016 – 17 wet season at the Magela Creek downstream site (Figure 9). This exceedance corresponded with the release of treated pond water at the DJKRP discharge point (Figure 2) and was likely due to the flushing of water from the Djalkmara wetland area, which has been known to have high EC caused by seasonal evapo-concentration of groundwater expressing from the nearby Djalkmara Land Application area. SSB monitoring shows that all water quality objectives for Magela Creek were met during the 2016–17 wet season.

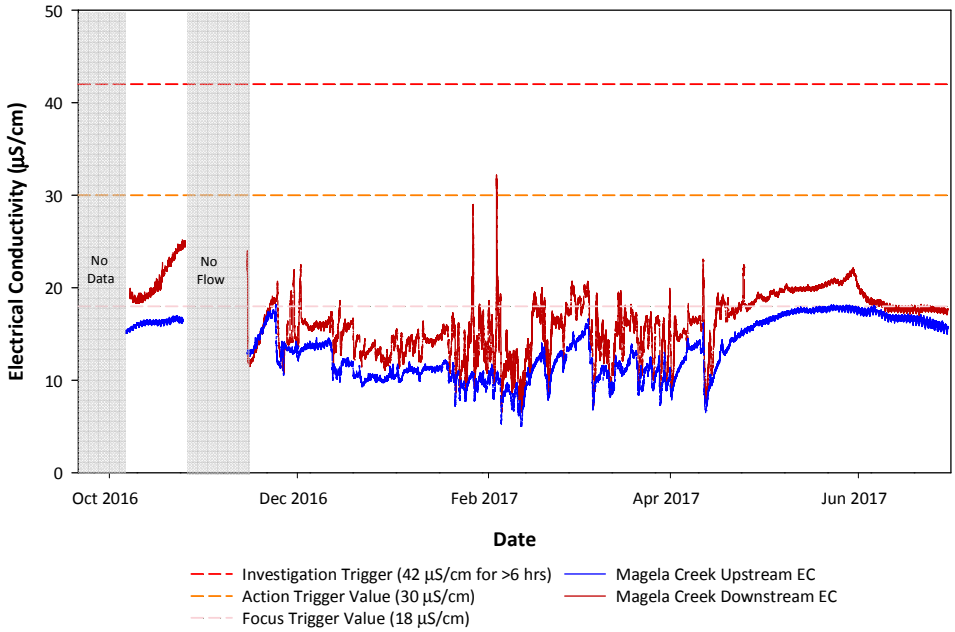

Figure 9 Magela Creek electrical conductivity (EC) data measured during the 2016–17 wet season.

Compliance with the ^{226}Ra Limit is assessed by calculating the difference in the geometric mean of ^{226}Ra concentrations, measured at the upstream and downstream sites for the entire season. Data assessed to date for the 2016–17 wet season are similar to historical values, indicating that the ^{226}Ra Limit was not exceeded (Figure 10).

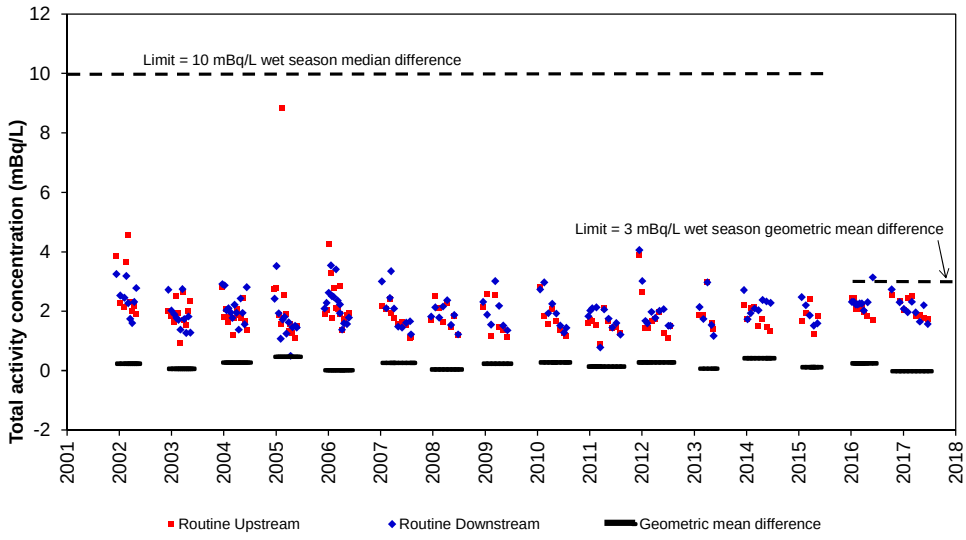

Figure 10 Magela Creek upstream and downstream ^{226}Ra data.

Biological monitoring

Toxicity monitoring

Ten in-situ toxicity monitoring tests were conducted on a fortnightly basis in Magela Creek, spanning the period 5 December 2016 to 20 April 2017.

For the 2016–17 wet season, snail egg production in 8 out of 10 tests was higher at the downstream site compared to the upstream site (control site; Figure 11). Analysis Of Variance (ANOVA) testing showed egg difference values between the sites were significantly different (p = 0.029) for the 2016–17 wet season compared to all previous wet seasons, reflecting the higher downstream egg production.

Egg difference values observed during the 2009-10 wet season were also observed to be significantly different to historical data, reflecting higher downstream egg production compared to previous wet seasons (Supervising Scientist Annual Report, 2009–2010). It was suggested that the higher downstream egg production in the 2009-10 wet season was a result of natural changes to the channel and hydrology at that site, resulting in increased deposition of organic matter (and food supply for snails) in the floating snail containers.

The reasons for the higher downstream egg production in the 2016–17 wet season are unclear at this stage and analyses are ongoing. In particular, the effects of higher (natural) water temperature and (mine-derived) electrical conductivity that typify downstream wet season water quality in Magela Creek will be examined further.

End of wet season macroinvertebrate community studies showed no changes to community structure at the Magela downstream site (see below).

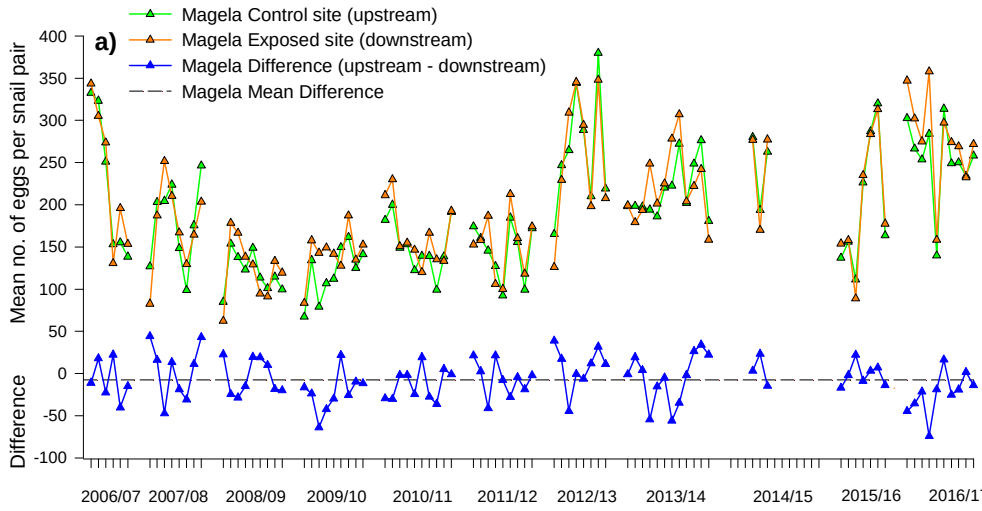

Figure 11 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Magela Creek.

Bioaccumulation in freshwater mussels

Freshwater mussels found in Magela Creek are a key component of the traditional aboriginal diet and as such, are an important contributor to the total annual radiation dose obtained from the ingestion of local bush foods. The SSB monitors the bioaccumulation of ^{226}Ra in mussels by measuring ^{226}Ra concentrations in the flesh of mussels collected annually from Mudginberri Billabong (potentially impacted site) and every three years from Sandy Billabong (un-impacted site) (Figure 3). See section 4.2.1.2 for results.

4.1.2 Early detection monitoring in Gulungul Creek

Monitoring undertaken in Gulungul Creek during the 2016–17 wet season indicates that there have been no observed environmental impacts from operations at Ranger uranium mine in the offsite environment.

Chemical and physical monitoring

Gulungul Creek flows along the western boundary of the Ranger Project Area (Figure 2). ERA does not actively discharge mine waters into Gulungul Creek; however, the creek does receive passive surface runoff and shallow groundwater flows from the minesite.

Prior to the 2015–16 wet season, locations of the Gulungul Creek upstream and downstream monitoring sites were adjusted to better assess the mine derived inputs into Gulungul Creek. The former downstream site (Gulungul Creek d/s in Figure 2) was relocated to the lease boundary (Gulungul Creek mid e/b in Figure 2) and a new upstream site was installed (GCNUS in Figure 2), which is used as the control site for the SSB monitoring program.

The EC measured in Gulungul Creek during the 2016-17 wet season indicates an improvement in water quality since the 2013-14 wet season, in particular, compared to the 2015-16 wet season (Figure 12).

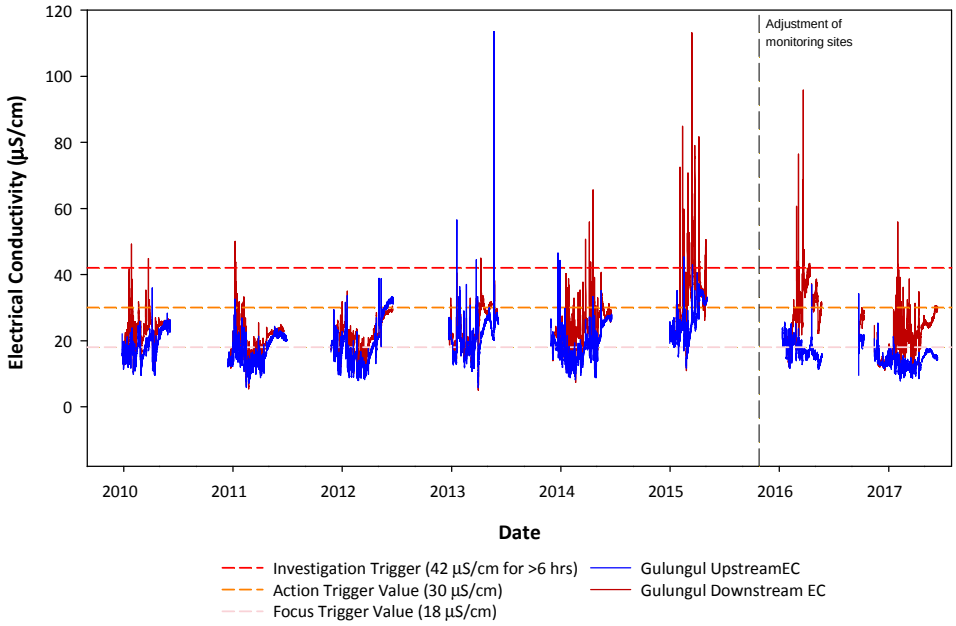

Figure 12 Gulungul Creek electrical conductivity (EC) data measured during the wet season.

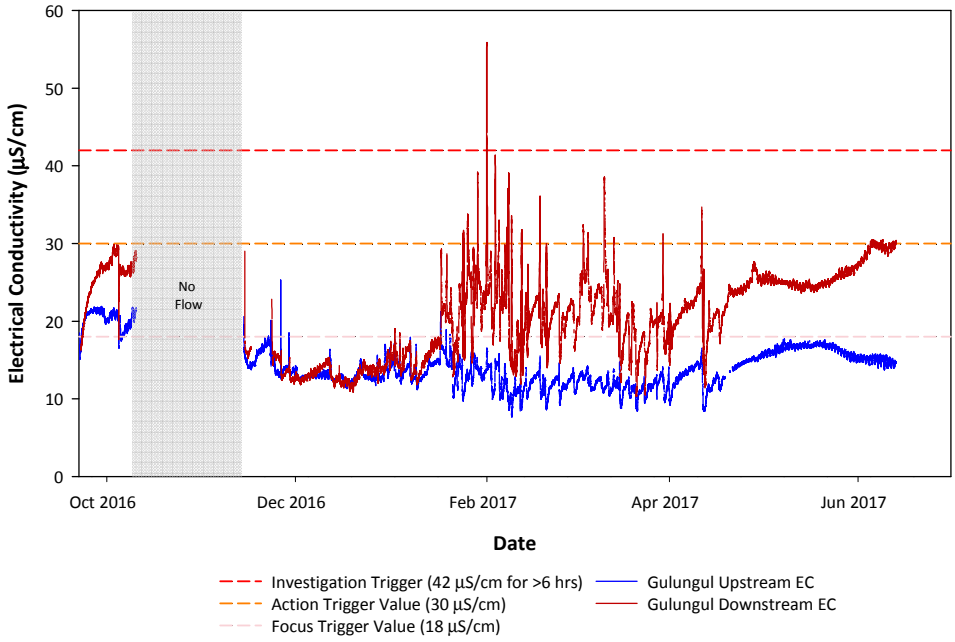

Figure 13 Gulungul Creek electrical conductivity (EC) data measured during the 2016–17 wet season.

TABLE 15 2016–17 GULUNGUL CREEK EC EVENTS

Date	Duration (hours)	Maximum EC (µS/cm)	Mg (mg/L)	U (µg/L)	Mn (µg/L)	SO_4 (mg/L)
Limits			*3 for >72 hrs*	*2.8*	*75*	*N/A*
31/01/2017	5.5	60.2	4.1 for <6 hrs	0.24	18	15

SSB monitoring showed that all water quality objectives for Gulungul Creek were met during the 2016–17 wet season (Figure 13 and Table 15).

The SSB EC event-sampling system was triggered on one occasion at the Gulungul Creek lease boundary site (Gulungul mid e/b; Figure 13) on 31 January 2017, and a number of water samples were collected. The contaminant concentrations during this event were assessed against relevant Guideline and Limit values and no exceedances were observed (Table 15). The event was likely to have been caused by the flushing of solutes from the shallow aquifer system between the TSF and Gulungul Creek into Gulungul Creek Tributary 2 (GCT2), which is known to be contaminated by high EC water originating from the north-western corner of the TSF.

Compliance with the ^{226}Ra Limit (3 mBq/L) was met, with the calculated difference for the 2016-17 wet season well below the defined Limit (Figure 14).

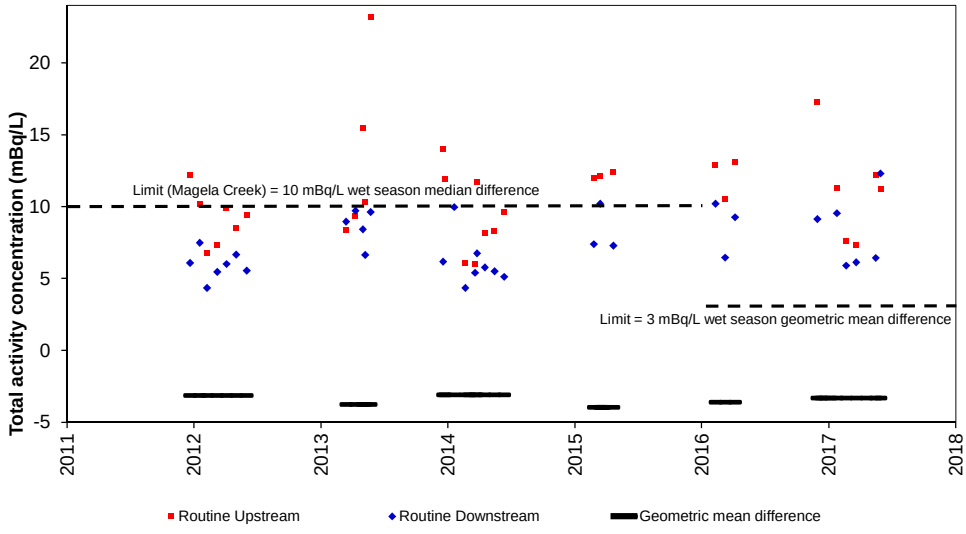

Figure 14 Gulungul Creek upstream and downstream ^{226}Ra concentrations

Upper Gulungul Catchment Investigation

The data presented in Figure 12 indicates that since the 2012-13 wet season, water quality measured at the original Gulungul Creek upstream control site, GCUS (Gulungul u/s in Figure 2) has deteriorated. A number of high EC events were observed in the 2012-13 wet season, and since that time there was a gradual elevation in the baseline EC measured at the site.

Figure 15 compares the EC measured at GCUS and at the new upstream control site, GCNUS. The data clearly show that the EC at GCUS is elevated compared to GCNUS, indicating input of solutes between the two sites. These findings suggested that the solutes may have originated from the Corridor Creek Land Application Area. In response to these data, ERA ceased irrigation in the southern portion of the CCLAA in 2015 while investigations were undertaken by both ERA and the SSB to determine the source of the solutes.

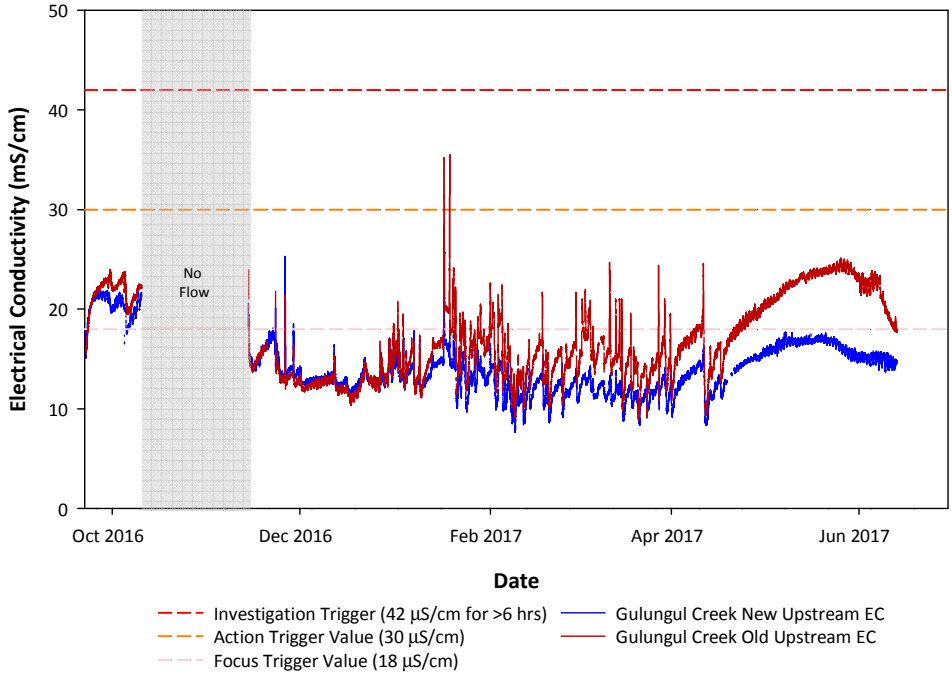

Figure 15 Comparison of EC values measured in Gulungul Creek upstream of the mine, at the exisitng control site (old upstream) and the new investigation site (new upstream).

In 2015, the SSB installed 'Diver' conductivity loggers in various tributaries in the upper Gulungul catchment to try to detect the source of the solutes. The data collected during the 2015-16 wet season was inconclusive, so additional loggers were installed prior to the 2016-17 wet season (Figure 16). The loggers were retrieved in early June 2017 and the data are summarised using box-plots in Figure 17.

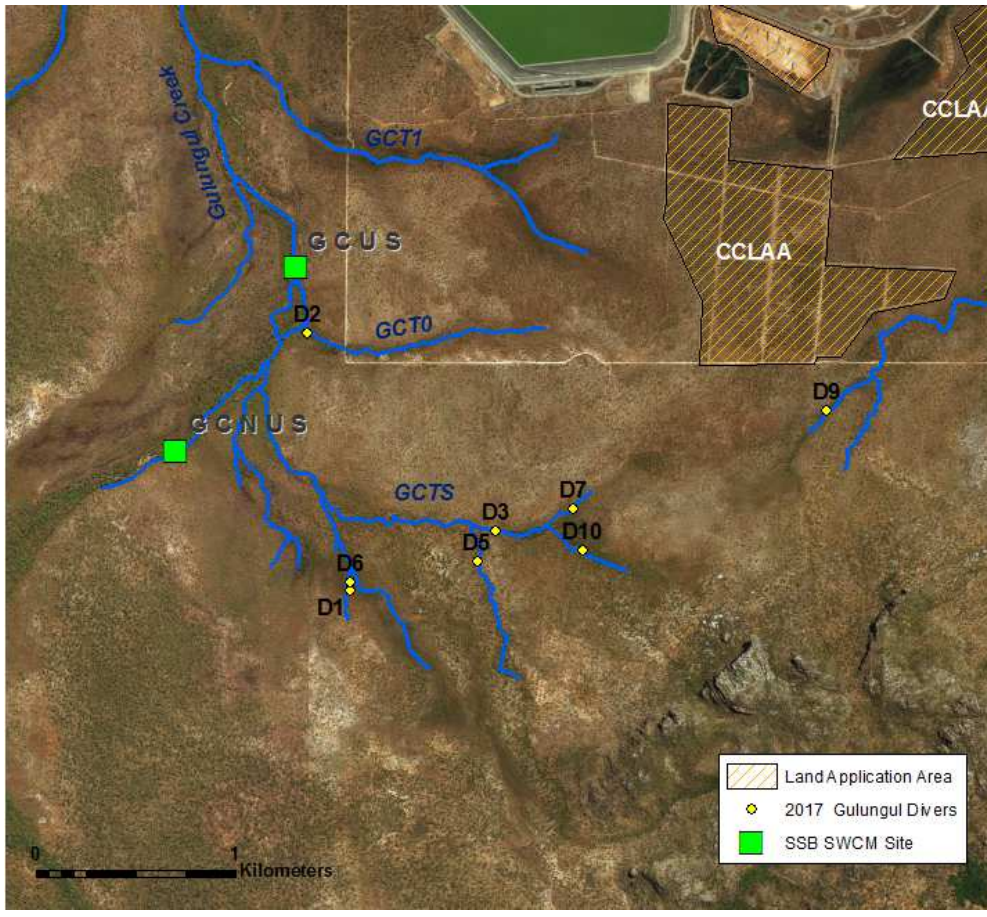

Figure 16 Location of the 'Diver' conductivity loggers deployed in the upper Gulungul tributaries.

The EC data in Figure 17 show that solutes are draining into Gulungul Creek along both Gulungul Creek Tributary South (GCTS) and Gulungul Creek Tributary 0 (GCT0). These data eliminate natural solute sources to the south of the minesite, such as the Anomaly 2 orebody, confirming that solutes observed at GCUS are not naturally occurring and are mine-derived, most likely originating from the CCLAA.

The ERA investigations concluded that groundwater levels beneath the CCLAA were elevated due to irrigation activities, resulting in a shift in the direction of the groundwater flow that allowed shallow groundwater to travel from the CCLAA region to the south of the minesite. Concurrently, concentrations of solutes in the groundwater were increasing due to enhanced evapotranspiration, occurring because the groundwater levels were closer to the ground surface.

In February 2017, ERA reported that groundwater elevations in the southern part of the CCLAA had declined and suggested that water levels in the area could be effectively managed by implementing appropriate controls on surface irrigation rates and locations, and targeted monitoring of groundwater elevations and depth to the water table. ERA is currently seeking to recommence irrigation activities in the southern section of the CCLAA.

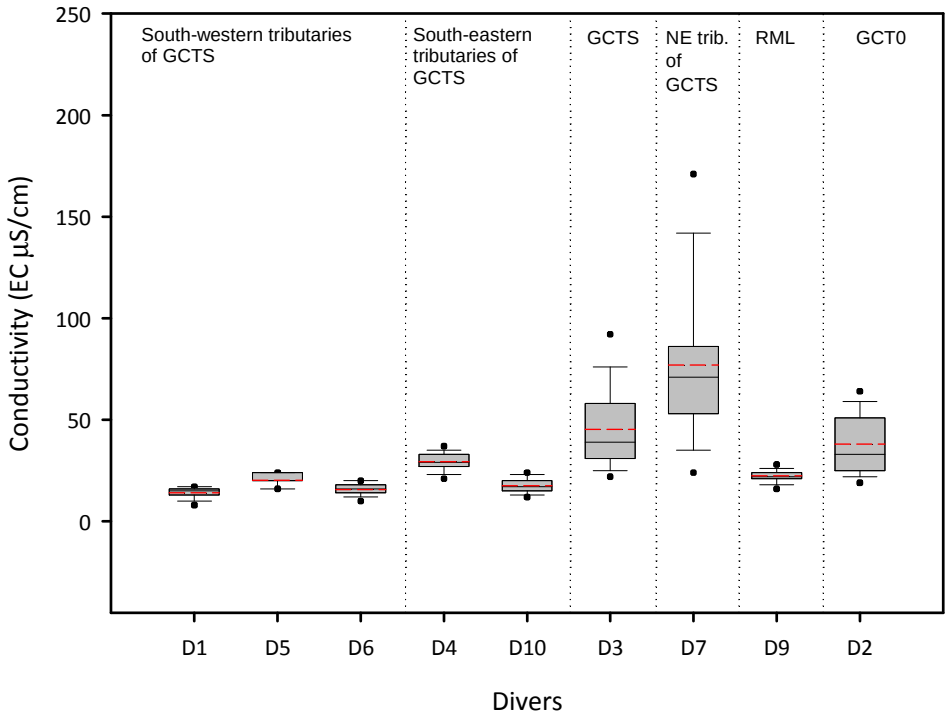

Figure 17 Box-plots showing distribtuion of electrical conductivity (EC) at each site during periods of surface flow.

Gulungul Creek Tributary 2 Investigation

A significant amount of work has been undertaken by ERA to manage surface and shallow groundwater to the west of the TSF, including the installation of a seepage interception and extraction system, comprising an interception trench adjacent to the north-western wall of the TSF and a number of downstream dewatering bores. The system collects shallow groundwater and surface water and transfers it to the pond water system for treatment. Approximately 148.5 ML of water was extracted by the interception system during the 2016–17 wet season.

SSB monitoring of surface water in the GCT2 tributary at a site called GCT2 Radon Springs Track (GCT2RST), which is located downstream of the interception system and the dewatering bores, has shown an improvement in water quality discharging from GCT2 into Gulungul Creek (Figure 18).

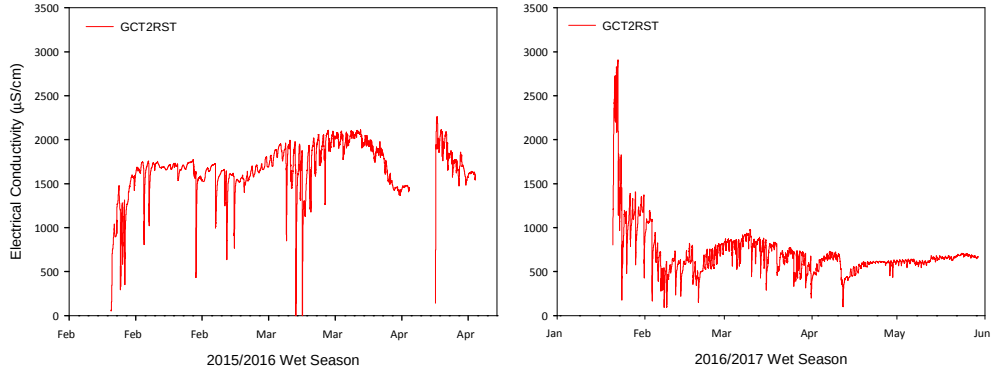

Figure 18 Electrical conductivity measured at the Gulungul Creek Triburtary 2 Radon Springs Track site during the 2015-16 and 2016-17 wet seasons.

The average EC of base flow in GCT2 was reduced from 2015–16 to 2016–17, with a concurrent reduction in guideline exceedances at the Gulungul Creek lease boundary site (Gulungul mid e/b), as shown in Figure 19.

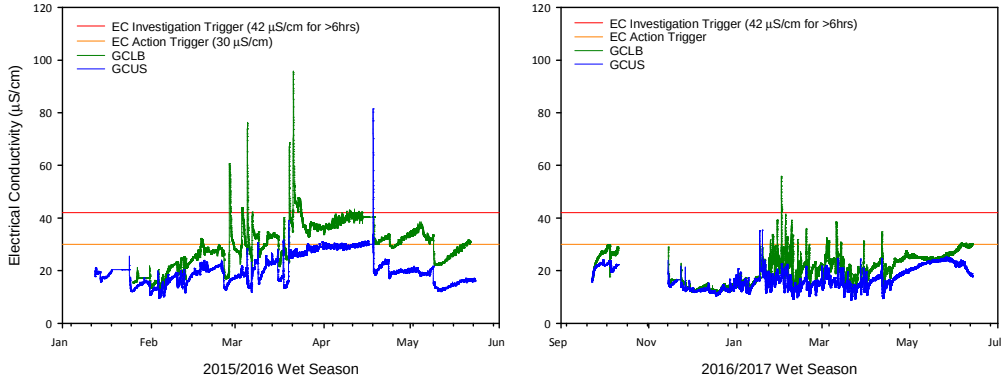

Figure 19 Electrical conductivity measured at the Gulungul Creek mid e/b site during the 2015-16 and 2016-17 wet seasons.

This, along with the data shown in Figure 12, indicate a general recovery of water quality in Gulungul creek downstream of the minesite. The SSB will continue to measure the EC at GCT2RST during the 2017-18 wet season. This will enable ongoing tracking of trends over a number of seasons and further confirmation of the effectiveness of the ERA mitigation measures.

Biological monitoring

Toxicity monitoring

Nine in situ toxicity monitoring tests were conducted in Gulungul Creek, spanning the period 6 January 2017 to 2 May 2017 (Figure 20 and Figure 21). Results show generally higher egg production at the downstream site compared to the upstream site, which was also observed in previous years (and in adjacent Magela Creek – see Figure 11 above). There was no significant difference in egg difference values observed in Gulungul Creek between the 2016–17 wet season and all previous wet seasons. This includes tests carried out at the Gulungul lease boundary site (referred to as midstream in Figure 21) downstream of GCT2, where snails were exposed to elevated EC levels compared to upstream.

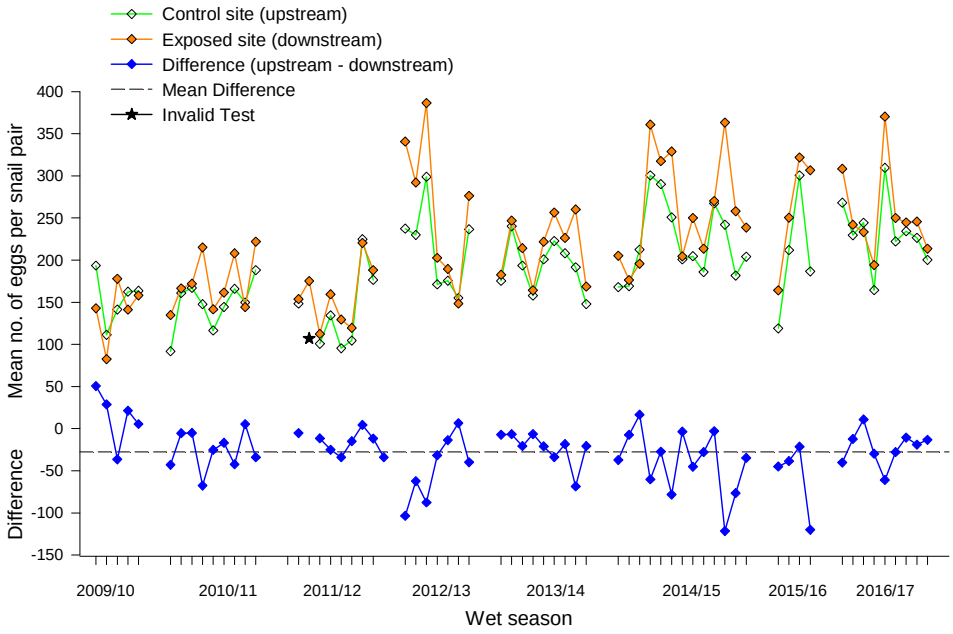

Figure 20 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek.

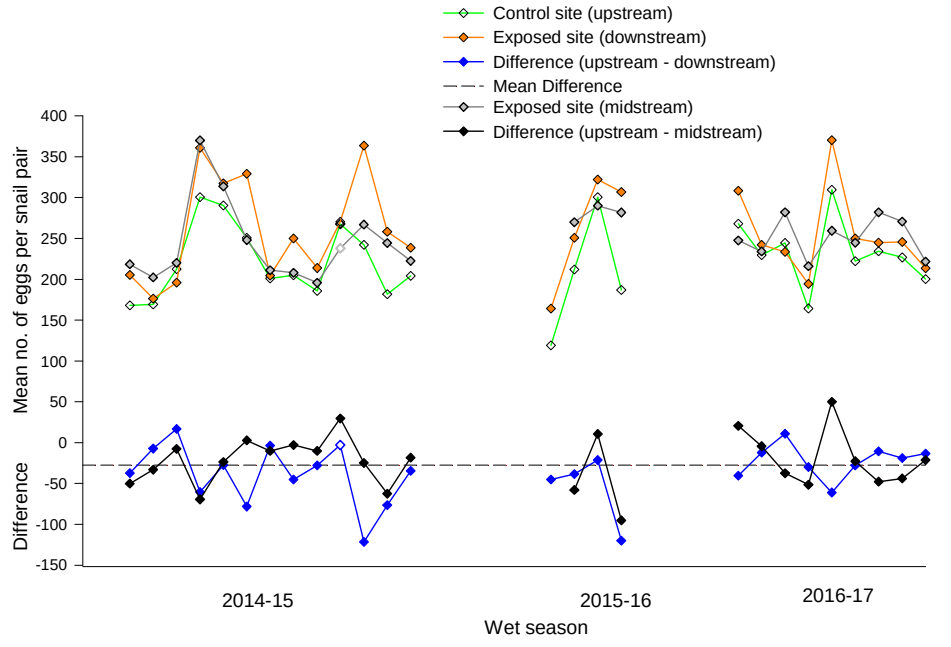

Figure 21 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek since 2015.

4.1.3 Ecosystem monitoring

Macroinvertebrate communities

During the recessional flow period of the 2015–16 wet season, macroinvertebrate communities were sampled from Magela and Gulungul creeks, upstream and downstream of the mine, and control sites, Burdulba creek and Nourlangie creek. In 2015 and thereafter, an additional site located downstream of the GCT2 confluence with Gulungul Creek has been sampled (GCT2GCC). At the time of reporting, only samples from the 'exposed' creeks (Magela and Gulungul creeks (including GCT2GCC)) from the 2016–17 wet season were available for analysis.

The dissimilarity values for the 2017 Magela and Gulungul data were comparable to those from previous years, indicating that no significant alteration of macroinvertebrate communities has occurred at the downstream exposed sites (Figure 22). Without the full 2016–17 dataset, it is not possible to run the full ANOVA testing at this time. Instead, a modified ANOVA model was run to determine if any change in the exposed creeks (Magela and Gulungul creeks) had occurred. The modified model used the factors: Before/After (BA; fixed), Year (nested within BA; random) and Stream (upstream verse downstream paired dissimilarities; random). The ANOVA completed on the original sites (i.e. without GCT2GCC data) showed no significant change from the before (pre 2016-17) to the after (2016-17) periods in the magnitude of upstream-downstream dissimilarity across both 'exposed' streams, and this was consistent between both streams (BA and BA*Stream interactions not significant respectively; Figure 22).

Graphical ordination methods can also be used to infer potential impacts if points associated with exposed sites sit outside of points representing reference sites. Data points associated with the 2017 Gulungul and Magela downstream sites are interspersed amongst the points representing the control sites from previous years, indicating that these 'exposed' sites have macroinvertebrate communities that are similar to those occurring at control sites (Figure 23). This result was further confirmed by PERMANOVA (PERmutational Multivariate Analysis Of Variance) testing on the individual sites (as opposed to the paired site dissimilarity for the above ANOVA) of the exposed streams (Magela and Gulungul sites, excluding GCT2GCC). This analysis showed no significant difference between the downstream data from 2017 with downstream data from previous years, and no significant difference between the upstream data from 2017 with upstream data from previous years. The same PERMANOVA test run with GCT2GCC paired with Gulungul upstream, instead of downstream Gulungul, returned the same non-significant result.

During the 2014–15 and 2015–16 wet seasons, GCT2GCC site replicates were exposed to higher EC water than Gulungul and Magela creek downstream replicates. For the 2017 wet season, however, no high EC events at GCT2GCC were recorded. The dissimilarity values for the GCT2GCC versus Gulungul upstream pairing have concomitantly reduced since 2014–15 and for 2017 better match the dissimilarity values of Gulungul Upstream versus Gulungul downstream (Figure 22). It is possible that macroinvertebrate communities have responded to water quality changes over this three year period and now reflect improved water quality in Gulungul Creek generally.

These collective results provide confidence that changes to water quality downstream of Ranger Mine as a consequence of mining during the period 1994 to 2017 have not adversely affected macroinvertebrate communities.

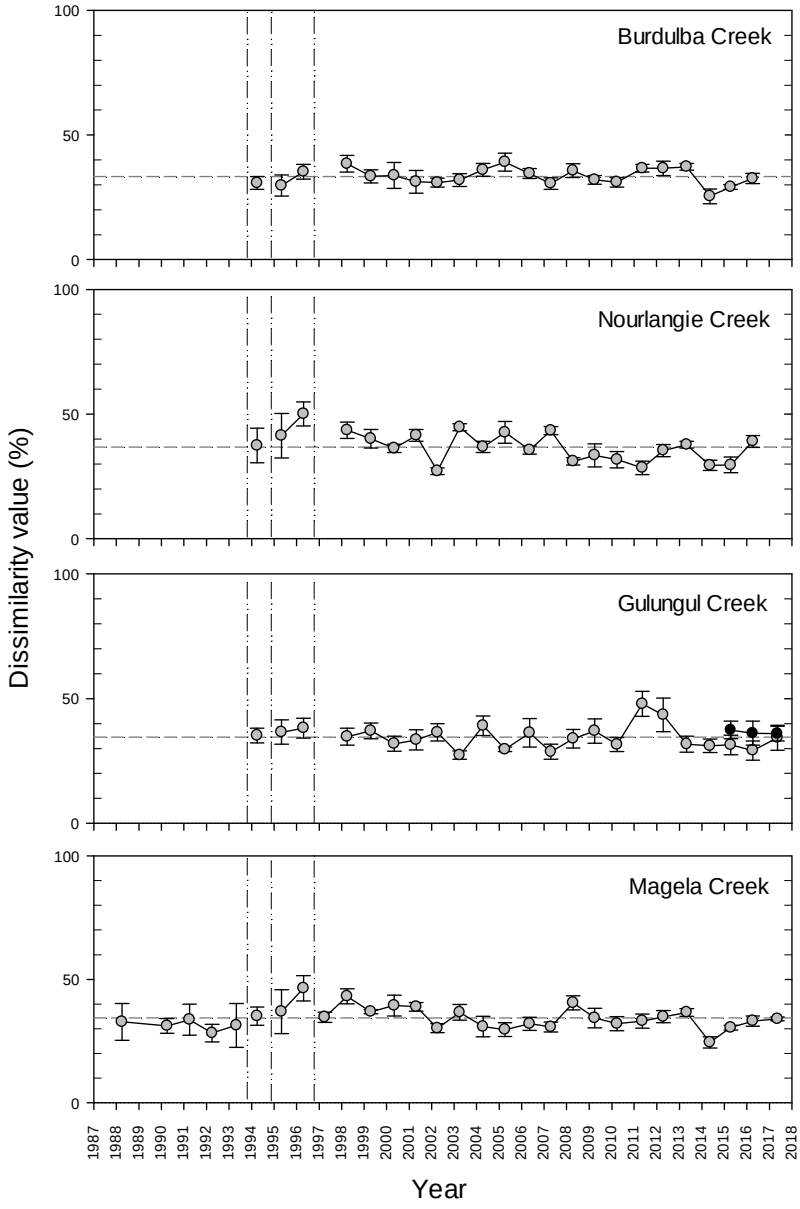

Figure 22 Paired upstream-downstream Bray-Curtis dissimilarity values using family-level (log transformed) data for macroinvertebrate community structure.

Black symbols represent the upstream Gulungul-GCT2GCC stream pairwise comparison. Dashed vertical lines delineate periods for which a different sampling and/or sampling processing method was used. Dashed horizontal lines indicate mean dissimilarity across years. Dissimilarity values represent means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of upstream-downstream replicate samples within each stream.

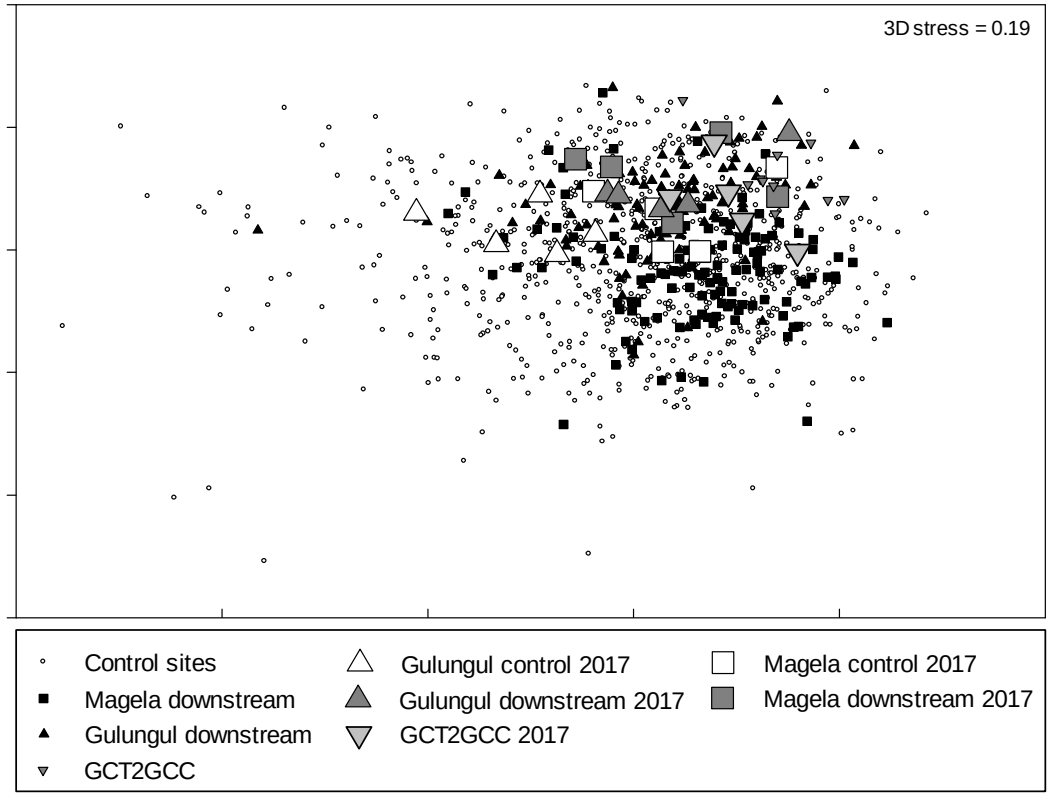

Figure 23 Ordination plot (axis 1 and 2) of macroinvertebrate community structure.

Fish communities

Fish communities in deep channel billabongs are assessed for impacts every year, and in shallow lowland billabongs every two years. Full analysis and reporting on the shallow lowland billabongs can be found in the Supervising Scientist's Annual Technical Report (2015-16). In summary, there were no significant changes in billabong fish communities in 2016 compared to all previous years, indicating that water quality downstream of Ranger mine has not adversely affected fish communities in shallow lowland billabongs.

Data analysis on the fish communities in deep channel billabongs in 2016 was recently undertaken. This had been delayed due to changes in data collection methodology from visual observations to videography that commenced in 2016 due to safety concerns. For 2017, videography-only sampling was undertaken. Historically SSB has compared (i) fish community dissimilarity and (ii) rainbowfish abundance in Mudginberri Billabong (directly exposed site downstream of Ranger in Magela Creek catchment) to those same summary variables in Sandy Billabong (control site in Nourlangie Creek catchment).

Annual mean paired-site dissimilarity showed an increase in 2016 from all previous years (Figure 24). The results also indicated that there were twice as many rainbowfish in Mudginberri Billabong compared to Sandy Billabong (data not shown here) with average maximum number of fish in

the imagery frame ("MaxN") of 6.5 and 3, respectively. With lower than average rainfall and stream discharge for the 2015-16 wet season, this result follows the natural relationship reported in the 2008-09 Supervising Scientist's Annual Report, i.e. a negative correlation between rainbowfish abundance in Mudginberri Billabong and the magnitude of wet season discharge in Magela Creek. Further validation of these result is required before conclusions can be drawn. This validation will arise from side by side comparisons of data arising from traditional visual observations and videography, conducted in July 2017. Data from the 2017 sampling period are currently being compiled and results will be reported at a later date.

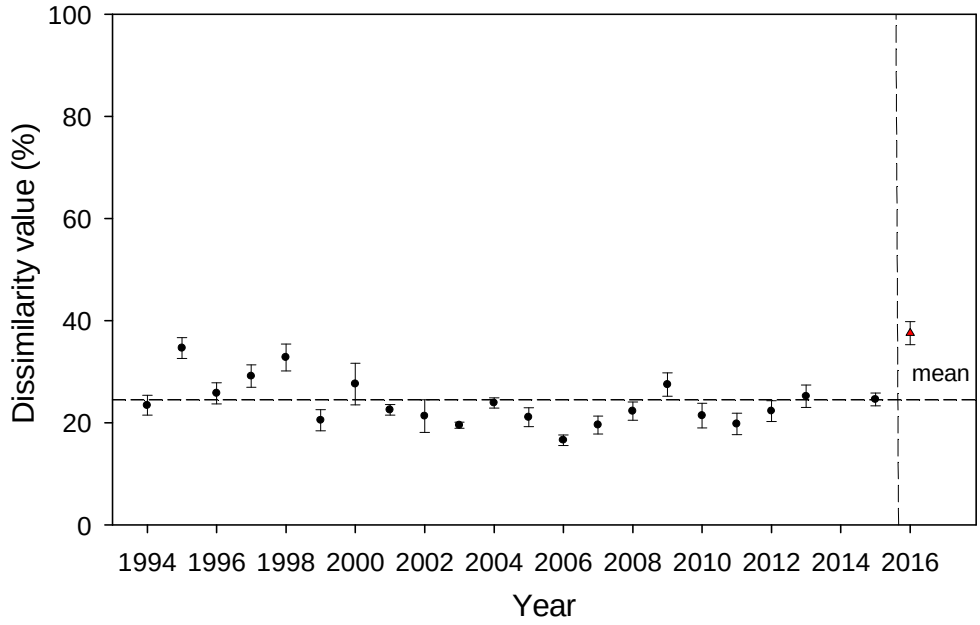

Figure 24 Paired control-exposed dissimilarity values for fish community structure.

Dissimilarity values calculated using the Bray-Curtis measure, for community structure of fish in Mudginberri ('exposed') and Sandy ('control') Billabongs. Values are means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of transect data between the two waterbodies. Data prior to and including 2015, were collected using visual observations (left of the vertical dashed line), while data post 2015 were collected using videography (right of the vertical dashed line, denoted by the red triangle).

4.2 Radiological monitoring

The radiation dose limits for workers and members of the public from other-than-natural sources recommended by the International Commission on Radiological Protection (ICRP) and adopted in Australia by ARPANSA are:

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

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. It is ERA's responsibility to ensure that the levels of exposure to ionising radiation received by workers and the general public are as low as reasonably achievable.

Dose constraints for the Ranger operation are revised annually and detailed in ERA's *Annual Radiation and Atmospheric Monitoring Report*. The current dose constraints for Ranger mine are listed in Table 16.

TABLE 16 ANNUAL RADIATION DOSE CONSTRAINTS FOR RANGER MINE (mSv)

Proposed operational area/work group	Existing work group	Annual dose constraint (mSv)
Ranger Operations	Processing Production	7.0
	Processing Maintenance	
Non-Designated Workers	Non-Designated Workers	5.0
Workers under the age of 18	Under 18	6.0
Members of the public	Members of the Public	0.3

4.2.1 Radiological exposure of ERA workers

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)

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 monitoring results for 2016 confirm that doses to designated and non-designated workers were well below the annual dose limits and the current dose constraints as listed in Table 16. For designated workers there was a slight increase in both maximum and mean effective dose for 2016 when compared to 2015 as shown in Table 17. This increase is attributed to increased non-routine operational activities in 2016, associated with the proccesing area tank inspection and refurbishment program. For non-deignated workers, the 2016 dose was compareable to the 2015 dose as shown in Table 18.

TABLE 17 2016 DESIGNATED WORKER DOSE (mSv)

	2016	2015
Occupational dose limit	20	20
Mean annual effective dose (% of dose limit)	1.14 (5.7%)	0.79 (4.0 %)
Maximum annual effective dose (% dose limit)	4.14 (20.7%)	3.04 (15.2%)

TABLE 18 2016 NON- DESIGNATED WORKER DOSE (mSv)

	2016	2015
Occupational dose limit	20	20
Mean annual effective dose (% of dose limit)	0.15 (0.8%)	0.12 (0.6 %)
Maximum annual effective dose (% dose limit)	1.07 (5.4%)	0.97 (4.9%)

4.2.2 Radiological exposure of the public

The two main pathways of potential radiation exposure to the public during the operational phase of Ranger mine and the care and maintenance phase at Jabiluka 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 2).

Inhalation pathway

A review of 16 years of atmospheric radiation monitoring data conducted in 2016 clearly indicated that the mine-derived radiation dose from airborne radon progeny and radioactive dust from Ranger uranium mine is negligable and does not currently pose a public health risk (typically contributing less than 5% of the public dose limit). Accordingly, the SSB ceased its atmospheric radiation monitoring program at the end of 2015, with the intention to review this decision if minesite activities change substantially (e.g. in 2021, when heavy earthworks will commence on the site).

In accordance with the Ranger mine Authorisation, ERA measures concentrations of radon progeny and dust-bound long-lived alpha activity (LLAA) radionuclides in air at the Jabiru town and Jabiru East Airport. These locations represent the main areas of permanent habitation in the vicinity of the Ranger mine.

Table 19 provides a summary of annual average radon progeny potential alpha energy concentration (PAEC) in air and estimated doses to the public in 2016. The total annual effective dose from radon progeny in air, which is largely due to the contribution from natural background, was estimated to be 0.348 mSv at Jabiru town in 2016. The mine-derived annual dose from radon progeny in air has been estimated to be 0.018 mSv at Jabiru town which is 1.8% of the public dose limit of 1 mSv in a year and a decrease from the 2015 dose of 0.038 mSv. 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.

TABLE 19 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN

	2016	2015
Annual average PAEC [µJ m^{-3}]	0.043	0.035
Total annual dose [mSv]	0.348	0.339
Mine-derived dose* [mSv]	0.018	0.038

*The radon progeny PAEC difference used in the mine-derived dose calculation was 0.009 µJ/m^3 for 2016 and 0.018 µJ/m^3 for 2015

ERA uses high volume air samplers to monitor airborne concentrations of LLAA in the township of Jabiru and at Jabiru East. Table 20 provides a summary of annual average LLAA radionuclide concentration and estimated total and mine-related doses to the public at Jabiru. The total annual effective dose from dust-bound LLAA radionuclides, which includes contribution from natural background, has been estimated to be 0.006 mSv at Jabiru town. This total annual dose has been estimated by calculating the annual average LLAA concentration from the individual samples and then multiplying with a dose conversion factor of 0.0061 mSv $Bq\alpha^{-1}$, breathing rate of 0.75 m^3 h^{-1} and assumed full year occupancy of 8,760 hours.

TABLE 20 LLAA RADIONUCLIDE CONCENTRATIONS IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN IN 2016

	2016	2015
Annual average concentration ($Bq\alpha^{-1}m^{-3}$)	1.4×10^{-4}	1.6×10^{-4}
Total annual dose [mSv]	0.006	0.006
Mine-related dose* [mSv]	3×10^{-4}	6×10^{-4}

*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

Freshwater mussels have previously been identified as the most important food source contributing to radiation dose from the traditional diet. This is because they strongly bioaccumulate ^{226}Ra in their flesh. Mussels have been collected annually from Mudginberri Billabong (Figure 3) since 2000 and analysed for ^{226}Ra as part of a routine bioaccumulation monitoring program.

Mussels were collected from Mudginberri Billabong in December 2016. Figure 25 shows ^{226}Ra activity concentrations in mussel flesh from this collection and compares them with average ^{226}Ra

activity concentrations measured in mussels since 2000. Mussel ^{226}Ra activity concentrations in 2016 were within the range of previously measured values.

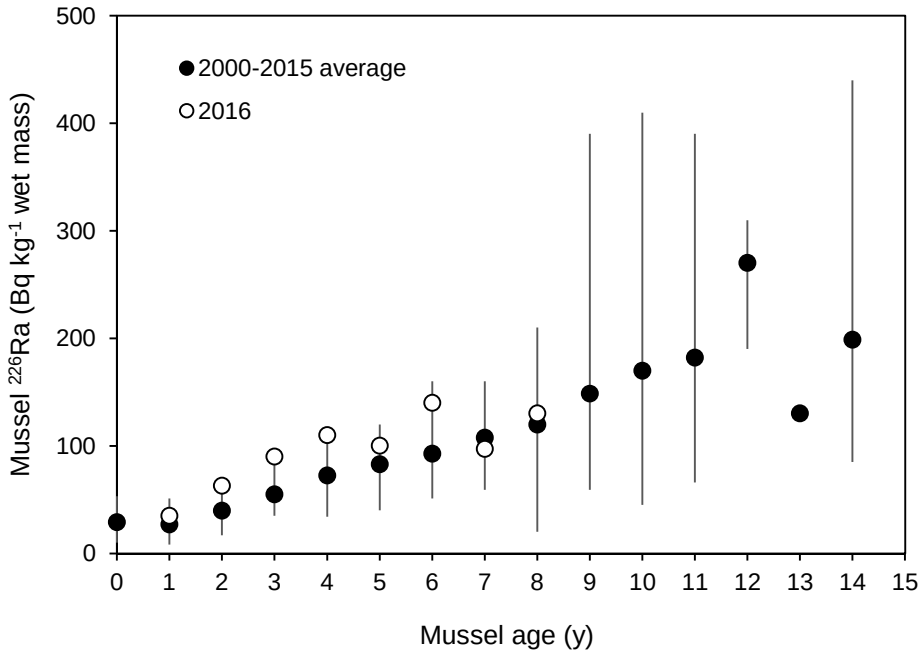

Figure 25 Flesh ^{226}Ra activity concentrations in mussels collected from Mudginberri Billabong.

The annual committed effective dose from ^{226}Ra in mussels has been calculated to be 0.13 mSv for a 10-year-old child who eats 2 kg (wet mass) of mussel flesh based on the 2016 measurement results. By comparison, the annual committed effective dose from ^{226}Ra in mussels based on the average of all measurement results from 2000 to 2015 has been calculated as 0.11 mSv, with a range from 0.06 mSv to 0.20 mSv during these years.

The radiation dose to traditional owners from freshwater mussels collected from Mudginberri Billabong is almost exclusively from natural background levels of ^{226}Ra in the environment and would be received irrespective of the operation of the Ranger uranium mine. This assertion can be made since: (1) the difference between ^{226}Ra activity concentrations measured in Magela Creek upstream and downstream of the Ranger uranium mine is very small; and (2) the findings from previously reported research show that mussel ^{226}Ra activities in Mudginberri Billabong are due to natural catchment sources rather than mining influences.

5 RESEARCH

5.1 Introduction

The Environmental Research Institute of the Supervising Scientist (ERISS) within the SSB provides specialist technical advice to the Supervising Scientist on the protection of the environment and people of the ARR from the effects of uranium mining. Its major function is to conduct research into developing standards and leading practice methodologies for monitoring and assessing the environmental impact of uranium mining in the ARR. The research spans the operational, decommissioning and post-rehabilitation phases of mining.

Although the remit of the Supervising Scientist covers all uranium mining activities across the ARR, the rehabilitation of the Ranger uranium mine remains the primary focus of the research program of ERISS. With rehabilitation works required to be completed by 2026, it is essential that the remaining knowledge needs are adequately mapped out, tracked and acquired in a timely manner. Consequently, SSB has developed and implemented an extensive planning and prioritisation process over the past 2 years. As well as annual work planning, this process included a 10 year plan of projects based on the ARRTC Key Knowledge Needs (KKNs; see below). The Supervising Scjentist's 2015-16 Annual Technical Report provided a description of the 2016-17 planning process, and the associated prioritisation process. The outcome of this process was a clear path forward that should enable SSB, in conjunction with all other responsible entities, to undertake the necessary work to ensure the continued protection of the environment of the ARR from current mining operations, as well as acquire the necessary knowledge to inform a successful rehabilitation of Ranger.

This chapter provides a summary of the Environmental Research Institute of the Supervising Scientist (ERISS) research progress for 2016-17. It captures the research and associated activities undertaken over the period. Short summaries of every research project are provided in Appendix 2. The schedule of projects from 2016 to 2026 is provided in Appendix 3. This schedule will be regularly reviewed, and will be updated in response to changes in the mine rehabilitation schedule or the KKNs

5.2 Status of 2016-17 research program

Research progress in 2016-17 was affected by a number of high priority activities, including the ERISS restructure (reported in the SSB 2015-16 Annual Technical Report), drafting of the Supervising Scientist's rehabilitation standards (see below) for Ranger, the 2017-18 and 10-year planning processes, and review of the Ranger Mine Closure Plan. Nevertheless, generally good progress has been made on key projects, as detailed below.

An important milestone was the completion of the revised ARRTC KKNs. The KKNs were endorsed by ARRTC at its 37th meeting in November 2016, and have recently been finalised and published[1]. The KKNs identify the critical knowledge requirements for achieving a successful

[1] Supervising Scientist 2017. *Alligator Rivers Region Technical Committee: Key Knowledge Needs: Uranium Mining in the Alligator Rivers Region*. Supervising Scientist Report 213, Supervising Scientist, Darwin NT.

rehabilitation at Ranger, and will continue to be the primary resource for guiding SSB's research program. In addition, SSB is integrating the KKNs within its formal assessment of the Ranger Mine Closure Plan. Consequently, the KKNs will be explicitly embedded in the ongoing work programs.

The ERISS research program for 2016-17 comprised 36 research projects, and was endorsed by ARRTC at its 36th meeting in August 2016. The projects are listed in Table 21 and described in Appendix 3, where they are listed in order of the mine phase. Rehabilitation-related projects are listed according to the closure themes (i.e. *Water and sediment*, *Radiation*, *Landform*, *Flora and fauna*) and, within these, according to the three key categories, *Developing closure criteria*, *Demonstrating achievement of closure criteria* and *Monitoring of closure criteria*. Of the 36 projects on the list, seven were completed during the reporting period (see Table 21). All except one of the 36 projects are relevant to Ranger uranium mine. In numerous cases, projects are applicable to more than one mine phase or closure category, although they will only appear once, typically wherever they are needed most urgently. For example, all the projects listed under the operational phase are also relevant in some way to rehabilitation.

Resource constraints and competing demands continue to result in a number of projects being suspended in order to focus on higher priority projects. As of the end of June 2017, 13 projects were suspended (Table 22). As always, assessing priorities and ways of achieving efficiencies are ongoing activities. As part of this, emphasis continues to be placed on working with external consultants and collaborators to achieve research outcomes. Almost half of the 37 research projects in 2016-17 involved external contracts and/or significant external collaboration with other research organisations. We will continue to look for such collaborative opportunities where they align with our strategic research priorities. Moreover, several of the suspended projects are scheduled to be re-activated in 2017-18, as other projects are completed.

Updates on the rehabilitation standards and the progress made during 2016-17 by the three SSB research teams are provided below.

5.2.1 Rehabilitation standards

The rehabilitation standards that are being developed represent the Supervising Scientist's view of what is required to achieve the environmental objectives detailed in the Ranger Environmental Requirements. They will enable clear visibility of the science underpinning each standard, and will provide a scientifically robust basis for decisions. The SSB will communicate the rehabilitation standards to ERA and all stakeholders with the aim of informing the development of closure criteria, and it will publish them and provide them as advice to the relevant ministers. They represent advice, and are not mandatory. In contrast, it is ERA's responsibility to propose closure criteria for the rehabilitation, which, once approved by the relevant minister, become mandatory. ERA may or may not elect to align its closure criteria with SSB's rehabilitation standards. The relevant minister will make a decision on whether the closure criteria are approved and, as part of this will consider the advice of the Supervising Scientist. Drafts of the standards will be circulated to relevant stakeholders (including the GAC) for comment before being finalised.

TABLE 21 ENVIRONMENTAL RESEARCH INSTITUTE OF THE SUPERVISING SCIENTIST RESEARCH PROJECTS COMPLETED OR ACTIVE DURING 2016-17

Project	Status
Ranger operational phase	
Desktop assessment of historical WET data to evaluate multiple single toxicant water quality limits	Completed
Developing a short-term chronic toxicity test for the fish, *Mogurnda mogurnda*	Active
Toxicity of ammonia to freshwater mussels	Active
Developing videography-based methods for monitoring fish	Active
Genomics-based identification of freshwater macroinvertebrates to species level	Active
Ranger rehabilitation	
Overarching	
Cumulative risk assessment for Ranger minesite rehabilitation and closure – Phase 1	Active
Water and sediment	
Magela Creek sand bed water quality and subsurface fauna – Pilot study	Completed
Monitoring billabong turbidity using a Remotely Piloted Aircraft System (RPAS)	Completed
Toxicity of ammonia to freshwater biota and derivation of a site-specific water quality guideline value	Completed
Review of acid sulfate soil knowledge and development of a rehabilitation standard for sulfate	Completed
Effects of uranium on the structure and function bacterial sediment communities	Completed
Billabong macroinvertebrates responses to mine-derived solutes	Active
Toxicity of ammonia to local species at a range of pHs	Active
Literature and data review of seasonal utility of Magela channel for connectivity processes	Active
Assess the cumulative toxicity of Ranger COPCs for operational and closure scenarios	Active
Assessing the ecological risks of mine water contaminants in the dry season, subsurface waters of Magela sand channel	Active

Groundwater - Time series analysis of groundwater levels	Active
Groundwater - Pit 3 Transmissivity Assessment	Active
Groundwater - Pit 1 Transmissivity Assessment	Active
Landform	
Analysis of historical unpublished erosion studies in the ARR	Active
Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to a rehabilitated ranger mine - Gulungul Creek scale	Active
Model geomorphic stability of pre-mine landform for up to 10,000 years	Active
Erosion and infiltration studies on the Ranger trial landform (formerly 'Trial Landform Research')	Active
Development of enhanced vegetation component for the CAESAR model	Active
Impact of rip lines on runoff and erosion	Active
Model the geomorphic stability of the landform for up to 10,000 years – finalising long-term rainfall datasets and weathering impacts for the landform.	Active
Site-specific turbidity and suspended sediment relationships, and determining suspended sediment event loads.	Active
Radiation	
Radionuclide uptake in traditional Aboriginal foods	Completed
Atmospheric dispersion of radon and radon daughters from the rehabilitated landform	Active
Dose rates to non-human biota	Active
Environmental fate and transport of Ac-227 and Pa-231	Active
Tissue to whole organism conversion factors for radionuclides in wildlife	Active
Flora and fauna	
Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria	Active
Vegetation analogue review	Active
Developing monitoring methods for revegetation using a UAS: Jabiluka revegetation	Active
Other sites	
Radiation monitoring at the El Sherana containment facility	Active

TABLE 22 LIST OF SUSPENDED RESEARCH PROJECTS AS OF JUNE 2017

Project No.	**Project title**
RES-2005-003	Use of analogue plant communities as a guide to revegetation and associated monitoring of the post-mine landform at Ranger
RES-2008-002	Development and implementation of a remote sensing framework for environmental monitoring within the Alligator Rivers Region (focus on the Magela Floodplain)
RES-2008-006	The direct effects of suspended sediment on tropical freshwater biota
RES-2009-002	The toxicity of uranium to sediment biota of Gulungul Billabong
RES-2009-003	Turbidity closure criteria for off-site billabongs and streams
RES-2009-009	Geological province of fine suspended sediment within the Magela Creek catchment
RES-2010-007	Assessing the geomorphic stability of the Ranger trial landform
RES-2012-014	Optimisation of cladoceran diet for toxicity testing
RES-2013-009	Radionuclide fluxes from the trial landform
RES-2013-012	Demonstrating the utility of unmanned aerial vehicles (UAVs) for monitoring rehabilitation and revegetation of the Ranger minesite
RES-2014-006	East Alligator Slackwater deposits.
RES-2014-009	Spectral investigation of Ranger salts
RES-2015-015	Characterising and mapping salt efflorescences using remotely sensed data

Currently, the draft rehabilitation standards are in various stages of development (Table 23). Drafts for radiation (for humans and wildlife), and uranium, manganese and magnesium in surface waters are essentially complete, while advanced drafts exist for others including ammonia in surface waters, sulfate in surface waters (for acid sulfate soils), landform stability and erosion, and flora. For others, further work is underway or being scoped, to provide the necessary information to complete them.

TABLE 23 PROGRESS OF THE SUPERVISING SCIENTIST'S REHABILITATION STANDARDS AS AT JUNE 2017

Closure theme	Rehabilitation standard	Estimated % completion
Water and sediment	Magnesium (surface water)	95%*
	Uranium and Manganese (surface water)	95%*
	Uranium (sediment)	50%
	Ammonia (surface water)	70%
	Nutrients (surface water)	50%
	Turbidity (surface water) and sedimentation	30%
	Sulfate – acid sulphate soils (surface water)	80%
	Herbicides (surface water)	10%
	Other contaminants of potential concern (surface water)	80%
Landform	Landform – stability and erosion	80%
Flora and fauna	Flora	80%
	Fauna	0%
Radiation	Dose to humans	95%*
	Dose to wildlife	95%*
Soils	Contaminants of potential concern	0%

* Drafts are essentially completed, with stakeholder consultation to commence in early 2017-18.

5.2.2 Water and Sediment Quality

The Water and Sediment Quality (WASQ) team has taken the lead in developing rehabilitation standards for the key contaminants of potential concern for receiving waters, including standards for magnesium, uranium, manganese and ammonia. Other standards are also currently being developed. The standard for magnesium used information from a number of different lines of evidence and active project work undertaken in the reporting period included:

1. Completion of a study of the effects of magnesium on macroinvertebrate communities of minesite waterbodies;
2. An initial analysis of the effects of magnesium on phytoplankton and zooplankton communities in mesocosm tubs (a study conducted in 2002); and
3. Toxicity of contaminated waters from Gulungul Creek Tributary 2 in 2015 and 2016.

The rehabilitated landform will contribute surface water runoff and groundwater egress to adjacent Magela Creek containing elevated concentrations of magnesium sulfate. To assess the potential impacts of this contamination on the Magela sand channels, work commenced in 2016 to characterise water quality and biota of the subsurface sands of the creek. An internal report

has been drafted describing results of the pilot study and this will guide further work carried out in 2017.

The PhD project that is developing acute and chronic toxicity tests using local freshwater mussels is progressing well. Standard acute and chronic toxicity test protocols have been developed and acute toxicity estimates for ammonia have been derived using larval mussels (glochidia). The chronic toxicity of ammonia to the mussels is currently being determined. A small side-investigation has also indicated that two different species of freshwater mussels are resident in Magela Creek sand channel and adjacent Mudginberri Billabong. The sensitivity of the different species to toxicants will be assessed.

Finalisation of the water quality guideline value (GV) for ammonia was placed 'on hold' in order to include the chronic toxicity estimate for the freshwater mussel. Due to the potential high sensitivity of freshwater mussels to ammonia, and cultural importance of this species to Aboriginal people living in the region, it was deemed necessary to include this information in the final GV. A project that aimed to validate algorithms developed by the United States Environment Protection Agency used to adjust ammonia GVs depending on pH and temperature is nearing completion.

An article describing the recent revision of the site-specific GV for uranium was published in the journal *Integrated Environmental Assessment and Management*. The paper includes the scientific justification for the revision of the site-specific uranium GV to 2.8 μg/L U and describes how the value can be adjusted to account for environmental concentrations of Dissolved Organic Carbon, a key toxicity-modifying factor. The revised GV was adopted as the statutory limit for Magela and Gulungul creeks in late 2015.

5.2.3 Revegetation and Landform

The Revegetation and Landform (R&L) team has an Unmanned Aerial Vehicle (UAV) Operator's certificate from the Civil Aviation Safety Authority (CASA), which is valid for three years. The certificate enables the team to apply to fly within three nautical miles of Jabiru airfield. Two members of the team are currently undertaking studies through CASA to be granted Beyond Visual Line of Sight qualifications for routine operations.

More recently, R&L has acquired a heavy lift drone (currently 25 kg take-off weight) with a LiDAR sensor integrated to capture high resolution elevation data, which will be used to monitor landform erosion and potential gully formation. R&L is also currently upgrading a number of our fixed wing platforms.

Routine monitoring flights have continued at Jabiluka to develop methods for assessing revegetation. Routine flights have been undertaken at the Ranger Trial Landform to assess long-term ecosystem establishment and to develop associated monitoring metrics.

The analysis of the descriptive statistics for assessing long-term landscape variability in the surrounding environment is near completion. The associated work to examine causes of the landscape change has been deferred to the next financial year.

The write-up and publication of the Ranger rehabilitation ecological risk assessment have been delayed due to higher priority work, including the development of a rehabilitation standard for revegetation.

The investigation into the effect of riplines on controlling erosion on a rehabilitated surface is being finalised. Final analysis of a range of simulation scenarios using the CAESAR-Lisflood Landform Evolution Model (LEM) has been completed, and the study is currently being prepared as an internal report, with peer-reviewed publications to follow.

Professor Tom Coulthard (University of Hull) has developed an enhanced vegetation growth component for the CAESAR-Lisflood LEM based on local vegetation growth and development data. This enables model simulations to better reflect the effect of a developing plant community on the erosion and geomorphic stability of the Ranger rehabilitated landform. Testing and calibration of this component is underway. An internal report documenting the data, and procedures used to generate the data, used as inputs to the model development has been completed.

The R&L team has continued to apply the long-term rainfall datasets developed by Associate Professor Greg Hancock and Dr Danielle Verdon-Kidd (University of Newcastle) to assess the geomorphic stability of the Ranger rehabilitated landform. Recent analysis has focussed on the long-term effect of extreme wet and extreme dry rainfall scenarios to the landform. A peer-reviewed paper relating to the development and use of synthetic rainfall datasets has been published in the *Journal of Hydrology*, while a further two papers have been accepted by the journals *Science of the Total Environment* and *Global and Planetary Change*.

A collaborative project with Professor Ken Evans (Charles Darwin University), which aims to calibrate the suspended sediment outputs of the CAESAR-Lisflood LEM with field observations to enhance the reliability of CAESAR-Lisflood model predictions, is continuing. Initial results from a Masters project have identified that additional testing is required. An internal report documenting the student's progress is being finalised.

5.2.4 Radiation

The Radiation team has led the development of rehabilitation standards for radiation protection of people and the environment for the Ranger uranium mine. The standards are based on current international recommendations and guidance issued by the ICRP, International Atomic Energy Agency (IAEA) and United Nations Scientific Committee on the Effects of Atomic Radiation.

The Radiation team has collated data and developed tools to estimate ingestion doses from Aboriginal bush foods for the Ranger final landform and surrounding aquatic ecosystems. The work goes towards demonstrating the achievement of radiation closure criteria and rehabilitation standards for the mine. Three papers describing the work have been published in *Journal of Environmental Radioactivity*.

A screening approach has been developed for radium-226 uptake in freshwater mussels based on radium-226, calcium and magnesium concentrations in surface water. The approach can be used to give a site-specific estimate of radium-226 in mussels of a given age class for given water quality ^{226}Ra conditions. The approach can be applied to prospective situations, such as changed water management practices or site rehabilitation, where downstream water quality may be affected, to facilitate dose estimates to Aboriginal people from mussel consumption and estimates of doses to mussels themselves.

Two new electronically cooled high-resolution gamma detectors have recently been commissioned. The new detectors replace the use of liquid nitrogen cooled detectors for routine gamma spectrometry analysis of environmental samples, including freshwater mussels and soils/sediments.

The Radiation team is involved in two working groups of the IAEA Modelling and Data for Radiological Impact Assessments (MODARIA II) scientific programme, which commenced in November 2016 and runs until 2019. One working group focuses on collation and analysis of radioecological data from tropical, sub-tropical and arid environments, while the other focuses on radiation exposures and effects to wildlife. Involvement with these working groups helps ensure that the research of the Radiation team is aligned with world's best practice standards for radiation protection of people and the environment.

5.2.5 Other activities

Research for other sites within the Supervising Scientist's remit has been scaled back to focus on the research needs for the rehabilitation of Ranger. The project developing UAS-based monitoring methods for the Ranger rehabilitation is using the Jabiluka rehabilitated area and, to a lesser extent, the El Sherana radiological containment site in the South Alligator River Valley, as study sites. At present, no research is being undertaken at Nabarlek. This is recognised as a critical gap, and Nabarlek knowledge needs will need to be reviewed at some stage in the future.

The key non-uranium mining related external activity for the reporting period was the involvement of several ERISS staff in the current revision of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

Researchers at ERISS continue to publish their work externally. In 2016-17, approximately 24 peer-reviewed publications were produced from the research program (see Appendix 1).

APPENDIX 1
SUPERVISING SCIENTIST PUBLICATIONS FOR THE PERIOD JULY 2016 TO JUNE 2017

Supervising Scientist 2017. *Annual Technical Report 2015–16*, Commonwealth of Australia 2017.

Bartolo R, Harford AJ, Bollhöfer A, van Dam RA, Parker S, Breed K, Erskine W, Humphrey CL & Jones D 2016. Causal models for a risk-based assessment of stressor pathways for an operational uranium mine. *Human and Ecological Risk Assessment: An International Journal* 23, 685-704.

Boyden JM, Lowry JBC, Coulthard T, Whiteside T, Hancock GR & Grant S 2016. Accounting for Vegetation Dynamics in Landform Evolution Modelling. In: *Life-of-Mine* 2016, Brisbane, Australasian Institute of Mining and Metallurgy, Vol N07/2016 pp 63–58.

Boyden, JM, Wurm, P, Boggs, G, Joyce, KE & Bayliss, P 2016. The distribution and dynamics of para grass (*Urochloa mutica*) on a monsoonal wetland of Kakadu National Park, NT Australia. In: *20th Australasian Weeds Conference,* 11–15 September. R Randall, S Lloyd & C Borger (Eds.). Perth, WA, Weed Society of Australia: p135.

Boyden JM, Saynor MJ & W Erskine 2016. Ranger Trial Landform: Hydrology – Rainfall & runoff data for Erosion Plot 1: 2009–2015. Internal Report 646, August, Supervising Scientist, Darwin.

Boyden JM, Saynor MJ & Rudge M 2016. Ranger Trial Landform: Hydrology – Standard Operating Procedures for Erosion Plot Data. Internal Report 649, October, Supervising Scientist, Darwin.

Doering, C & Bollhöfer, A 2016. A tool for calculating concentration ratios from large environmental datasets. *Journal of Environmental Radioactivity*, 165, 32.

Doering C, Bollhöfer A & Medley P 2017. Estimating doses from Aboriginal bush foods post-remediation of a uranium mine. *Journal of Environmental Radioactivity* 172, 74-80.

Doering C & Bollhöfer A 2017. Water hardness determines 226Ra uptake in the tropical freshwater mussel. *Journal of Environmental Radioactivity* 172, 96-105.

Erskine WD, Saynor MJ, Boyden JM & Evans KG 2017. Sediment fluxes and sinks for Magela Creek, Northern Territory, Australia. *Marine and Freshwater Research*, DOI: 10.1071/MF16107.

Erskine WD, Saynor MJ & Lowry JBC 2017. Application of a new river classification scheme to Australia's tropical rivers. *Singapore Journal of Tropical Geography*, 38, pp167-184

Hancock GR, Coulthard TJ & Lowry JBC 2016. Use of Landform Evolution Models to Assess Uncertainty in Long-term Evolution of Post-mining Landscapes. In: *Life-of-Mine* 2016, Brisbane, Australasian Institute of Mining and Metallurgy, Vol N07/2016 pp 67-70.

Hancock GR, Lowry JBC & Coulthard TJ 2016. Long-term landscape trajectory – Can we make predictions about landscape form and function for post-mining landforms*? Geomorphology*, 266, pp121–132.

Hancock GR, Lowry JBC & Saynor MJ 2016 Early landscape evolution — A field and modelling assessment for a post-mining landform. *CATENA*, 147, pp. 699–708.

Hancock GR, Lowry JBC & Dever C 2017. Surface disturbance and erosion by pigs – a medium term assessment for the monsoonal tropics. *Land Degradation and Development.* 28(1) pp 255-264 DOI: 10.1002/ldr.2636.

Hancock GR, Lowry JBC & Saynor MJ 2017. Surface armour and erosion – impacts on long-term landscape evolution. *Land Degradation and Development.* Article DOI: 10.1002/ldr.2738.

Hancock GR, Verdon-Kidd D & Lowry JBC 2017. Sediment output from a post-mining catchment – Centennial impacts using stochastically generated rainfall. *Journal of Hydrology*, 544 pp 180–194.

Hancock GR, Verdon-Kidd D & Lowry JBC 2017. Soil erosion predictions from a landscape evolution model – an assessment of a post-mining landform using spatial climate change analogues. *Science of the Total Environment* 601-602, pp. 109-121

Lowry JBC, Verdon-Kidd D, Hancock GR & Saynor MJ 2016. Application of Synthetic Rainfall Data to Long Term Modelling of a Rehabilitated Landform. In: *Life-of-Mine* 2016, Brisbane, Australasian Institute of Mining and Metallurgy Vol N07/2016 pp 75–79.

Medley P 2016. Pb-210 determination using liquid scintillation counting (LSC). Internal Report 627, November, Supervising Scientist, Darwin.

Medley P, Doering C, Evan F & Bollhöfer A 2017. Natural radionuclides and stable elements in weaver ants (*Oecophylla smaragdina*) from tropical northern Australia. *Journal of Environmental Radioactivity.* DOI 10.1016/j.jenvrad.2017.05.003

Saynor MJ & Erskine WD 2016. Bed Load losses from Experimental Plots on a Rehabilitated Uranium Mine in Northern Australia. In: *Life-of-Mine* 2016, Brisbane, Australasian Institute of Mining and Metallurgy, Vol N07/2016 pp 168–171.

Saynor M & Erskine W 2016. Morphodynamic changes caused by Cyclone Monica in April 2006 on Ngarradj Creek, Northern Territory, Australia. *International Journal of Research in Engineering and Science* (IJRES), 4 (12), pp 80–86.

Sutcliffe B, Chariton AA, Harford AJ, Hose GC, Paul G, Elbourne LD, Oytam Y, Stephenson S, Midgley DJ & Paulsen IT 2017. Effects of uranium concentration on microbial community structure and functional potential. *Environmental Microbiology*. In press.

Trenfield MA, van Dam JW, Harford AJ, Parry D, Streten C, Gibb K & van Dam RA 2017. Assessing the chronic toxicity of copper and aluminium to the tropical sea anemone *Exaiptasia pallida. Ecotoxicology and Environmental Safety*. 139, 408–415.

van Dam JW, Trenfield MA, Harries SJ, Streton C, Harford AJ, Parry D & van Dam RA 2016. A novel bioassay using the barnacle Amphibalanus amphitrite to evaluate chronic effects of aluminium, gallium and molybdenum in tropical marine receiving environments. *Marine Pollution Bulletin* 112, 427–435.

van Dam RA, Hogan AC & Harford AJ 2017. Development and implementation of a site-specific water quality limit for uranium in a high conservation value ecosystem. *Integrated Environmental Assessment and Management* 13, 765–777.

Warne M St J, van Dam RA, Batley G & Stauber J 2017. Response to Buchwalter et al. Further considerations for modernizing water quality criteria in the United States and elsewhere. *Environmental Toxicology and Chemistry* 36, 1422–1424.

Zawadzki A, Cook M, Cutmore B, Evans F, Fierro D, Gedz A, Harrison JJ, Loosz T, Medley P, Mokhber-Shahin L, Mullins S & Sdraulig S 2017. Comparison of radium-228 determination in water among Australian laboratories. *Journal of Environmental Radioactivity*. DOI 10.1016/j.jenvrad.2017.05.012

APPENDIX 2 SUMMARIES OF RESEARCH PROJECTS ACTIVE OR COMPLETED IN 2016–17

RANGER–OPERATIONAL PHASE (AND DECOMMISSIONING)

1 Research (5 projects)

2 Monitoring (0 projects)

RANGER - REHABILITATION

1 Closure criteria theme: Overarching (1 project)

2 Closure criteria theme: Water and sediment (10 projects)

3 Closure criteria theme: Landform (8 projects)

4 Closure criteria theme: Radiation (5 projects)

5 Closure criteria theme: Flora and fauna (3 projects)

6 Closure criteria theme: Groundwater (3 projects)

OTHER SITES

1 Research (0 projects)

2 Monitoring (1 project)

RANGER

Operational phase (and decommissioning)

1 Research

2 Monitoring

Ranger – Operational phase (and decommissioning)

Research projects (5 projects)

Project details					
Project title	Developing videography-based methods for monitoring fish communities				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Development of a replacement observational method for SSB's channel billabong fish community study, based on improved WH&S.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 2	**Time-frame**	1
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2013-016	**Project commencement date**		1/3/2013	
		Estimated completion date		10/6/2019	
Project duration (months)	36	**Date required**		30/6/2019	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	WASQ	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	CDU				
Project manager	Mooney, Tom	**Project total estimated internal resources (person weeks)**		20	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**		100	

Aims

- To develop a quantitative and easily-repeatable fish monitoring method, using remote cameras, that will replace the current visual census method used in channel billabongs (MON-1989-001), the latter approach having significant (crocodile) safety concerns.
- To compare the fish community structure data from the former visual and new video methods for fish observations in suitable clear-water, crocodile-free, locations in Kakadu National Park and elsewhere.

Background

For monitoring and assessment of potential mine-related changes to biodiversity downstream of Ranger, an annual visual fish monitoring technique has been conducted in two channel billabongs by SSB since 1994 (MON-1989-001). This method employed a small custom-made boat with a clear Perspex dome, in which an observer lay to identify and count fish. While this method has produced a valuable long-term dataset of fish community structure along the littoral margins of the channel billabongs, the risk of crocodile attack associated with this technique has increased in recent years. Since a larger (unwieldy) replacement boat is not a suitable option for the habitats sampled, underwater videography has been identified as a potential alternative technology.

Initial research and development was conducted in channel and shallow lowland billabongs of the ARR in 2015 to assess different cameras and relative locations of the cameras (near-surface, benthic, littoral and central channel). These findings have guided decisions for work conducted since 2016. In July 2016, videography was undertaken in the same two channel billabongs surveyed since 1994, placing near-surface and benthic cameras along six transects in each billabong. The full imagery is currently being analysed in order to derive the necessary subset of data required for the same paired-billabong comparisons as used for the previous method. Comparative (side-by-side) observer-based and videographic imagery will be sought in 2017 to assess the implications of the change in methodology.

Progress against plan

- Fish videography fieldwork to replace the previous visual census method commenced in July 2016, following trials in 2015 to determine suitable camera types for ongoing deployment. The design imitated that of the previous method, utilising five existing 50 meter transects at both Mudginberri (exposed) and Sandy (control) billabongs, an additional 50 meter central transect, and deploying ten GoPro cameras at five meter intervals for each transect. The cameras were orientated for surface or benthic deployment (five of each) and set to record for 1 hour and 30 minutes each.
- Channel Billabong fish videography surveys were successfully completed in May 2017. SSB staff are currently being trained in fish identification and counting metrics for videography and the collection of data from the 2017 videos is currently underway.
- Field work for the videography method validation study has been completed. This involved conducting side-by-side fish surveys using both the visual census and the videography methods in crocodile-free environments (Gunlom and Edith falls) in July 2017. Data from these surveys will be analysed in late 2017 by Charles Darwin University.

Key findings

- Results of the 2015 pilot study provided in the draft report (King et al. 2016) recommended the GoPro Hero4 camera for future deployment as it provided: value for money, ease of replicating/replacing equipment, reasonably good image quality and field of view, diverse deployment options, best for capturing movement and use for patchy light conditions.
- The draft report (King et al. 2016) also recommended the most suitable method for both billabong types was stationary, unbaited cameras, in either surface or benthic orientation, as

this provided: no bias towards 'bait-friendly' fishes, less attraction for predators such as crocodiles, greater species richness and total abundance than moving cameras, less operator bias in sampled habitat, less fouling in dense vegetation, option for sampling multiple habitat types at once, ability to sample at depths previously out of view from visual census, and increased detection of 'shy' or 'flighty' species.

- A further eight specific recommendations for SSB for direction of future research were provided in the draft report. These findings, along with further discussions with CDU, helped inform SSB on a suitable methodology for replicating the fish community observations in the channel billabongs monitoring project (MON-1989-001) for ensuing wet seasons.
- Analysis of the 2016 channel billabong data determined the optimal video length to be 60 minutes. This was the shortest video length at which most species present were recorded. Overall results from the 2016 channel billabong monitoring are reported in the Environmental Monitoring section of the 2016-17 Annual Technical Report.

Workplan for 2017–18

- June-July 2017: Collect imagery from Mudginberri and Sandy billabongs using the same design as 2016 (basis of continuing monitoring technique). (Depending upon recessional flow conditions this imagery may be collected earlier than July 2017).
- July 2017: Undertake side-by-side comparisons of the two monitoring techniques in crocodile-free locations (Gunlom, Barramundie Gorge, Edith Falls).
- August-October 2017: Responsible staff will undertake fish identification training and learn the appropriate methods for the analysis of videography data.
- October-December 2017: Prepare data for subsequent reports and publications.

Planned project outputs and associated outcomes

The primary outputs for this project are reports providing a Standard Operating Protocol (SOP) for continuing videographic-based fish monitoring in channel billabongs, and outlining the results of the observer-based and videographic technique comparisons.

The project outcome is the establishment of a replacement monitoring method to that used previously, to enable continued public assurance of environmental protection associated with mining at Ranger.

Planned communication activities

The primary communication activities for the project are:

- Annual update of monitoring results on the Supervising Scientist website
- Annual reporting of results in the Supervising Scientist Annual Technical Report
- Reports and presentations for ARRTC and ARRAC meetings

Project publications to date (if applicable)

King, A.J., George, A., Buckle, D. and Novak, P. (2016). Developing remote underwater video camera techniques for monitoring fish communities in wetlands of the wet/dry tropics. Unpublished technical report. Charles Darwin University and the Department of the Environment's Environmental Research Institute of the Supervising Scientist (ERISS).

Project details					
Project title	Desktop assessment of historical WET data to evaluate multiple single toxicant water quality limits (including the Mg Limit)				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Completed		
What business need does this project inform?	Informs the water quality Guideline Values, especially Mg, at different Mg:Ca ratios.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame** 2	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	RES-2015-018	**Project commencement date**	1/3/2015		
		Estimated completion date	30/6/2017		
Project duration (months)	6	**Date required**	1/12/2016		
In-house or outsourced	Internal	**Actual completion date**	30/6/2017		
Lead team	WASQ	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	N/A				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**	12		
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**	0		

Aims

- To collate historical chemistry data from on-site and off-site water bodies and groundwater to determine patterns in Mg:Ca ratios (and, if possible, other patterns in major ions) in the waters from the Magela Creek catchment.
- To collate historical pre-release biological toxicity testing data for Ranger mine waters to determine any patterns in U and Mg toxicity to local freshwater species at particular Mg:Ca ratios.

Background

To date, ERISS has produced site-specific water quality Guideline Values (GVs) for the key contaminants of potential concern (COPCs) from the Ranger mine, i.e. uranium (U), magnesium

(Mg) and manganese (Mn). A GV for ammonia is in the process of being derived. The COPCs have been assessed individually. However, modelling from Pit 1 and 3 shows that contaminated groundwater will reach surrounding creeks and billabongs as a mixture of these contaminants. Hence, a key question remains to be answered: are the single contaminant GVs protective of the environment for mixtures of the COPC?

Guidance from the ANZECC and ARMCANZ (2000) recommends that where five or less significant contaminants are present then an additive calculation (i.e. sum of toxic units approach) can be used to predict toxicity, so long as the toxicity is not known to be more than additive or non-additive. In cases where there is uncertainty, Direct Toxicity Assessments (DTA) are recommended. However, over many decades numerous studies have aimed to predict if contaminant mixtures result in less-than-additive, additive or more than additive effects. Reviews of these studies have concluded that there is no clear pattern that would allow quantitative, or even qualitative, prediction of the effect of contaminant mixtures (Meyer et al 2015). Consequently, this project is needed to provide assurance that the GVs will protect the environment.

Progress against plan

- Historical chemistry data from 2010-2016 have been collected from ERA, the Supervision and Monitoring group and from the Aquatic Ecosystem Protection Program.
- Historical toxicity data from 23 whole effluent toxicity tests conducted from 1983 to present have been collated and initial analyses undertaken. These tests represent 13 different sets of DTAs using 13 different batches of water.
- Toxicity and chemistry data were presented at ARRTC.
- Toxicity of the DTA mixtures was assessed against known toxicity of the single toxicants, U, Mg and Mn, to determine, in the case of each water type, which metal could be attributed to causing toxicity.
- Multivariate analyses were performed on the site chemistry data to group the sites according to chemistry.

Key findings

- Summary of chemistry data determined that an average Mg:Ca ratio on site is approximately 5:1, although for process water this is 13:1-23:1. For Magela and Gulungul creeks, the ratio is 2-3:1.
- Only minimal sections of the toxicity data could be reanalysed and used, but indicated that in all cases the toxicity observed in the DTAs (RP2, Pit 3 and Djalkmara) was due to U and not Mg or Mn. Site groupings of specific water qualities have been determined, which will be used to assist in the selection of sites for DTA testing in a subsequent project.

Workplan for 2017–18

- Desktop analyses are complete
- Further writing to communicate results via journal publication

Planned project outputs and associated outcomes

- The analysis of the historical DTA data will be included in an appendix of the IR on the GCT2 toxicity assessment conducted in 2015.
- The results of the analyses will contribute to the understanding of the toxicity of mine water mixtures at Ranger, and what this means for operational water quality objectives and rehabilitation closure criteria.

Planned communication activities

- A summary of these data was included in a presentation to ARRTC
- Data are included in an Internal Report on the GCT2 study and a journal publication is in progress

Project publications to date (if applicable)

Trenfield M, Harford A, Mooney T, Ellis M, Humphrey C and van Dam R. 2017. Toxicity of contaminated waters from Gulungul Creek Tributary 2 in 2015 and 2016. Internal Report 652, July, Supervising Scientist, Darwin.

Project details					
Project title	Genomics-based identification of freshwater macroinvertebrates to species level				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Optimising SSB's stream monitoring program				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 2	**Time-frame** 3	
			Importance 3	**Time buffer** D	
Project number (if already commenced)	RES-2015-019	**Project commencement date**	1/4/2015		
		Estimated completion date	31/12/2026		
Project duration (months)	60	**Date required**	30/6/2018		
In-house or outsourced	Collaboration	**Actual completion date**	N/A		
Lead team	WASQ	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	MQU/NTG				
Project manager	Hanley, Julie	**Project total estimated internal resources (person weeks)**	36		
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**	15		

Aims

- To build a baseline DNA barcode library for freshwater macroinvertebrate species from ARR streams, commencing with caddisflies (Trichoptera), mayflies (Ephemeroptera) and non-biting midges (Diptera: Chironomidae).
- To test and trial this barcode database for species-level identifications arising from samples gathered in monitoring programs.

Background

Macroinvertebrate communities are the most commonly employed biological monitoring group for freshwater ecosystems, including monitoring and assessment of potential mining impacts in the ARR. An ongoing impediment to their use is the labour-intensive processing of samples and accurate identification of the constituent fauna. Emerging genetic techniques in monitoring

(eDNA, ecogenomics) offer vastly improved and cost effective approaches to deriving accurate, species-level information for macroinvertebrate samples, and there are moves worldwide to undertake the necessary R&D to build regional baseline DNA barcode libraries. This library provides the basis for determining the composition of fauna in collected samples, using suitable new generation genomic technologies. Preliminary discussions have been undertaken amongst SSB, NT Government and Macquarie University researchers to pilot a proof of concept using two freshwater insect orders, caddisflies (Trichoptera) and mayflies (Ephemeroptera), and Dipteran family, Chironomidae. Material for this study is being drawn from NT Top End streams, including the ARR.

At this stage, SSB's main contribution to the study is provision of material for genetic analysis.

Progress against plan

- SSB, Macquarie University and NT Government researchers have held meetings to coordinate and integrate information needs.
- A collaborative consultancy partnership between SSB and Macquarie University is being developed.

Key findings

There are no key findings to date.

Workplan for 2017–18

- With collaborators from Macquarie University and NT Government, develop a regional, baseline DNA barcode library for freshwater NT invertebrates.
- Provide material for genetic analysis.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Initial proof of concept, development of a regional, baseline DNA barcode library for caddisflies (Trichoptera), mayflies (Ephemeroptera) and non-biting midges (Diptera: Chironomidae).

The outcomes that this project will achieve are cost effective approaches to sample processing and identification of freshwater macroinvertebrate species used as indicators of water quality in the ARR.

Planned communication activities

The primary communication activities for the project are:

- Reports to ARRTC and ARRAC
- SSB / Science Division website updates

Project publications to date (if applicable)

There are no publications to date.

Project details					
Project title	Toxicity of ammonia and other key COPCs to freshwater mussels				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Informs the ammonia surface water quality limit for operations, as well as the rehabilitation standards for COPCs generally.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2015-025	**Project commencement date**		1/9/2015	
		Estimated completion date		1/7/2019	
Project duration (months)	12	**Date required**		31/01/2018	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	WASQ	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	RMIT University				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**		30	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		0	

Aims

The aims of this project are as follows:

- Complete the collation and review of available information on freshwater mussel culturing and toxicity testing.
- Collect *Velesunio* spp. mussels and develop a culturing method for this species (larvae and juvenile stages).
- Develop standardised acute and chronic test methods for this species.
- Conduct ammonia toxicity testing using this species and publish results.
- Conduct toxicity testing with other COPCs.

Background

An assessment of ammonia toxicity is currently underway in order to develop a site-specific water quality Guideline Value (GV) for the Ranger uranium mine. An interim ammonia GV was developed using toxicity estimates from international species with adjustments made for site-specific pH and temperature conditions. In a preliminary review of all the Genus Mean Chronic Values collected by the USEPA (USEPA 2013), *Lampsilis* and *Vilosa* (both genera of freshwater mussel) were the most sensitive to the effects of ammonia. Unionid mussel feeding includes filtration of surface and pore water, suspended sediment, and sediment-associated fine particles, which may increase their exposure to ammonia in their surrounding media (Augspurger et al. 2003). Two species of freshwater mussels are present downstream of the Ranger uranium mine and are important bushtucker of the Mudginberri Aboriginal community. Thus, it was identified that ammonia toxicity should be assessed using these species. Toxicity estimates from local mussel species will be incorporated into a site-specific Species Sensitivity Distribution, allowing for the derivation of a GV and thereby ensuring the protection of freshwater mussels as well as other species.

This project is being carried out by PhD student, Linda Kleinhenz (RMIT University), using external funding. The toxicity test protocol will also be used for an assessment of the effects of uranium (U) and magnesium (Mg) on freshwater mussels. If time allows, it may also include the effect of key toxicity modifying factors, e.g. the amelioration of Mg toxicity by calcium (Ca).

Progress against plan

- *Velesunio* spp. broodstock have been collected from multiple local creek and billabong sites. Toxicity testing has been carried out with *Velesunio* larvae and ammonia using the acute test method, while 6 chronic exposure tests to ammonia have also been conducted using newly-metamorphosed juveniles.
- A study on genetic diversity of *Velesunio* spp. has been conducted.
- A journal paper describing the acute toxicity test method is being edited by co-authors. Journal papers describing the genetic work and the chronic test method are being drafted.

Key findings

- Local *Velesunio* mussel species are relatively sensitive to copper and ammonia. Exposure of larvae to 6-7 ug/L copper for 24 h resulted in a 50% reduction in survival (referred to as a Lethal concentration: LC50). Copper is used as a reference toxicant with which to compare to international toxicity data.
- Larvae are also sensitive to ammonia with a 24-h LC50 of 7 mg/L TAN. Larvae have not yet been tested with other contaminants.
- Juvenile mussels are less sensitive than the larvae and show a 50% reduction in growth when exposed to ammonia at 7-12 mg/L TAN. Genetic analyses show that what was thought to be a single mussel species is actually at least 2 different species which in early studies are showing differences in sensitivity.

Workplan for 2017–18

- 2017: Toxicity testing of COPCs (ammonia, U, Mg and Mn). Writing up and publication of results.
- 2018: Publication and thesis writing.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Standard Operating Protocols (SOPs) for acute and chronic toxicity tests using larvae and juveniles of freshwater mussels, *Velesunio* spp.
- Toxicity data for mine-related contaminants such as ammonia, U, Mn and Mg.
- At least four journal papers and a PhD thesis.

The outcome of this project is increased confidence in site-specific GVs, which are used to inform operational water quality limits and closure criteria for rehabilitation.

Planned communication activities

The primary communication activities for the project are:

- Four journal papers covering different aspects of the project
- An oral presentation at a conference each year over the course of the project
- Contributions to Supervising Scientist Annual Technical Report
- Reports/presentations as necessary to ARRTC and other key stakeholders
- Research updates to the university involved (RMIT)

Project publications to date (if applicable)

Kleinhenz L, Nugegoda D, Trenfield MA, Harford AJ & van Dam RA 2016. Development of an acute and chronic toxicity test for the freshwater mussel *Velesunio angasi* and an assessment of ammonia toxicity. Proceedings of the 4th SETAC – Australasia Conference, 4-7 October 2016, Hobart, Australia.

Project details					
Project title	Developing a short-term chronic toxicity test for the fish, *Mogurnda mogurnda*				
SSB function	Research	**Site**	Other		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Improves the accuracy of fish toxicity estimates used in deriving all local water quality Guideline Values.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance**	2	**Time-frame** 1/ongoing
			Importance	2	**Time buffer** A
Project number (if already commenced)	RES-2015-028	**Project commencement date**			1/6/2015
		Estimated completion date			30/6/2017
Project duration (months)	6	**Date required**			1/1/2018
In-house or outsourced	Internal	**Actual completion date**			1/12/2017
Lead team	WASQ	**Reason for project delay (where applicable)**			Further testing required to finalise 28d protocol. Some writing and testing expected in 17-18
Supporting team(s)	N/A				
Project manager	Pease, Ceiwen	**Project total estimated internal resources (person weeks)**			10
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**			0

Aims

Develop a short term (7 d) chronic toxicity test for *Mogurnda mogurnda* incorporating sub-lethal (growth) endpoints and compare the sensitivity of this test to the 4-d acute survival test and the 28-d growth test using key COPCs.

Background

In the ERISS ecotoxicology laboratory, a suite of local species has been routinely used to derive water quality GVs for two creeks adjacent to Ranger uranium mine - Magela and Gulungul creeks - in Kakadu National Park. The current routine toxicity test for the Northern Trout Gudgeon,

Mogurnda mogurnda, is an acute 96-h exposure (using a survival endpoint). This test is typically a less sensitive indicator of toxicity than the chronic tests used for the other species in the suite. The acute data generated from this test are not ideal for water quality GV derivation as they do not represent the long term effects of the contaminant within the environment. Thus, there was a need to update the current method to a cost-effective, chronic test based on sub-lethal endpoints.

A 28 day chronic toxicity test for *M. mogurnda* was previously developed using length and weight as sub-lethal endpoints (Cheng et al., 2010). This test detected responses to uranium (U) at lower concentrations than the acute test and found that dry weight was the most sensitive sub-lethal endpoint. The present project aims to develop a chronic toxicity test, specifically, a 7 d larval growth toxicity test, as this is the minimum test duration required for a test to be considered chronic in Australia and New Zealand (Batley et al., 2014, Warne et al., 2015).

Progress against plan

- A test method has almost been completed with some refinements to the feeding method required to enhance growth rates.
- Acceptability criteria for initial fish size and also growth rate have been established.
- Two toxicity tests have been performed using ammonia and three using uranium. Testing is currently underway applying the new method for Direct Toxicity Assessments (DTAs) of minesite water. The 7-d test will be compared with a 28-d test in Magela Creek water to determine whether the longer exposure time is more sensitive.

Key findings

A chronic sub-lethal toxicity test method has been successfully developed for *M. mogurnda*. The sensitivity of this method will be compared to a revised version of the 28-d method developed by Cheng et al. (2010).

Workplan for 2017–18

Final testing and report writing is expected in 2017-18.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A routine chronic sub-lethal toxicity test for the fish, *M mogurnda.*
- An Internal Report and subsequent peer-reviewed journal paper describing the new methodology.

The outcomes of this project will be an improved toxicity testing program for assessing the sub-lethal effects of contaminants on local aquatic biota and, hence, improved site-specific water quality guideline values.

Planned communication activities

The primary communication activities for the project are:

- Presentation at the annual SETAC Australasia conference

- A peer reviewed journal article
- Reports/presentations to key stakeholders as appropriate

Project publications to date (if applicable)

No publications to date.

RANGER

Rehabilitation

1 Closure Criteria theme: Overarching

2 Closure Criteria theme: Water and sediment

3 Closure Criteria theme: Landform

4 Closure Criteria theme: Radiation

5 Closure Criteria theme: Flora and fauna

6 Closure Criteria theme: Groundwater

Ranger – Rehabilitation

CC theme: Overarching (1 project)

Project details					
Project title	Cumulative risk assessment for Ranger minesite rehabilitation and closure - Phase 1 (on-site risks)				
SSB function	Research	**Site**	Ranger		
Project category	Rehabilitation - overarching	**Project status**	Active		
What business need does this project inform?	This project informs the need to determine the integration and potential cumulative impacts of risks identified through the risk screening component of the ecological risk assessment. The focus in this phase of the project is on-site risks.				
Closure criteria theme (if applicable)	Overarching	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2016-014	**Project commencement date**		2/2/2017	
		Estimated completion date		11/12/2017	
Project duration (months)	11	**Date required**		19/12/2017	
In-house or outsourced	External	**Actual completion date**		N/A	
Lead team	R&L	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	WASQ, CSIRO, Dave Walden				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**		16	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		40	

Aims

- Determine the most appropriate methodology for undertaking a quantitative assessment of cumulative ecological risks for the rehabilitation and closure of RUM.
- Identify and catalogue datasets that will be used in the risk assessment.
- Develop an agreed conceptual model and supporting narrative to undertake a Quantitative Ecological Risk Assessment (QERA) for the rehabilitation and closure of RUM that addresses cumulative risks.

- Undertake Qualitative Modelling (QM) on the conceptual models developed through the rehabilitation and closure ecological risk assessments to date.
- Complete a QERA for the on-site (revegetation, landform and contaminants) risks.

Background

The screening level ecological risk assessment for Ranger rehabilitation and closure focussed on the risks of multiple individual stressors in isolation of other stressors, to the environment and, in the case of chemical and radiological contaminants, humans also. However, stressors typically co-occur in the environment and have the potential to interact with each other. Consequently, the risk assessment needs to be extended to characterise the cumulative risks of multiple stressors including their interactions.

Cumulative risk assessment is defined by the United States Environmental Protection Authority as "an analysis, characterisation, and possible quantification of the combined risks to health or the environment from multiple agents or stressors". Cumulative risk is further defined as "the combined risks from aggregate exposures to multiple agents or stressors". Key aspects framing the use of cumulative risk assessment include:

- Cumulative risk assessment does not have to be quantitative (as long as it meets other requirements).
- The combination of risks from multiple agents or stressors must be combined, but it does not necessarily mean the risks are additive. Some analysis should be undertaken to determine how risks interact.

Initial examination of the conceptual causal models and risk screening results indicated that the primary focus of the QERA, at least in the first instance, should be on rehabilitation and closure risks associated with landform development/stabilisation and revegetation, and the interaction between the two. Other components of rehabilitation risk, such as on-site and off-site water quality as affects in situ and downstream aquatic and terrestrial ecosystems, respectively, will be assessed after completion of a minesite surface water model currently being developed by ERA.

Progress against plan

- Milestone report completed detailing statistical and quantitative risk modelling methods and summarising associated literature and data collation. A high-level conceptual model for on-site rehabilitation was also produced that links risks to landform development and revegetation, and associated contaminant risks.
- Searchable database established containing key datasets and literature to be used in the quantitative modelling.

Key findings

An Agent-Based Modelling framework is an appropriate method for the quantitative assessment because it can integrate a range of risk analyses and system modelling approaches at multiple spatial and temporal scales and can be readily updated with new research and knowledge.

Workplan for 2017–18

- Qualitative Modelling (QM) workshop facilitated by Jeff Dambacher from CSIRO (August 2017).

- Complete and report on the QERA - provision of final risk assessment report (December 2017).

Planned project outputs and associated outcomes

Project outputs are:

- Report on the most appropriate methodology for undertaking the quantitative assessment of cumulative ecological risks at RUM.
- Report on the identification and cataloguing of datasets identified for use in the risk assessment.
- Agreed conceptual model for integrated risk.
- Report on QERA for on-site risks at RUM during rehabilitation and closure.

There are multiple outcomes from this project. The two immediate outcomes are:

- Identifying interactions between risks and how this can affect risks as a whole. Interactions between risks have the potential to change the profile of risks, for example, moving a low or moderate risk to a high risk.
- As a result of such findings, identification of knowledge gaps and prioritisation of research.

Other longer term outcomes from the project include the ability to use the cumulative risk assessment to undertake scenario testing and adaptive management.

Planned communication activities

- Presentation to ARRTC
- Supervising Scientist Branch Coffee Break seminar presentation
- Relevant communication products for the different stakeholder groups, developed with the Public Assurance and Advice team

Project publications to date (if applicable)

Bayliss P 2017. Cumulative Ecological Risk Assessment (CERA) for the Rehabilitation and Closure of Ranger Uranium Mine: Phase 1 milestone report.CSIRO. Unpublished paper.

Ranger – Rehabilitation

CC theme: Water and sediment (10 projects)

Project details						
Project title	Billabong macroinvertebrate responses to mine-derived solutes					
SSB function	Research	**Site**	Ranger			
Project category	Developing closure criteria	**Project status**	Active			
What business need does this project inform?	A line of evidence informing closure criteria for $MgSO_4$					
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance**	1	**Time-frame**	1/ongoing
			Importance	1	**Time buffer**	A
Project number (if already commenced)	RES-2005-002	**Project commencement date**			1/5/2006	
		Estimated completion date			25/6/2017	
Project duration (months)	120	**Date required**			30/6/2017	
In-house or outsourced	Internal	**Actual completion date**			N/A	
Lead team	WASQ	**Reason for project delay (where applicable)**			Competing priorities	
Supporting team(s)	N/A					
Project manager	Chandler, Lisa	**Project total estimated internal resources (person weeks)**			0	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**			0	

Aims

- Quantify macroinvertebrate community structure across a gradient of mine-related water quality disturbance in ARR lentic waterbodies.
- Determine a threshold response to Mg that would be protective of assemblages and thereby serve as a line of evidence contributing to closure criteria for this contaminant.

Background

Biological effects data provide the basis for deriving water quality guideline and closure criteria values for protection of aquatic ecosystems from Ranger mine wastewaters. Criteria based upon

field effects data offer a complementary approach to those derived from laboratory toxicity testing, and when confounding by stressors or environmental variation unrelated to the contaminant of concern is minimised, can incorporate environmental realism not possible from laboratory-based criteria. The present study has been underway since 2006 and aims to inform closure criteria for magnesium based upon field-effects data, specifically, macroinvertebrate community data from lentic onsite, mine water-exposed and offsite reference waterbodies. Initially, the work focused on Georgetown Billabong, a Ranger onsite waterbody that had until recent years (~2009) received only mildly contaminated mine wastewaters. Closure criteria were to be based upon that water quality supporting 'no effects'. Since 2013, the study has expanded to include the full mine water-contaminated gradient available in Djalkmara (1995 and 1996), Coonjimba, Georgetown and Retention Pond 1, for the period 1979 to 2013. Analysis of the full dataset, including data gathered concurrently from reference waterbodies, has been completed. Adverse biological effects are evident at Mg concentrations at or less than 5 mg/L, supporting the conservative laboratory value (of 2.5 mg/L mg).

Progress against plan

- Analysis of the full macroinvertebrate dataset from lentic waterbodies (exposed and reference) was completed in June 2016, to derive a Mg value protective of ecosystems.
- A draft Supervising Scientist Report has been externally reviewed, and authors are attending to the reviewers' comments.
- The results have been incorporated with other laboratory and field evidence in a weight of evidence evaluation to derive a Mg rehabilitation standard for Ranger minesite closure.

Key findings

- Using biological monitoring data from the 34-year record, 1% effect concentrations for magnesium based on macroinvertebrate community structure and taxa number were 5.6 mg/L and 3.9 mg/L, respectively.
- This work indicated that magnesium toxicity at the community level was not reduced by the presence of calcium. Thus, the field studies indicated that higher guideline values for magnesium should not be set on the basis of anticipating ameliorative effects of calcium in waters that have lower magnesium: calcium ratios.

Workplan for 2017–18

- October 2017: Revise and finalise Supervising Scientist Report on the basis of external reviewers' reports.
- December 2017: Incorporate and publish results in a wider weight of evidence evaluation of other lines of evidence relevant to Mg, which provides the basis for final closure criteria for this contaminant of potential concern.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Supervising Scientist Report: Use of field-effects information to inform surface water closure criteria for magnesium sulfate in Magela Creek.

- Presentation to SETAC Asia-Pacific Conference in Singapore, September 2016.
- Weight of evidence evaluation of lines of evidence relevant to Mg effects on Ranger receiving waters.

The outcomes that this project will achieve are lines of evidence contributing to development of closure criteria for Mg in Ranger receiving waters.

Planned communication activities

The primary communication activities for the project are:

- Presentation to SETAC Asia-Pacific Conference in Singapore, September 2016
- ARRAC and ARRTC meetings for 2016-17
- Discussions with stakeholders as appropriate
- Peer-reviewed Supervising Scientist Report

Project publications to date (if applicable)

Humphrey CL & Chandler L. in review: Use of field-effects information to inform surface water closure criteria for magnesium sulfate in Magela Creek. Supervising Scientist Report, Darwin, NT.

Project details					
Project title	Toxicity of ammonia to freshwater biota and derivation of a site-specific water quality guideline value				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Completed		
What business need does this project inform?	Derivation of a site-specific water quality guideline value for ammonia				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2012-003	**Project commencement date**		1/12/2012	
		Estimated completion date		1/1/2015	
Project duration (months)	24	**Date required**		1/2/2017	
In-house or outsourced	Internal	**Actual completion date**		30/9/2017	
Lead team	WASQ	**Reason for project delay (where applicable)**		Technical issues with data analysis	
Supporting team(s)	N/A				
Project manager	Mooney, Tom	**Project total estimated internal resources (person weeks)**		100	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- Assess the toxicity of ammonia to six local species.
- Derive a site-specific water quality guideline value for ammonia to be applied to Magela and Gulungul creeks.

Background

Ammonia is present at high concentrations in Ranger process water (~1000 mg/L Total Ammonia Nitrogen, TAN). To date it has presented negligible environmental risk as process water is not discharged to the off-site environment. However, these risks may increase in the future, through potential seepage of ammonia from in-pit tailings post-closure.

Consequently, there is a need to understand ammonia toxicity under physico-chemical conditions relevant to the off-site surface water environment (i.e. Magela and Gulungul creeks) to a range of local freshwater species, and to use this information to derive site-specific trigger values/closure criteria.

Progress against plan

- The toxicity of ammonia to eight local species has been assessed at approximately pH 6 and 29°C.
- Toxicity estimates from these species have been used in the derivation of a site-specific water quality guideline value for Magela and Gulungul creeks.
- All data analysis has been completed and a manuscript is currently being prepared.

Key findings

- Toxicity of ammonia varied greatly among the eight species tested with EC50 values ranging between 8 to 227 mg/L total ammonia nitrogen.
- These values were used to derive a matrix of water quality guideline values, adjusted to a range of pH and water temperatures, which reflect local conditions.

Workplan for 2017–18

Complete manuscript, and communicate results to the stakeholders.

Planned project outputs and associated outcomes

The primary outputs for the study are:

- Ammonia toxicity data for six local species.
- A site-specific water quality guideline value for Magela and Gulungul creeks.

The outcomes of the study are an improved understanding of the potential effects of ammonia to local aquatic species, and a water quality Guideline Value that will prevent effects from occurring.

Planned communication activities

Key findings for this project will be published in a scientific journal and communicated to key stakeholders through the minesite technical committee, ARRTC and ARRAC.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Effects of uranium on the structure and function of bacterial sediment communities		
SSB function	Research	**Site**	Ranger
Project category	Developing closure criteria	**Project status**	Completed
What business need does this project inform?	This project informs the development of a closure criterion for uranium in sediments.		
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1 **Time-frame** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	RES-2014-001	**Project commencement date**	6/1/2014
		Estimated completion date	30/6/2017
Project duration (months)	36	**Date required**	01/02/2018
In-house or outsourced	Collaboration	**Actual completion date**	30/6/2017
Lead team	WASQ	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	Macquarie University		
Project manager	Harford, Andrew	**Project total estimated internal resources (person weeks)**	6
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**	80

Aims

The aim of this project was to assess the effect of uranium on sediment bacteria.

Background

A project that aimed to derive a sediment guideline value for uranium commenced in 2009. Briefly, sediments spiked with U were deployed in an undisturbed billabong (Gulungul) for the duration of the wet-season with the primary aim of the main experiment was to quantify the toxicity of U in sediment to benthic biota of the Magela Creek catchment – specifically, communities of shallow, backflow billabongs. Sub-samples of the spiked sediments were used in this a metagenome study, which will investigate both the structure and function of the communities. Specifically, the abundance of all functional gene sequences were quantified in

order to determine the function of the bacteria in the sediments and this was compared to the communities' structures as determined by 16S rRNA sequencing. This study was undertaken by a PhD student beginning in 2014 and was a collaboration with CSIRO and Macquarie University.

Progress against plan

This project has been completed. The DNA extracted from the spiked sediments was sequenced for 16S rRNA gene and a metagenome was constructed from unamplified DNA. The results have been published in one paper and another is under review.

Key findings

At uranium concentrations of ≥ 1,500 mg U/kg, genes associated with methanogenic consortia and processes increased in relative abundance, while numerous significant changes were also seen in the relative abundances of genes involved in nitrogen cycling. Such alterations in carbon and nitrogen cycling pathways suggest that functional changes to microbial communities may result in changes in ecosystem processes but at concentration markedly higher than those measured on the Ranger minesite.

Workplan for 2017–18

N/A. The project is completed.

Planned project outputs and associated outcomes

This project has provided:

- An understanding of the biological effects of U on billabong bacterial communities and biogeochemistry.
- An understanding between the link between structure of bacterial communities and their function in billabong sediments.
- The expertise and experience to undertake, complex field experiments for assessing sediment toxicity, including next-generation DNA and RNA sequencing techniques.

The project has produced one published paper and another is under review. The results have been presented at a national conference and an international conference.

Planned communication activities

- The outcome from this project has been presented at a national and an international conference.
- One paper has been published in Environmental Microbiology and another is currently under review.

Project publications to date (if applicable)

Sutcliffe B, Chariton AA, Harford AJ, Hose GC, Paul G, Elbourne LD, Oytam Y, Stephenson S, Midgley DJ & Paulsen IT 2017. Effects of uranium concentration on microbial community structure and functional potential. Environmental Microbiology. Accepted manuscript doi: 10.1111/1462-2920.13839.

Project details			
Project title	Magela Creek sandbed water quality and subsurface fauna - Pilot		
SSB function	Research	**Site**	Ranger
Project category	Developing closure criteria	**Project status**	Completed
What business need does this project inform?	Assessing impacts of surface water runoff and groundwater egress from current operations and the final landform on Magela Creek sand channels.		
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1 **Time-frame** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	RES-2016-004	**Project commencement date**	20/6/2016
		Estimated completion date	30/4/2017
Project duration (months)	12	**Date required**	30/4/2017
In-house or outsourced	Internal	**Actual completion date**	31/3/2017
Lead team	WASQ	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	N/A		
Project manager	Chandler, Lisa	**Project total estimated internal resources (person weeks)**	30
Project sponsor	Tomlinson, Moya	**Project total estimated collaborator resources (person weeks)**	0

Aims

- Characterise the dry season subsurface faunal communities in Magela Creek sandbed.
- Characterise the dry season surface and subsurface water quality in Magela Creek.

Background

The site-specific limit for magnesium (Mg) in Magela Creek is 3 mg/L. Preliminary sampling in December 2015 identified elevated Mg in Magela Creek 5 km downstream of Ranger (MCDW). There have been several previous occurrences of Mg contamination, either unusually high concentrations or outside the period of main creek flows. Efflorescence of magnesium sulfate (MgSO4) in the Magela Creek area was first noticed at the base of the Magela Creek Land Application Area and on the creek banks in the 1993 dry season. Conductivity in small residual pools in the creek bed in the affected area was much higher than in other pools (1450 µS/cm cf.

22 – 115 μS/cm), and pH was much lower (3.26 cf. 6.04 – 7.05). There has also been efflorescence of MgSO4 in the Djalkmara Land Application Area in 2007 and 2009, resulting in an estimated Mg concentration of 5.4 mg/L entering Magela Creek and 6 mg/L entering Coonjimba Billabong due to transport during first flush. In 2014, several EC events and elevated levels of Mg and SO4 were observed in Magela Creek, primarily associated with flushing of solutes from Gulungul Creek Tributary 2. In addition, modelling of post-closure solute migration from Pit 3 predicts that a plume of Mg will intersect the Magela Creek sandbed within 10 years if no mitigation is in place.

A workshop in March 2016 scoped specific research needs regarding potential impacts of elevated Mg on the subsurface ecology in Magela Creek. The presence, composition of, and risks to, subsurface faunal communities in Magela Creek are unknown.

Detailed spatial characterisation is required to determine the extent of this contamination, and to determine whether it is seasonal only, or indicative of long-term residency along the creek channel and through the sand depth profile. Characterisation of the subsurface fauna in the sands is also required for impact and risk assessment. Information arising from a study of current contamination should inform assessment of risks associated with predicted groundwater expression of contaminants in Magela Creek from Pit 3 closure modelling.

Progress against plan

Internal Report completed in July 2017. Project completed.

Key findings

- Elevated EC (220 microsiemens/cm) and Mg (14 mg/L), and low pH (3.1–3.4), were recorded in Magela Creek sandbed adjacent to the Magela Land Application Area and Coonjimba Billabong in July 2016.
- Elevated EC (370 microsiemens/cm) was recorded at sites adjacent to Coonjimba Billabong again in August 2016.
- Continuous data recorded maximum EC values of 566 microsiemens/cm from a site near Coonjimba Billabong.
- Shallow groundwater appears influenced by surface water with all sites experiencing significant decreases in EC with advent of flow in the creek in September 2016.
- Preliminary investigations of fauna samples estabilished the presence of a groundwater community with a total of 144 individuals from 13 taxa collected.
- A number of specimens of Syncarida (tentatively identified as members of the Parabathynellidae) were collected. Potentially these are a new record for the Northern Territory.

This study has been used to scope and design further water quality and biological studies on Magela sands for 2017.

Workplan for 2017–18

N/A. The project is completed.

Planned project outputs and associated outcomes

Report on findings of pilot project (2015 and 2016 sampling) including a spatial and temporal description of the presence and composition of subsurface faunal communities in the Magela Creek sandbed, and of surface and subsurface water quality including Mg contamination.

The results will improve understanding of the location and movement of current contamination in Magela Creek sand bed. It will also provide an understanding of the potential impacts of elevated Mg on the subsurface ecology in Magela Creek, and inform more detailed future sampling.

Planned communication activities

The primary communication activities for the project are:

- Presentations as required to key stakeholders and at conferences
- Publication in an Internal Report

Project publications to date (if applicable)

Chandler L, Tomlinson M & Humphrey C 2017 Water quality and biota in the subsurface sands of Magela Creek – report of a pilot project, Internal Report 626, Supervising Scientist, Darwin.

Project details					
Project title	Toxicity of ammonia to local species at a range of pHs				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Protection of aquatic ecosystems, specifically lentic water bodies, from the effects of ammonia, particularly post-rehabilitation.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame** 1	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	RES-2016-006	**Project commencement date**	5/9/2016		
		Estimated completion date	30/6/2017		
Project duration (months)	12	**Date required**	30/6/2017		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	WASQ	**Reason for project delay (where applicable)**	Delayed due to competing demands		
Supporting team(s)	N/A				
Project manager	Mooney, Tom	**Project total estimated internal resources (person weeks)**	9		
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**	0		

Aims

To provide evidence that the algorithms used to adjust ammonia water quality Guideline Values (GVs) are appropriate for local species and conditions.

Background

Water quality GVs for ammonia have been derived for Magela and Gulungul creeks. The pH of the local environment can affect the toxicity of ammonia due to speciation of NH^{4+} to NH_3. Algorithms are used to adjust ammonia GVs based on local pH and temperature. It is important to provide evidence that the algorithms applied to local species and conditions are appropriate. Therefore, this project will contribute by the validating whether the algorithms used to adjust ammonia water quality GVs (dependant on pH) derived for the creeks are appropriate for use on local species (inferred from one species *H. viridissima*) and conditions.

Progress against plan

Laboratory testing and data analysis have been completed. A draft manuscript is being reviewed by the authors.

Key findings

- *Hydra viridissima* was among the most sensitive species to ammonia in the international literature. Its sensitivity to ammonia increased with increasing pH.
- The pH-dependence model accurately described the relationship between pH and ammonia toxicity for *H. viridissima*. However, when the shape parameters for the pooled relationship were used, the fit was less accurate.

Workplan for 2017–18

Finalise journal manuscript.

Planned project outputs and associated outcomes

The key output is an assessment, and associated journal publication, of the effect of pH on ammonia toxicity to *H. viridissima*.

This project will provide confidence in the site-specific alogorithm derived GV for ammonia.

Planned communication activities

- Journal manuscript
- Discussions with key stakeholders as appropriate

Project publications to date (if applicable)

No project publications to date.

Project details					
Project title	Review of acid sulfate soil knowledge and development of a rehabilitation standard for sulfate				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Completed		
What business need does this project inform?	Protection of aquatic ecosystems from contaminants arsing from the mine site or processes occurring due to mining-related activities, during both operations and after rehabilitation.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2016-010	**Project commencement date**		30/3/2017	
		Estimated completion date		30/6/2017	
Project duration (months)	3	**Date required**		31/7/2017	
In-house or outsourced	External	**Actual completion date**		30/6/2017	
Lead team	WASQ	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Rivers & Wetlands				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**		1	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		12	

Aims

Task 1 – Review of ERA's Ranger ASS investigation reports, SSB's draft dry season Magela Creek water quality report and long-term water quality datasets for Coonjimba Billabong and Retention Pond 1 (RP1).

Task 2 – Review of, and assistance with, SSB's Rehabilitation Standard for sulfate.

Background

There is a need to develop a Rehabilitation Standard for sulfate in the context of ongoing issues associated with 'mine-generated' acid sulfate soils (ASS). Drafting of such a document has commenced, but requires specialist ASS expertise to be completed. SSB does not have such in-house expertise and this project will inform the rehabilitation standard.

Moroever, there is a need to review ERA's recent studies on ASS in Coonjimba Billabong, where significant acid events have been occurring in the early wet season since 2012.

Progress against plan

SSB's consultant, Dr Darren Baldwin, has completed both milestones after being provided with relevant site information and chemistry data. The consultant has provided a written report for both Stages 1 and 2.

Key findings

Long term sulfate concentrations in surface waters need to be <15 mg/L to prevent long term accumulation of ASS. However, even sulfate concentrations over 10 mg/L have been associated with accumulation of ASS. Therefore, in order to not have any accumulation of ASS, long-term average concentrations need to be <10 mg/L. These results will be further considered in the context of water quality closure criteria for Ranger on-site and offsite billabongs.

Workplan for 2017–18

N/A. Project completed.

Planned project outputs and associated outcomes

Outputs:

- Report summarising water and sediment chemistry data available for Coonjimba Billabong (CJB) and the status of ASS in the billabong.
- Report providing recommendation for the rehabilitation standard that should be proposed for sulfate.

Outcomes:

- Increased knowledge of the risks to CJB posed by ASS.
- Increased knowledge on the sulfate concentrations that need to be maintained to ensure protection of the RPA and surrounds from ASS.
- Clearer direction on the future work and data needed in order to assess the status of ASS in CJB.

Planned communication activities

- Rehabilitation standard for sulfate.
- Communicate outcomes and recommendations of consultants' reports to key stakeholders, including ERA.

Project publications to date (if applicable)

Baldwin DS, (2017) *Understanding acid sulfate soils in Coonjimba Billabong*. Prepared for the Supervising Scientist Branch, the Department of Environment and Energy by *Rivers and Wetlands*, May 2017, 24 pp.

Baldwin DS, (2017) *Review of Supervising Scientist Branch Rehabilitation Standard for Sulfate*. Prepared for the Supervising Scientist Branch, the Department of Environment and Energy by *Rivers and Wetlands*, June 2017, 8 pp.

Project details					
Project title	Assessing the ecological risks of mine water contaminants in the dry season, subsurface waters of Magela sand channel				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Contributes to assessing and understanding the risks of groundwater contaminant pathways to Magela Creek sand channel post-decommissioning.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2016-012	**Project commencement date**		31/3/2017	
		Estimated completion date		31/3/2020	
Project duration (months)	36	**Date required**		30/6/2020	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	WASQ	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Jenny Davis (CDU); Grant Hose (Macquarie Uni)				
Project manager	Chandler, Lisa	**Project total estimated internal resources (person weeks)**		87	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**		114	

Aims

- To characterise the hyporheic and groundwater communities and associated habitat and water quality in Magela Creek.
- To assess the sensitivity of these communities to contaminants of potential concern arising from Ranger minesite.
- To investigate the implications for ecological functions with regard to subsurface water in Magela Creek of elevated contaminants of potential concern arising from Ranger mine site.

Background

Following closure of the Ranger uranium mine in 2026, the rehabilitated site is predicted to become a source of both contaminated surface water runoff and exfiltrating groundwater with elevated electrical conductivity (EC). The major component of the elevated EC is magnesium sulfate (MgSO4) derived from the waste rock landform and pit capping. Solute egress modelling predicts that within 10 years of closure, groundwater with MgSO4 concentrations greater than the current chronic exposure limit (3 mg/L) will reach Magela Creek and that concentrations above this limit will remain for 10,000 years.

The effects of magnesium on surface water organisms have been well documented by the Supervising Scientist Branch. However, to date, little is known of the groundwater ecology of Magela Creek, nor of the potential impacts of elevated magnesium concentrations and other COPCs on these communities.

During the dry season, and when there are no longer surface waters, there is a reported resident fauna in the dry and moist surface sands of Magela Creek. Through re-wetting experiments, Paltridge et al (1997) observed invertebrates in the top 20 cm of the sands that were a mix of (i) dormant taxa commonly observed in the surface waters and associated benthos, as well as (ii) groundwater (presumably obligate) specialists (i.e. stygofauna). A pilot study was undertaken in 2016 to characterise fauna and water quality in subsurface sands of Magela Creek during the dry season. The results are reported in Chandler et al (in press). These authors also observed stygofauna (i.e. Parabathynellidae and harpacticoid copepods) in samples collected from the top 1.5 m of the saturated sand channel.

Stygofauna are particularly sensitive to groundwater environment disturbance because they are adapted to near steady-state environment conditions and have very narrow spatial distributions (Hose et al 2015). Changes to environmental conditions, such as those predicted to occur in the Magela Creek sand channel after closure could be considered a potential threat to stygofauna.

Progress against plan

- The design of this water quality and biological study has been informed by the associated pilot study reported elsewhere (RES-2016-004: Chandler et al, in press).
- Piezometer sites were installed in late July 2017.
- Initial water quality and biological sampling occurred during the second week of August 2017.

Key findings

N/A. Project has just commenced.

Workplan for 2017–18

- Monthly collection of biota and water chemistry samples: June-December
- Initial investigations into habitat variables such as subsurface flow rates
- Genomics and morphological analysis of biota samples

Planned project outputs and associated outcomes

The project will deliver new knowledge on subsurface (to 2 m) biota, flow pathways and water quality of waters in the dry streambed of Magela Creek.

Planned communication activities

The primary communication activities for the project are:

- Four journal papers covering different aspects of the project
- An oral presentation at a conference each year over the course of the project
- Reports/presentations as necessary to ARRTC and other key stakeholders and research updates to the university involved (CDU)
- A PhD thesis

Project publications to date (if applicable)

No project publications to date.

Project details					
Project title	Literature and data review of seasonal utility of Magela channel for connectivity processes				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Assessment of potential impacts of saline plumes emanating after closure of the Ranger mine upon key connectivity processes in Magela Creek, including fish migration				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 2	**Time-frame**	2
			Importance 2	**Time buffer**	B
Project number (if already commenced)	RES-2016-005	**Project commencement date**		23/5/2016	
		Estimated completion date		28/10/2017	
Project duration (months)	12	**Date required**		28/10/2017	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	WASQ	**Reason for project delay (where applicable)**		Staff loss	
Supporting team(s)	N/A				
Project manager	Tomlinson, Moya	**Project total estimated internal resources (person weeks)**		20	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**		0	

Aims

The overall aim of the literature and data review is to use the concept of ecological connectivity as a framework for understanding the implications of predicted egress of a solute plume from the final landform, including Pit 3 into Magela Creek. The literature review will:

- Summarise use of the Magela Creek by dispersing and migrating fauna, focusing on fish migration and invertebrate drift.
- Describe the existing and potential sources, pathways and concentrations of Mg contamination in Magela Creek.
- Summarise where possible data on tolerance of resident creek fauna to Mg.

- Identify implications for ecological connectivity in Magela Creek of current and potential Mg contamination.

Background

The main contaminant of potential concern in Magela Creek, arising from mining at Ranger, is magnesium (Mg), derived primarily from weathering of Mg-dominant, chlorite schists in the mine waste rock. Solute modelling predicts egress of a plume of Mg contamination from (at least) Pit 3 into Magela Creek sand channel following filling of the pit with tailings and waste rock. Natural EC levels in Magela Creek are very low. Magela Creek is a conduit for fish movement between the floodplain and the upstream dry season refugia. With the start of flow, fish from permanent waterbodies move into seasonally- inundated floodplains, lowland sandy channels and backflow billabongs to breed and feed. In the second half of the wet season including recessional flow, individuals representing a large number of fish species from a number of lowland habitats (floodplains, billabongs and creek channels) move upstream along the length of the creek to dry season refuges. The effect on fish movement of elevated Mg concentrations in Magela Creek is unknown. Macroinvertebrate communities of the Magela sand channels are diverse, observe successional changes over the wet season and may colonise the creek at first-flow through downstream drift. Potential disruption to dispersion and recruitment processes of these assemblages arising from solute egress also needs to be assessed. This literature review will review the available data on fish migration, invertebrate recruitment processes and the scientific literature to identify the implications of potential disruption to ecological connectivity caused by Mg contamination.

Progress against plan

This project was inactive in the 2016-17 period because the senior researcher resigned from the Department.

Key findings

A literature review and analysis of fish migration were undertaken and are proposed to be finalised in the latter half of 2017.

Workplan for 2017–18

- Finalise the draft report on ecological connectivity in Magela Creek and publish as an internal report.
- Consider recommendations in the internal report for further work and scope as required.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Presentations as required
- Internal report

The project will identify knowledge gaps and research questions to test hypothesised effects of Mg contamination on connectivity values in Magela Creek.

Planned communication activities

The primary communication activities for the project are:

- Presentations as required
- Internal report

Project publications to date (if applicable)

There are no publications to date.

Project details					
Project title	Assess the cumulative toxicity of Ranger contaminants of potential concern for operational and closure scenarios				
SSB function	Research	**Site**	All		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Validating operational water quality objectives and rehabilitation standards/closure criteria for contaminants of potential concern, to ensure protection of aquatic ecosystems				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2017-001	**Project commencement date**		1/5/2017	
		Estimated completion date		31/7/2018	
Project duration (months)	12	**Date required**		30/6/2018	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	WASQ	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	N/A				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**		60	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- To test the effect of Contaminants of Potential Concern (COPCs) (U, Mg, Mn and NH3) at their water quality Guideline Value concentrations to freshwater biota when they occur in the form of a mixture.
- To validate and determine the interaction amongst the water quality Guideline Value concentrations for each of the COPCs (U, Mg, Mn and NH_3) by conducting Direct Toxicity Assessments on various site waters of varying water quality, including Pond water, Process water, waste rock seepage and GCT2 water.

Background

Much effort has been invested in deriving water quality limits for individual toxicants. However, this approach does not incorporate potential interactive (e.g. additive, synergistic, antagonistic) effects of toxicant mixtures or other modifying effects occurring in the field. As additional limits for new toxicants (e.g. ammonia) are included in the regulatory framework, the continuing rigour of this approach needs to be tested in laboratory and field settings to ensure that it is appropriately protective of the aquatic environment within and surrounding the Ranger Project Area. This project will contribute to the development, validation, understanding of COPC interactions and development and application of operational water quality objectives and closure criteria for toxicants.

Progress against plan

- Advice has been provided by Peter Bayliss on building a conceptual model for this work and determining the best statistical program and approach to analyse what will be a very complex data set.
- Toxicity testing has begun using all six freshwater species of the suite used at eriss. Two series of tests at the guideline value concentrations of the COPCs have been conducted. The first series was under conditions of no added calcium. The second series has been run at two Mg:Ca ratios (5:1 & 9:1) reflective of conditions relevant to on-site and off-site waters. Direct toxicity assessments for two on-site process waters (PJ and TDWW) have commenced. Two series of tests have been run in the TDWW water and one series in the PJ water. The second series of PJ tests will be carried out in September. Tests in the other two site waters will be conducted in October and November.

Key findings

- Testing of a COPC mixture at each of the COPCs' guideline value concentrations and at background calcium concentrations (Mg:Ca ratio ~ 28:1) resulted in toxicity to 5 of the 6 species. The same testing at Mg:Ca ratios of 5:1 and 9:1 resulted in the COPCs at their GV concentrations being not toxic to these species. Hence, the addition of calcium appears to greatly influence the toxicity of the COPCs, probably mostly Mg, and does so to varying extents for each of the organisms.
- The TDWW water with a Mg:Ca ratio of 14:1 is very toxic to all species with the snail most affected (EC10 = 0.002% strength water) and the lemna least affected (EC10 = 0.4% strength water). The PJ water is much less toxic to all species, which has so far only been tested at up to 1% strength. Again, the snail and the flea are most sensitive with EC10s of 0.05-0.1% and the lemna was stimulated in growth at up to 1% strength.

Workplan for 2017–18

Aim 1:

> Laboratory toxicity exposures in a mixture containing COPCs spiked at their individual GV concentrations will be carried out with each of the 6 species (*Chlorella sp., L. aequinoctialis, A. cumingi, H. viridissima, M. macleayi* and *M. mogurnda*)

Aim 2:

Laboratory toxicity exposures with each of the 6 species (*Chlorella sp., L. aequinoctialis, A. cumingi, H. viridissima, M. macleayi* and *M. mogurnda*) will be carried out in mine waters from various sites on the RPA.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Journal manuscript
- Conference presentations (2 oral, 1 poster)

The outcomes that this project will achieve are:

- Additional knowledge regarding the toxicity of Ranger COPCs to local freshwater species when those contaminants occur as mixtures.
- Information to assess the appropriateness of the guideline values for the individual contaminants.
- These data will also be verified or assessed using Direct Toxicity Assessments of various site waters.

Planned communication activities

- Journal manuscript
- Conference presentations in 2017 and 2018
- Discussions with key stakeholders as appropriate

Project publications to date (if applicable)

No project publications to date.

Project details					
Project title	Monitoring billabong turbidity using a Remotely Piloted Aircraft System (RPAS)				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Completed		
What business need does this project inform?	Monitoring closure criteria				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 3	**Time-frame** 3	
			Importance 4	**Time buffer** D	
Project number (if already commenced)	RES-2014-007	**Project commencement date**		22/9/2014	
		Estimated completion date		4/7/2016	
Project duration (months)	18	**Date required**		13/10/2016	
In-house or outsourced	Collaboration	**Actual completion date**		13/10/2016	
Lead team	R&L	**Reason for project delay (where applicable)**		Thesis submission delayed	
Supporting team(s)	Charles Darwin University				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**		8	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		36	

Aims

The main objective of the project was to develop a methodology based on RPAS technology to monitor turbidity in billabongs.

The specific aim was to develop a quantitative method to map turbidity in floodplain billabongs using data derived from a Remotely Piloted Aircraft System (RPAS).

Background

The Supervising Scientist conducts an independent surface water quality monitoring program 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. This is a

point sampling program and as such does not capture spatial variability in water quality variables such as turbidity.

This project is focused on developing a methodology for measuring turbidity in billabongs using eriss's RPAS. This application has the potential to value add to the soil erosion monitoring program during decommissioning and rehabilitation, by providing distribution maps of suspended sediment in the surrounding creek systems and provide extra information for interpreting biological monitoring results.

Furthermore, maps showing the spatially continuous distribution of suspended sediments can be useful aids in designing or improving point sampling monitoring programs through highlighting the best locations for sampling. This may become more relevant during the decommissioning and rehabilitation phase of the mine with potential fluctuations in suspended sediments within Magela Creek.

Progress against plan

The project has been completed with the Honours thesis submission. A journal publication will be drafted as time and resources permit.

Key findings

- Water quality algorithms for remote sensing imagery were investigated for mapping turbid water conditions for Coonjimba Billabong. Multi-spectral RPAS data were collected over Coonjimba Billabong. At the same time, in situ turbidity measurements were obtained using an autonomous small water craft.
- The relationships between the algorithms applied to the Unmanned Aerial Vehicle (UAV) data and in situ water turbidity were assessed. Results show the Normalised Difference Water Index (NDWI) was a good indicator for water turbidity in the billabong and comparable to the in situ measurements.
- This study developed a new method to process multi-spectral RPAS imagery for turbidity monitoring in inland water bodies.

Workplan for 2017–18

N/A. Project completed.

Planned project outputs and associated outcomes

Specific outputs are:

- Honours thesis on developing and testing a quantitative method for mapping billabong turbidity using a RPAS.
- Journal publication – Using a RPAS to map and monitor turbidity in tropical billabongs (technical paper).

The outcome of this project was a cost-effective method for monitoring turbidity in waterbodies (creeks and billabongs) in the off-site environment during the operational and rehabilitation phases of Ranger mine. This method will also have the ability to measure spatial variability in turbidity.

Planned communication activities

- Coffee Break Seminar presentation at SSB - 25 August 2016
- Honours seminar at Charles Darwin University - 27 September 2016
- Peer-reviewed journal paper

Project publications to date (if applicable)

Chen, H. 2016. Monitoring tropical billabong water turbidity using Remotely Piloted Aircraft System (RPAS) derived imagery, Honours thesis, Charles Darwin University.

Ranger – Rehabilitation

CC theme: Landform (8 projects)

Project details					
Project title	Erosion and infiltration studies on the Ranger trial landform				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Gather data on suspended sediment, bedload transport, hydrology and infiltration of a rehabilitated site in order to validate predictions from the landform evolution model, CAESAR-Lisflood				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2009-011	**Project commencement date**	1/7/2009		
		Estimated completion date	30/6/2018		
Project duration (months)	146	**Date required**	30/6/2018		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	R&L	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	N/A				
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**	240		
Project sponsor	Bartolo, Renee	**Project total estimated collaborator resources (person weeks)**	0		

Aims

- To measure erosion rates in terms of hydrology, bedload, suspended load and solute load from a constructed trial landform at the Ranger mine to assess effects of different surface treatments and vegetation establishment strategies.
- To measure and determine infiltration rates on the trial landform.

- To provide data which may be used to validate the predictions of long term landform evolution modelling of proposed landform designs.

Background

Construction of the trial landform was completed in early March 2009, and construction and instrumentation of erosion plots and planting of tube stock and direct seeding was completed by November 2009. The results from this project will provide quantitative data on runoff water quality bed load, suspended load and solute load yields. Data have been collected from the trial landform since the 2009-2010 wet season.

Rainfall, runoff and bedload data have been collected for seven wet seasons 2009–2010 to 2015–16 and data is currently being collected for 2016-17. The project was scaled back during the 2014/2015 wet season with only rainfall runoff and bedload collected during the 2014–2015, 2015–2016 and 2016–17 wet seasons.

Progress against plan

- Rainfall and runoff data have been cleaned, quality assessed and checked, and archived in Hydstra for all for plots for the wet season 2009–2010 to 2015–2016.
- Bedload yields have been completed for all four plots for seven wet seasons (2009–2010 to 2015–2016) and bedload is being collected during the 2016–2017 wet season.
- Continuous monitoring of EC, turbidity and stage has been done at each of the four plots over the five wet seasons (2009–2010 to 2013–2014), and these data will be used to derive total loads of suspended sediment and solutes.
- Chemical analysis was completed for selected runoff samples collected by turbidity and/or EC activated auto samplers during the first five wet seasons (2009–2010 to 2013–2014).
- Particle size distribution was completed for samples of bedload, and selected sediment samples were analysed for metal content and radionuclide activity.
- Particle size distribution has also been completed for the surface samples collected in 2009, 2012 and in 2014 and the earlier data have been reported in an internal report.

Key findings

- Bedload has been found to be declining in the eight years since the trial landform was constructed.
- Suspended sediment has been analysed and in general appears to comprise less than 20% of the total load, although this is still being written up.
- Rainfall and runoff data have been processed for the eight wet seasons. Rainfall on the trial landform is showing variations similar to Jabiru Airport although no rainfall intensity analysis has been undertaken to date.
- High initial sediment loads with a subsequent rapid decline predicted by modelling from the trial landform are matched by the field results.

Workplan for 2017–18

- Finalise the suspended sediment turbidity relationship from the trial landform so that total loads leaving the erosion plots can be calculated.

- Finalise and review Supervising Scientist Report in relation to the trial landform project.
- Prepare a journal paper on the hydrology of the erosion plots on the trial landform.
- Monitor some of the erosion plots on the trial landform during the 2017–2018 wet season.
- Determine infiltration on the trial landform using the disc permeameter.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- To determine rainfall, runoff, solute, suspended sediment and bedload yields from the trial landform.
- Development of suspended-sediment turbidity relationships for the trial landform so that suspended-sediment losses can be indirectly monitored by continuous turbidity measurements.
- Use of these relationships to derive event-based and annual loads of suspended sediment.

The outcomes of this project will be to determine rainfall, runoff, sediment and solute loads from the trial landform to assist with the validation of the CAESAR LEM. This will be used to assist with the development of the rehabilitated landform.

Planned communication activities

- Presentations and discussions with the Landform technical working group and ARRTC
- Journal publication
- Supervising Scientist Report
- Internal reports and annual research summaries

Project publications to date (if applicable)

Hancock GR, JBC Lowry and M Saynor 2017. Surface armour and erosion – impacts on long-term landscape evolution. Land Degradation & Development DOI: 10.1002/ldr.2738.

Hancock GR, Lowry JBC & Saynor MJ 2016. Early landscape evolution - a field and modelling assessment for a post-mining landform. Catena, 147, pp. 699-708.

Saynor MJ & Erskine WD 2016. Bed load losses from experimental plots on a rehabilitated uranium mine in northern Australia. In Proceedings of the Life-of-Mine 2016 Conference, 28-30 September, Brisbane Australia, The Australasian Institute of Mining and Metallurgy, pp. 168-171.

Saynor M, Boyden J & Erskine W 2016. Ranger Trial Landform: Hydrology – Rainfall & runoff data for Erosion Plot 2: 2009 - 2014. Internal Report 632 Supervising Scientist, Darwin. Unpublished paper.

Boyden J, Saynor M & Erskine W 2016. Ranger Trial Landform: Hydrology – Rainfall & runoff data for Erosion Plot 1: 2009 - 2015. Internal Report 646 Supervising Scientist, Darwin. Unpublished paper.

Lowry, J, Saynor, M, Erskine, W, Coulthard, T and Hancock, G, 2014. A multi-year assessment of landform evolution model predictions for a trial rehabilitated landform, in Proceedings: Life-of-Mine 2014, The Australasian Institute of Mining and Metallurgy, Melbourne.

Saynor MJ, Lowry J, Erskine WD, Coulthard T, Hancock G, Jones D & Lu P 2012. Assessing erosion and run-off performance of a trial rehabilitated mining landform. In Proceedings: Life-of-Mine 2012. Maximising Rehabilitation Outcomes, 10–12 July 2012, Brisbane, Qld, The Australasian Institute of Mining and Metallurgy, Carlton Victoria, 123–134.

Saynor MJ & Houghton R 2011. Ranger trial landform: Particle size of surface material samples in 2009 with additional observations in 2010. Internal Report 596, August, Supervising Scientist, Darwin.

Project details					
Project title	Model the geomorphic stability of pre-mine landform for up to 10,000 years				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Calibration of landform evolution model for different surfaces, i.e. pre- and post-mine				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 3	**Time-frame**	1/ongoing
			Importance 3	**Time buffer**	A
Project number (if already commenced)	RES-2015-017	**Project commencement date**	1/7/2015		
		Estimated completion date	1/12/2017		
Project duration (months)	6	**Date required**	1/12/2017		
In-house or outsourced	Collaboration	**Actual completion date**	N/A		
Lead team	R&L	**Reason for project delay (where applicable)**	Collaborator from CDU left, providing first draft only. Additional modelling simulations were required to complete the work.		
Supporting team(s)	CDU - Professor Ken Evans and Dr Monishka Narayan				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**	3		
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**	8		

Aims

- To assess the geomorphic stability of a pre-mine landform for a simulated period of 10,000 years.
- To better understand the range of parameters and variables that should be employed in the CAESAR-Lisflood model for landform modelling purposes.

Background

The project aims to model the geomorphic and erosional stability of a pre-mine landform of the Ranger environment for a period of 10,000 years. The simulations will be used to visually assess how the landscape may evolve without the presence of the mine. As much as practically possible, the same parameters and inputs will be used in the simulations of the pre-mine landform as will be used in the simulations of the rehabilitated landform. For example, it is expected that the rainfall dataset developed for 10,000 years will be used as input for simulations in this project to enable the same climate and rainfall scenarios to be modelled. As with the assessment of the rehabilitated landform, both the CAESAR-Lisflood and SIBERIA landform evolution models will be used.

This project was originally conceived as a potential collaborative honours project that could be undertaken by a student at Charles Darwin University. However, a post-doctoral research fellow has since expressed interest in undertaking this work as part of their research program.

It is anticipated that the project will be a desktop modelling project. The Supervising Scientist involvement will be limited to providing advice and support in applying the landform evolution models and collaborating on updating parameter input values.

Progress against plan

- A digital elevation model (DEM) of the pre-mine surface has been compiled and used to delineate catchment areas of Corridor, Coonjimba, Djalkmara and Gulungul creeks.
- Model parameters have been revised and enhanced for modelling conditions representing both disturbed (post-mine) and undisturbed (pre-mine) landforms.
- Simulations for a simulated period of 1,000 years have been run using the synthetic rainfall dataset replicates developed for the Ranger site plus extreme wet and extreme dry climate analog scenario datasets as simulations on the post-mining surface.
- An Internal Report summarising findings has been completed and is currently in press.

Key findings

- Landform modelling simulations of a pre-mining landscape using same the rainfall and climate scenarios as those applied to post-mining landscape simulations indicate denudation rates of the pre-mine catchments are all within the background environmental range (0.01-0.4 mm/yr) from the commencement of simulation. This contrasts with the post-mining landscape where it is predicted to take thousands of years for the denudation rate to reach the background level.
- These results are attributed to differences in the topographical characteristics of the pre- and post-mine catchments, and the particle size characteristics used to represent the surface conditions of the pre- and post-mining catchments.
- The return of denudation rates from a undisturbed landform that are within the range of the natural background rates indicates that the model is correctly calibrated and is able to model both natural and disturbed / rehabilitated surfaces.

Workplan for 2017–18

- Complete the publication of the internal report summarising simulation results (October 2017).
- Present results in a journal publication (June 2018).

Planned project outputs and associated outcomes

The primary output for the project is:

- Conference or journal paper on comparing evolution of pre-and post-mining landforms.

The outcomes that this project will achieve are a better understanding of:

- The performance of the CAESAR-Lisflood evolution model in a natural, undisturbed environment.
- How an undisturbed landscape may evolve in the long term.

Planned communication activities

The primary communication activities for the project are:

- Conference presentation or journal submission
- Contribution to Landform Technical Working Group

Project publications to date (if applicable)

Lowry L, Narayan M, Evans K & Hancock G. in review. Utilising landform evolution models to assess the long-term stability of pre- and post-mining landforms. Internal Report, Darwin, NT.

Project details			
Project title	Analysis of historical unpublished erosion studies in the ARR		
SSB function	Research	**Site**	Ranger
Project category	Developing closure criteria	**Project status**	Active
What business need does this project inform?	The analysis of the concentrated flume experiments will provide results to assist with the validation of CAESAR-Lisflood.		
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1 **Time-frame** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	RES-2015-022	**Project commencement date**	1/7/2015
		Estimated completion date	30/6/2018
Project duration (months)	36	**Date required**	30/6/2018
In-house or outsourced	External	**Actual completion date**	N/A
Lead team	R&L	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	Professor Ken Evans - CDU		
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**	2
Project sponsor	Bartolo, Renee	**Project total estimated collaborator resources (person weeks)**	20

Aims

Analyse the erosion data for Ranger uranium mine collected by Steve Riley in the early 1990s that was not published.

Background

In the late 1980s and early 1990s, a series of experiments was undertaken by Steve Riley (former ERISS employee) to investigate erosion from and around the Ranger mine site. These experiments included monitoring of natural events, concentrated flume experiments and rainfall simulation. These experiments were undertaken at the Ranger site (Waste Rock dumps –cap and batter slopes) and at natural sites adjacent to the mine site and at Tin Camp Creek in Arnhem Land. The majority of this work has not been published. This project involves sifting through the

data to see what might be useful particularly with regard to landform evolution modelling. It is planned to outsource the work as a small non-consultancy to Professor Ken Evans (Charles Darwin University).

Progress against plan

The data sheets have been looked through and electronic data sets have been located.

Key findings

Flume experiments were conducted in the early 1990s. Data have been located for sites on the Ranger mine site, a nearby natural site and for several sites at Tin Camp Creek. These data will be analysed by Professor Ken Evans.

Workplan for 2017–18

- Set up non-consultancy with Ken Evans at CDU.
- Provide data to Ken and comment on report.

Planned project outputs and associated outcomes

The output of this project will be an analysis of results from previously unpublished experiments (concentrated flume), which will be used to asisst with the development/validation of the CAESAR-Lisflood model.

The outcome of the project will be increased rigour or, and confidence in, the CAESAR-Lisflood model for predicting erosion on the Ranger mine site.

Planned communication activities

- Report from Ken Evans
- Journal publication
- Reporting and presentations to key stakeholders as necessary

Project publications to date (if applicable)

There are no project publications to date.

Project details					
Project title	Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to a rehabilitated Ranger mine - Gulungul Creek scale				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	This project works towards ensuring confidence in landform model predictions of suspended sediment output - specifically, that model predictions reflect actual measured / monitored observations at a catchment scale.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Time-frame**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2016-002	**Project commencement date**		1/7/2016	
		Estimated completion date		31/12/2016	
Project duration (months)	6	**Date required**		31/12/2017	
In-house or outsourced	Collaboration	**Actual completion date**		30/6/2018	
Lead team	R&L	**Reason for project delay (where applicable)**		Masters project was unable to answer question fully	
Supporting team(s)	Professor Ken Evans, CDU				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**		8	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		20	

Aims

The aim of this project is to calibrate and validate the CAESAR-Lisflood model outputs of suspended sediment load at the catchment scale.

Background

This project will contribute to the work of the Supervising Scientist by assessing what effect the transport of suspended sediment will have on the on-site and off-site habitats of the rehabilitated landform. Specifically, the project will assist with the calibration of the CAESAR-Lisflood model to enable it to reliably predict the quantity of suspended sediment material that may be produced by the rehabilitated landform under a range of scenarios, by comparing simulated outputs with

field measured values. This project is being undertaken as a Masters-by-coursework student at Charles Darwin University, supervised by Professor Ken Evans. There is no external cost for this project, as it will be undertaken by a self-funded student.

Progress against plan

- Work was undertaken as part of a Masters project in collaboration with Charles Darwin University, to attempt to assess and calibrate the suspended sediment outputs of the CAESAR-Lisflood model against field measurements.
- A Masters of Engineering thesis has been submitted and has passed.
- An internal report summarising the thesis results is in preparation.

Key findings

- Results from initial study were unable to conclusively assess reliability of modelled outputs versus field measurements to calibrate the model.
- The study identified further work that could be undertaken to address this issue.

Workplan for 2017–18

The proposed work plan for the student is as follows:

- Analysis and calibration of field data (July-August 2017).
- Generation of model outputs through simulations of CAESAR-Lisflood model in Gulungul Creek (August-October 2017).
- Comparison of field data with model outputs (August-October 2017).
- Calibration and validation of suspended sediment outputs from CAESAR-Lisflood project (September-October 2017).
- Finalise analysis (November 2017).
- Internal report on calibration methodology and results (March 2018).

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Revised / enhanced parameters sets for measuring modelled suspended sediment loads from the CAESAR-Lisflood model.
- Internal Report describing suspended sediment methodology and results.
- A completed Masters thesis.
- A conference or peer-reviewed journal paper.

The outcome of this project is an enhanced capability of the CAESAR-Lisflood model to reliably simulate the amount of suspended sediment that may be produced at a catchment scale on a rehabilitated landform.

Planned communication activities

The planned communication activities for the project are:

- Internal Report
- Input into landform technical working group discussions

- Conference proceedings or peer-reviewed journal paper

Project publications to date (if applicable)

There are no project publications to date.

Project details					
Project title	Model the geomorphic stability of the landform for up to 10,000 years - finalising longterm rainfall datasets and weathering impacts for the landform				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Ensuring the rehabilitated landform is designed to minimise erosion and sediment transport off the site, through rigorous modelling of long-term stability under different rainfall/climate scenarios.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Time-frame**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2012-005	**Project commencement date**		1/7/2012	
		Estimated completion date		30/6/2017	
Project duration (months)	30	**Date required**		31/12/2017	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	R&L	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Professor Tom Coulthard, University of Hull; Associate Professor Greg Hancock & Dr Danielle Verdon-Kidd, University of Newcastle				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**		45	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		9	

Aims

To assess the geomorphic stability of the proposed rehabilitated final landform for a simulated period of 10,000 years.

Background

The project aims to assess the geomorphic and erosional stability of the rehabilitated Ranger landform for a period of 10,000 years. A key requirement is the ability to incorporate and model the range of climate / rainfall extremes that may be expected to occur over 10,000 years. Related to the different climate / rainfall regimes, is identifying and determining size and distribution of gullies on the landform; the composition (bedload, suspended sediment), volume and distribution of sediment transport; and the effects of mass movement and weathering. Modelling will be principally undertaken using the CAESAR-Lisflood LEM, supported and supplemented by the SIBERIA LEM, which will be run separately to validate and assess CAESAR-Lisflood results.

Progress against plan

- Sensitivity testing of CAESAR-Lisflood parameters completed. Parameters used in model simulations have been revised/ updated and implemented in current and future model simulations.
- Long-term rainfall datasets of climate analogues for extreme wet and extreme dry climate scenarios developed and applied to long-term simulations of rehabilitated landform.
- Synthetic rainfall datasets have been utilised in long-term modelling simulations to assess landform stability to different rainfall intensities, frequencies and volumes.
- Enhanced vegetation modelling component developed – testing and calibration ongoing.
- Peer-reviewed conference paper presented on the use of long-term modelling of rehabilitated landform using synthetic rainfall datasets.
- Peer-reviewed papers on early landscape evolution (Catena); application of synthetic rainfall datasets for landform modelling simulations (Journal of Hydrology); and erosion predictions using climate change analogues (Science of the Total Environment) published.

Key findings

- The frequency and intensity of rainfall events in the climate analogue and synthetic rainfall datasets used in model simulations produced variations in predicted sediment loads, and the extent and magnitude of erosion and gully formation across the landform. However, while the predicted volume and magnitude/ erosion depth varied with the individual rainfall scenario used in the simulations, the distribution / location of large erosion features was constant.
- Model predictions of initial high sediment loads in years immediately after rehabilitation, which rapidly reduce in the following years are supported by multi-year field measurements from the trial landform.
- CAESAR-Lisflood simulations indicate that it will take several thousand years for the denudation rate of the rehabilitated landform to reach the background denudation rate of 0.01-0.04 mm/yr
- Model simulations show that differences in the geomorphology / topography of catchment areas produces variations in the rates of erosion and gully formation. This is demonstrated in the reduced erosion occurring from the modified landforms applied of the catchments containing Pit 1 and Pit 3; and reinforced through the comparison with simulations of pre-mining (undisturbed) catchments.

- Model results provide a best estimate of the potential extent of erosion and areas of potential gully formation, but are not absolute indicators of gully position or erosion depth.

Workplan for 2017–18

Complete write-up and publication of outputs.

Planned project outputs and associated outcomes

The main outputs for this project will be:

- A long-term (10,000 year) assessment of the geomorphic stability of the conceptual rehabilitated landform of the Ranger mine. A variety of scenarios will be simulated, incorporating a range of weathering, surface cover types, vegetation scenarios, and climate/ rainfall regimes, using the CAESAR-Lisflood and SIBERIA landform evolution models.
- Peer-reviewed papers describing the processes involved in the long-term modelling process, including the use of the CAESAR-Lisflood and SIBERIA LEMs to complement and validate model outputs.
- Two conference presentations (Life of Mine and Climate Adaptation conferences).
- Two journal publications (Journal of Hydrology; additional publication to be decided).

The outcome of this project will be an optimum landform design with respect to erosional stability and geomorphic impact on the surrounding catchment, incorporating the potential impact of extreme climate events.

Planned communication activities

The primary communication activities for the project in 2017-18 are:

- Conference presentations, including a paper at the Enviromine conference
- Technical Working Group presentations
- Journal publications (two journal papers currently in preparation)

Project publications to date (if applicable)

Hancock GR, Lowry J & Coulthard, T 2014a. Catchment reconstruction – erosional stability at millennial time scales using landscape evolution models, Geomorphology, Vol. 231, pp. 15–27.

Hancock GR, Willgoose GR, & Lowry, J 2014b. Transient landscapes: gully development and evolution using a landscape evolution model, Stochastic Environmental Research and Risk Assessment, Vol. 28(1), pp. 83-98 DOI 10.1007/s00477-013-0741-y.

Hancock GR, Coulthard TJ & Lowry JBC 2015. Predicting uncertainty in sediment transport and landscape evolution the influence of initial surface conditions. Computers and Geosciences Vol. 90(Part B) pp117-130 DOI: 20.1010/j.cageo.2015.08.014.

Hancock GR, Lowry JBC & Coulthard TJ 2016a. Long-term landscape trajectory – can we make predictions about landscape form and function for post-mining landforms? Geomorphology, Vol. 266, pp121-132. DOI: 10.1016/j.geomorph.2016.05.014.

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Hancock GR, Lowry JBC & Saynor MJ 2016. Early landscape evolution – a field and modelling assessment for a post-mining landform. Catena, Vol. 147, pp 699-708.

Hancock GR, Verdon-Kidd D & Lowry JBC 2017a. Sediment output from a post-mining catchment – centennial impacts using stochastically generated rainfall. Journal of Hydrology. Vol. 544, pp 180-194.

Hancock GR, Verdon-Kidd D & Lowry JBC 2017b. Soil erosion predictions from a landscape evolution model – an assessment of a post-mining landform using spatial climate change analogues. Science of the Total Environment 601-602, pp. 109-121.

Hancock GR, Lowry JBC & Saynor M 2017c. Surface armour and erosion – impacts on long-term landscape evolution. Land Degradation and Development. DOI 10.1002/ldr.2738.

Lowry, JBC, Coulthard, TJ & Hancock GR. 2013. Assessing the long-term geomorphic stability of a rehabilitated landform using the CAESAR-Lisflood landscape evolution model, in Proceedings of the 8th International Conference on Mine Closure, M Tibbett, AB Fourie and C Digby (eds), 18–20 September 2013, Cornwall, United Kingdom, Australian Centre for Geomechanics, Perth, pp. 611–624.

Lowry, JBC, Hancock GR & Coulthard TJ 2015a. Assessing the evolution of a post-mining landscape using landform evolution models at millennial time scales. In Proceedings of the 10th International Conference on Mine Closure, AB Fourie, M Tibbett, L Sawatsky and D vanZyl (eds) , 1-3 June 2015, Vancouver Canada, Infomine Inc. pp. 207-220.

Lowry J, Erskine W, Pickup G, Coulthard T & Hancock G 2015b. Future Directions for Application of Landform Modelling by the Supervising Scientist: Response to the Review of the application of the CAESAR-Lisflood model by the ERISS Hydrologic, Geomorphic and Chemical Processes program. Supervising Scientist Report 210, Supervising Scientist, Darwin NT.

Lowry JBC, Verdon-Kidd D, Hancock GR, Saynor MJ & Coulthard TJ 2016. Application of synthetic rainfall data to long term modelling of a rehabilitated landform. In Proceedings of the Life-of-Mine 2016 Conference, 28-30 September, Brisbane Australia, The Australiasian Instititute of Mining and Metallurgy, pp. 75-79.

Project details					
Project title	Impact of rip lines on runoff and erosion				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Assess impact of rip lines on a landform surface, through modelling amounts of erosion resulting from comparable ripped and non-ripped surfaces				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 2	**Time-frame**	2
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2015-016	**Project commencement date**		1/7/2015	
		Estimated completion date		1/12/2016	
Project duration (months)	6	**Date required**		1/12/2016	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	R&L	**Reason for project delay (where applicable)**		Staff resources and conflicting priorities, including the Ranger mine Closure Plan	
Supporting team(s)	N/A				
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**		10	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		0	

Aims

To determine what impact rip lines have on erosion and runoff from the final landform at Ranger for time periods up to 50 years.

Background

This project contributes to the understanding and quantification of the impact that rip lines have on runoff and erosion using the landform evolution model, CAESAR. There are differing ideas on the impacts rip lines have on erosion and runoff off rehabilitated landforms while there is

concern regarding the costs associated with the construction of rip lines. This project will of assist with the development and assessment of the final rehabilitated landform at the Ranger mine. It will inform closure on whether rip lines are required on the final landform to reduce both runoff and erosion.

Progress against plan

- The evolution of ripped and non-ripped surfaces on slopes of 2, 4, 8 and 12% have been modelled using CAESAR-Lisflood for simulated periods of up to 50 years.
- An internal report summarising study methods and results is in press.

Key findings

- Rip lines are very effective at reducing the sediment load from a landform under certain conditions. Specifically, under the conditions modelled in this study riplines are more effective at reducing erosion on slopes of up to 4% than non-ripped surfaces.
- On slopes of 8 and 12% ripped surfaces are predicted to become less effective than non-ripped surfaces at minimising sediment loads. Specifically, on steep slopes of 12%, ripped surfaces are predicted to produce higher sediment loads than non-ripped surfaces after a simulated period of 20 years.
- Simulations show that the structure of rip lines break down over time, with depressions infilling and peaks being eroded and reduced in height. These model results indicate that rip lines will not exist in perpetuity in the landscape.

Workplan for 2017–18

An internal report has been written and is currently with the Team Leader before commencing the internal review process. The internal report will be completed by 31 October 2017. A journal paper will be produced from the internal report during 2017-18 with a completion by June 2018.

Planned project outputs and associated outcomes

The main outputs for the project will be:

- Information on the impact of rip lines on runoff and erosion.
- Internal Report November 2016.
- One peer reviewed journal paper.

The outcome of this project will be information on the impacts that rip lines have on erosion from the final landform at Ranger.

Planned communication activities

The primary communication activities for the project are:

- Communication to the landform technical working group
- Peer reviewed journal publication

Project publications to date (if applicable)

There are no project publications to date.

Project details					
Project title	Development of enhanced vegetation component for the CAESAR model				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Enhance the capacity to incorporate vegetation growth patterns into long term land form evolution modelling, thereby increasing confidence in the accuracy and reliability of long-term model predictions.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Time-frame**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2015-027	**Project commencement date**		1/7/2015	
		Estimated completion date		1/12/2017	
Project duration (months)	6	**Date required**		1/12/2017	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	R&L	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Professor Tom Coulthard, University of Hull; Associate Professor Greg Hancock, University of Newcastle				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**		6	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		7	

Aims

- Finalise collation and analysis of remotely sensed data delineating temporal vegetation growth patterns for input into the CAESAR-Lisflood vegetation growth model.

- Calibrate vegetation parameters of the CAESAR-Lisflood LEM for the Ranger mine site and so inform closure design for the final rehabilitated landform.
- Prepare material for presentation at Life of Mine conference and in publication of special edition.

Background

Landform Evolution Models (LEMs) are important in the assessment of the closure design for the Ranger mine site as they provide a rational spatial framework to assess the long term stability of post-mining landscapes. However, factors controlling landscape evolution must be accurately portrayed in LEMs. This requires that input parameters for a LEM be scaled and calibrated to represent the landscape and environment of interest.

This project applies remote sensing to calibrate vegetation parameters used in the CAESAR-Lisflood LEM for application to the Ranger uranium mine located in the Alligator Rivers Region (ARR). Vegetation exerts strong controls on the hydrologic and geomorphic processes that drive landscape evolution. Hence, vegetation and the scales over which typical patterns in vegetation are represented, are important considerations in LEM calibration. Remote sensing enables patterns in vegetation to be measured at extents and spatial and temporal scales relevant to landscape evolution.

Progress against plan

- Multi-scale remotely sensed data and field observations collated for integration and input into enhanced vegetation cover growth model developed for CAESAR-Lisflood.
- Initial phase of vegetation growth model development complete.
- Progress on development of enhanced vegetation model presented at Life of Mine conference in Brisbane in September 2016.
- Methodology for calibration and validation of vegetation developed.
- Testing and application of the enhanced vegetation growth component is continuing.

Key findings

- CAESAR-Lisflood simulations are able to simulate the dynamic growth of vegetation communities in response to variable rainfall intensity and topography and predict erosion extent and quantity under those conditions.
- Initial sensitivity tests indicate that the 'vegetation critical shear' parameter is a key factor in controlling / reducing the amount and quantity of erosion that may result during a model simulation.

Workplan for 2017–18

Complete write-up and publication of outputs.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Conference presentation at Life of Mine 2016.
- Peer-reviewed journal paper on development of vegetation component of CAESAR model.

The outcomes that this project will achieve are an enhanced vegetation growth model integrated into the CAESAR-Lisflood model.

Planned communication activities

The primary communication activities for the project are:

- Attendance at Life of Mine conference in Brisbane, September 2016.
- Submit peer-reviewed journal paper to appropriate publication (to be decided).
- Reporting and presentations to key stakeholders.

Project publications to date (if applicable)

Boyden J, Lowry JBC, Coulthard TJ, Whiteside T, Hancock GR & Grant S 2016. Accounting for vegetation dynamics in landform evolution modelling. In Proceedings of the Life-of-Mine 2016 Conference, 28-30 September, Brisbane Australia, The Australiasian Instititute of Mining and Metallurgy, pp. 63-66.

Project details			
Project title	Site specific turbidity and suspended sediment relationships and determining suspended sediment event loads		
SSB function	Research	**Site**	Ranger
Project category	Demonstrating achievement of closure criteria	**Project status**	Active
What business need does this project inform?	Once the relationships have been determined at sites on Gulungul and Magela creeks, continuous suspended sediment will be used to determine what if any impact the mine is having. It informs achievement of the closure criteria.		
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1 **Time-frame** 2 **Importance** 1 **Time buffer** A
Project number (if already commenced)	RES-2016-007	**Project commencement date**	1/7/2016
		Estimated completion date	30/6/2018
Project duration (months)	24	**Date required**	1/12/2019
In-house or outsourced	External	**Actual completion date**	N/A
Lead team	R&L	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	Ken Evans		
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**	3
Project sponsor	Bartolo, Renee	**Project total estimated collaborator resources (person weeks)**	16

Aims

- Determine site specific relationships for suspended sediment and turbidity.
- Use these relationships to synthesise/develop a continuous suspended sediment trace from in-situ turbidity traces.
- Determine environmental impact using suspended sediment event load compared to background.

Background

Fine suspended sediment (FSS) concentrations in streams has been measured indirectly using turbidimeters in numerous studies in the ARR. As part of several studies in the ARR, in situ

turbidimeters were installed at gauging stations within the Magela Creek catchment to measure turbidity values on an almost continuous basis.

The measurement of suspended sediment is a time and resource dependant activity. Water samples collected at gauging stations by an automatic pump sampler during larger rainfall-runoff events have the FSS concentration determined by sieving, filtering and oven drying techniques. These FSS data along with concurrent in situ turbidity can be used to derive statistically significant relationships between FSS concentration and turbidity for gauging stations. These relationships allow the continuous turbidity data to be used to derive surrogate continuous FSS. In Moliere and Evans (2010), suspended sediment and turbidity relationships were developed up until 2008 for stations on Magela and Gulungul creeks.

This project will check FSS versus turbidity relationships for Gulungul Creek and Magela Creek (MCDS & MCUS) using samples collected since 2008, and update as necessary.

Progress against plan

Professor Ken Evans has written a consultant's report on the analysis of fine suspended sediment transport in Gulungul Creek. This report analysed existing data on Gulungul Creek.

Key findings

The suspended sediment turbidity relationships were analysed for Gulungul Creek upstream (GCUS) and Gulungul Creek downstream (GCDS). The relationship at GCUS had changed slightly from previous analysis and there was insufficient additional samples at GCDS to determine if the relationship had changed. Recommended that fine suspended sediment sample should be collected to further check these relationships.

Workplan for 2017–18

- Check the suspended sediment turbidity relationship for Magela Creek.
- Determine natural suspended sediment loads for Magela Creek.

Planned project outputs and associated outcomes

The output of this project will be site specific suspended sediment turbidity relationships that will enable continuous suspended sediment loads to be determined.

This will be used firstly in total event load determinations (by regression equation) and possibly using BACIP to asses mine related impacts downstream of the rehabilitated landform.

Planned communication activities

- Consultant report
- Journal publication
- Presentations and discussions with relevant stakeholders

Project publications to date (if applicable)

Evans KG, Naravan M & Saynor MJ 2017 Analysis of fine suspended sediment transport in Gulungul Creek adjacent to Ranger Mine, Jabiru NT, Unpublished Confidential Report.

Moliere DR, Evans KG, Saynor MJ & Smith BL 2005. Hydrology and suspended sediment of the Ngarradj catchment, Northern Territory: 2003–2004 wet season monitoring. Internal Report 497, February, Supervising Scientist, Darwin. Unpublished paper.

Moliere DR & Evans KG 2010. Development of trigger levels to assess catchment disturbance on stream suspended sediment loads in the Magela Creek, Northern Territory, Australia. Geographical Research 48, 370–385.

Ranger – Rehabilitation

Radiation (5 projects)

Project details					
Project title	Radionuclide uptake in traditional Aboriginal foods				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Completed		
What business need does this project inform?	Protecting the health of Aboriginals and other members of the regional community				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Time-frame**	1
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-1996-002	**Project commencement date**		1/1/1996	
		Estimated completion date		1/12/2016	
Project duration (months)	6	**Date required**		1/6/2016	
In-house or outsourced	Internal	**Actual completion date**		1/12/2016	
Lead team	ENRAD	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	JFS				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**		10	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		0	

Aims

- To measure radionuclides in Aboriginal bush foods and determine their concentration ratios
- To estimate doses to Aboriginal people from radionuclides in bush foods
- To develop tools to calculate concentration ratios and ingestion doses

Background

Bush foods form the traditional diet of Aboriginal people. Areas downstream and surrounding Ranger mine serve as bush food reservoirs for Aboriginal people. Concerns have been raised

about potential radionuclide contamination of bush foods in these reservoirs due to the operation and pending rehabilitation of the mine. Supervising Scientist has been collecting bush foods and measuring radionuclides in them for more than 30 years, resulting in a substantial database of bush food radionuclide activity concentrations. This database can be used to calculate bush food concentration ratios and facilitate ingestion dose assessments.

Progress against plan

- Bush foods collected and measured for their radionuclide content for more than 30 years.
- Database of bush food radionuclide concentrations developed and published.
- Tool for calculating concentration ratios from the database developed and published.
- Bush food dose calculator developed and published.

Key findings

- Po-210 is the priority radionuclide for ingestion doses from terrestrial bush foods due to higher accumulation and dose coefficients than other radionuclides.
- Ra-226 is the priority radionuclide for ingestion doses from aquatic bush foods due to its higher accumulation (particularly in freshwater mussels) than other radionuclides.
- Bush food ingestion doses during the operational phase of Ranger uranium mine are estimated to be low.
- Bush food ingestion doses after rehabilitation of Ranger uranium mine will depend on radionuclide activity concentrations on the final landform and in surface water, as well as land use for hunting and gathering by traditional owners.

Workplan for 2017–18

N/A. The project is completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Data on radionuclide activity concentrations and concentration ratios in bush foods.
- Database for storing data in a standardised format.
- Tool for calculating concentration ratios from the database.
- Calculator for estimating ingestion doses from bush foods.

The outcomes that this project will achieve are:

- Community assurance that bush foods remain 'safe' to eat during operational phase of the mine.
- Demonstrating (in part) the achievement of radiological closure criteria for the mine.

Planned communication activities

The primary communication activities for the project are:

- Liaison with Aboriginal people on traditional diet and involving them in bush food collections
- Supervising Scientist Annual Technical Report

- Publication in scientific journals

Project publications to date (if applicable)

Past five years:

Doering, C., Bollhöfer, A., Medley, P., 2017. Estimating doses from Aboriginal bush foods post-remediation of a uranium mine. Journal of Environmental Radioactivity 172, 74-80.

Doering, C., Bollhöfer, A., 2016. A tool for calculating concentration ratios from large environmental datasets. Journal of Environmental Radioactivity 165, 32–34.

Doering, C., Bollhöfer, A., 2016. A database of radionuclide activity and metal concentrations for the Alligator Rivers Region uranium province. Journal of Environmental Radioactivity 162–163, 154–159.

Medley, P., Bollhöfer, A., Parry, D., Martin, P., 2013. Radium concentration factors in passionfruit (Passiflora foetida) from the Alligator Rivers Region, Northern Territory, Australia. Journal of Environmental Radioactivity 126, 137–146.

Medley, P., Bollhöfer, A., 2016. Influence of group II metals on Radium-226 concentration ratios in the native green plum (Buchanania obovata) from the Alligator Rivers Region, Northern Territory, Australia. Journal of Environmental Radioactivity 151, 551–557.

Project details					
Project title	Dose rates to non-human biota				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Protecting wildlife from exposures to ionising radiation associated with the rehabilitated landform				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Time-frame**	1
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2012-002	**Project commencement date**	1/1/2016		
		Estimated completion date	31/12/2017		
Project duration (months)	24	**Date required**	1/1/2018		
In-house or outsourced	Collaboration	**Actual completion date**	N/A		
Lead team	ENRAD	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	ARPANSA				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**	8		
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**	8		

Aims

The aims of this project are to:

- Derive a soil radiological quality guideline value for terrestrial wildlife.
- Derive scaling factors between absorbed dose rate to aquatic organisms and radionuclide activity concentrations in surface water.

Background

The current recommendations of the International Commission on Radiological Protection (ICRP) recognise the need to consider radiation exposures to wildlife in addition to those to people. The reason is to demonstrate directly that the environment is protected from deleterious radiological impacts associated with industrial activities. Evaluation of radiation exposures to

wildlife for environmental protection purposes is currently based on comparing estimates of whole organism dose rates from internal and external radionuclides to effects-based benchmark values of absorbed dose rate. This project will provide methods for estimating dose rates to wildlife.

Progress against plan

- Paper published on soil radiological quality guideline value for terrestrial wildlife.
- Final consultancy report received from ARPANSA in November 2016 with results of dose scaling factors for aquatic organisms.

Key findings

- A guideline value of 1000 Bq/kg of uranium-238 in surface waste rock would result in closure criteria for radiation protection of terrestrial wildlife being achieved.
- Dose scaling factors for aquatic organisms were generally highest for freshwater mussels, particularly for radium-226 and polonium-210.

Workplan for 2017–18

July 2017-September 2017: Write up of research paper on dose scaling factors for aquatic organisms.

Planned project outputs and associated outcomes

The outputs for this project include:

- Two papers in international and peer reviewed scientific journals. A soil radiological quality guideline value for terrestrial wildlife.
- Dose scaling factors for aquatic organisms.

The primary outcome for this project is wildlife dose modelling for the Ranger rehabilitation context using available site-specific data to demonstrate radiation protection of the environment against rehabilitation standards.

Planned communication activities

- Papers published in international and peer reviewed scientific journal.
- Key findings published in the Supervising Scientist Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community.

Project publications to date (if applicable)

Doering C & Bollhöfer A 2016. A soil radiological quality guideline value for wildlife-based protection in uranium mine rehabilitation. Journal of Environmental Radioactivity 151, 522-529.

Carpenter J, Orr B, Urban D & Grzechnik M 2016. Radiological assessment of freshwater ecosystem downstream of Ranger uranium mine. Report prepared under MoU 1516-0447.

Project details					
Project title	Atmospheric dispersion of radon and radon daughters from the rehabilitated landform				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Protecting the health of Aboriginals and other members of the regional community.				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Time-frame**	1
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2014-004	**Project commencement date**		1/1/2016	
		Estimated completion date		31/12/2017	
Project duration (months)	24	**Date required**		1/1/2018	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	ENRAD	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	ANSTO				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**		8	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		8	

Aims

The aims of this project are to:

- Model the atmospheric dispersion of radon-222 from the Ranger final landform.
- Develop maps of radon progeny dose potential for people in the vicinity of the final landform.
- Demonstrate (in part) the achievement of radiological closure criteria for Ranger mine.

Background

Radon-222 is an inert radioactive gas formed from the decay of radium-226 in the uranium decay series. When radium-226 in soil or rock decays, the resulting radon-222 atom can emanate into the pore space, be transported to the ground surface and exhale to the atmosphere. It is then

dispersed in the atmosphere by wind and thermal currents. When radon-222 decays it produces a series of short-lived progeny radionuclides. Unlike radon, these progeny radionuclides are metals (not gases) and can attach to aerosols. The main contribution to dose from the radon exposure pathway comes from the inhalation of progeny radionuclides because of their retention in the lung tissue and subsequent alpha decay. Radon-222 itself does not contribute much to inhalation dose, as it is immediately exhaled from the lung, with little decay occurring inside the lung due to its long half-life of ~3.8 days.

The current rehabilitation strategy for Ranger mine involves the creation of a final landform overlaid with several metres of waste rock, which is excavated material with a uranium-238 activity concentration of up to 2100 Bq/kg. This is distinctively elevated compared to the surrounding natural environment (~30–100 Bq/kg) and the average pre-mining baseline of the Ranger site (~260 Bq/kg). Thus, the rehabilitated landform represents a potential source of above baseline radon progeny exposure to people in its vicinity. This project will model the atmospheric dispersion of radon-222 from the final landform for use in dose assessments of the radon progeny inhalation pathway.

Progress against plan

- Initial dispersion modelling performed by ANSTO has been refined using a better resolution footprint of the final landform and wet/dry season atmospheric stability array files.
- Maps of radon-222 dispersion and radon progeny dose potential out to 10 km from the final landform developed.

Key findings

- Much higher radon dose potential in the dry season due to higher exhalation flux densities from waste rock.
- Dose potential is highest along the prevailing wind direction, which, in the dry season, is towards the west.

Workplan for 2017–18

July 2017-September 2017: Draft and submit manuscript on dispersion modelling method and results to international and peer-reviewed scientific journal.

Planned project outputs and associated outcomes

The outputs for this project include:

- Paper published in international and peer reviewed scientific journal.
- Maps of radon-222 dispersion and radon progeny dose potential for the final landform.

The project outcome is:

- Dose modelling of the radon exposure pathway which, when combined with modelling results of other radiation exposure pathways, will demonstrate whether the rehabilitation standard for radiation protection of people can be achieved for the Ranger final landform.

Planned communication activities

- Paper published in international and peer reviewed scientific journal.
- Key findings published in annual technical report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community.

Project publications to date (if applicable)

ANSTO 2016. Radon and dust inhalation dose rate scaling factors from RESRAD modelling of the future rehabilitated Ranger uranium mine site. Consultancy report ANSTO-C-1479, ANSTO, commercial in confidence.

Project details					
Project title	Environmental fate and transport of Ac-227 and Pa-231				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Protecting the health of Aboriginals and other members of the regional community. Protecting the environment of the Alligator Rivers Region from the effects of uranium mining.				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Time-frame** 1	
			Importance 2	**Time buffer** A	
Project number (if already commenced)	RES-2015-014	**Project commencement date**		1/2/2015	
		Estimated completion date		1/2/2021	
Project duration (months)	72	**Date required**		1/2/2021	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	ENRAD	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	ANU				
Project manager	Medley, Peter	**Project total estimated internal resources (person weeks)**		180	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		24	

Aims

The aims of this project are to:

- Develop methods to prepare and measure environmental samples for actinium-227 and protactinium-231.
- Measure actinium-227 and protactinium-231 in environmental samples and determine concentration ratios.
- Estimate radiation dose contributions to people and non-human biota from actinium-227 and protactinium-231.

Background

Although a significant body of research has been undertaken on the behaviour of radionuclides of the uranium series in the environment, there is very little information for actinium series radionuclides, in particular actinium-227, partly because techniques for measurement of two key isotopes in the actinium series – protactinium-231 and actinium-227 – are limited and prone to technical difficulties (particularly in the chemical separation steps). It is also argued that the activity concentration of uranium-235, at the head of the actinium series, is ~20 times below that of uranium-238 for natural uranium and is therefore less significant. However, actinium-227 dose conversion coefficients are typically higher than those for the uranium-238 series radionuclides, with ingestion doses similar to those of polonium-210, 1.6 times higher than lead-210 and 4 times higher than radium-226. Inhalation dose coefficients for both actinium-227 and protactinium-231 are higher than for polonium-210, lead-210 and radium-226 even after taking into account the relative abundances of the parents of the different decay chains. Uranium mining and milling may significantly increase the mobility of radionuclides in both the uranium and actinium series compared to the natural state creating the potential for these isotopes to be released into the environment and potentially leading to increased exposure to ionising radiation for humans and non-human biota.

Environmental assessment of the Ranger uranium mine, both before and after mine closure, requires that all potential pathways of exposure to ionising radiation be considered. This project involves research into techniques for measurement of environmental concentrations of protactinium-231 and actinium-227, and the potential mobility of these isotopes in aquatic and terrestrial environments in the vicinity of Ranger mine.

Progress against plan

- Method developed for preparation of a protactinium-233 tracer for determining the recovery efficiency of protactinium-231 in environmental samples undergoing radiochemistry processing.
- Calibration of actinium-227 tracer solution completed and the solution used to validate an extraction chromotography method for actinium-227 separation.
- Preliminary testing of a liquid scintillation counting method for actinium-227 measurement undertaken.
- Confirmation of the use of alpha spectrometry for measurement of actinium-227.

Key findings

- The use of liquid scinitillation counting would not be able to achieve the required detection limits for Ac-227.
- Source preparation of Ac-227 as a lanthanide hydroxide for alpha spectrometry will be able to achieve the desired detection limits.
- Using the injection species of PaO2 is the most efficient in the 14UD accelerator mass spectrometer for measurement of Pa-231 and reduces interference from U-233 to non-significant levels.
- Pa-233 can be effectively separated from Np-237 for use as a tracer isotope for Pa-231 measurement via accelerator mass spectrometry.

- Sufficient activity of Pa-231 is present in freshwater mussels of the ARR to enable the use of current sample preparation methods for anlaysis of Pa-231.

Workplan for 2017–18

- Calibration of the Accelerator Mass Spectrometer for measurement of protactinium-231.
- July 2017-September 2017: Calibration of alpha spectrometer and/or liquid scintillation counter for measurement of actinium-227.
- October 2017-December 2017: Assessment of potential chemical analogues of Ac and Pa for estimating concentration ratios in bush foods and wildlife.
- January 2018-March 2018: Development of a sample preparation protocol for samples requiring measurement of actinium-227 and protactinium-231.
- April 2018-June 2018: Measurement of actinium-227 via alpha spectrometry or liquid scintillation counting on a selected suite of environmental samples.

Planned project outputs and associated outcomes

The outputs for this project include:

- Development of a new method for preparing a protactinium-233 tracer for radiochemical measurement of protactinium-231.
- Development of new methods for separating protactinium-231 from environmental samples and measurement via accelerator mass spectrometry.
- Development of new methods for separating actinium-227 from environmental samples and measurement via alpha spectrometry and/or liquid scintillation counting.
- Measurement of protactinium-231 via accelerator mass spectrometry and actinium-227 via alpha spectrometry on a selected suite of environmental samples.
- Actinium-227 and protactinium-231 concentration ratios for bush foods and wildlife.

The outcome from this study will be an evidence-based understanding of the radiological importance of actinium-series radionuclides in the Ranger rehabilitation context.

Planned communication activities

- Papers published in international and peer reviewed scientific journal.
- Key findings published in annual technical report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community.

Project publications to date (if applicable)

There are no publications for the project to date.

Project details			
Project title	Tissue to whole organism conversion factors for radionuclides in wildlife		
SSB function	Research	**Site**	Ranger
Project category	Demonstrating achievement of closure criteria	**Project status**	Active
What business need does this project inform?	Protecting the environment of the Alligator Rivers Region from the effects of uranium mining.		

Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance**	2	**Time-frame**	1
			Importance	2	**Time buffer**	A

Project number (if already commenced)	To be advised	**Project commencement date**	1/1/2016
		Estimated completion date	31/12/2017
Project duration (months)	24	**Date required**	1/1/2018
In-house or outsourced	Collaboration	**Actual completion date**	N/A
Lead team	ENRAD	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	ARPANSA		
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**	8
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**	8

Aims

To derive tissue to whole organism conversion factors for radionuclides and stable elements across a range of wildlife groups and tissue types.

Background

The current recommendations of the International Commission on Radiological Protection (ICRP) recognises the need to consider radiation exposures to wildlife in addition to those to people. The reason is to demonstrate directly that the environment is protected from deleterious radiological impacts associated with industrial activities.

Most radionuclide data for wildlife is for specific tissue components. By contrast, wildlife dose assessments require knowledge of the whole organism radionuclide activity concentrations.

Factors are needed to convert existing radionuclide data for specific tissues to the whole organism format required for wildlife dose assessments.

This project is part of the broader project on dose rates to non-human biota and will use existing tissue radionuclide data to derive site-specific tissue to whole organism conversion factors for a range of wildlife groups. The factors will be used within wildlife dose assessments to demonstrate whether the remediation strategy for Ranger mine can achieve closure criteria for radiation protection of the environment.

Progress against plan

Preliminary data analysis performed by ARPANSA and report provided in November 2016 as part of the project on dose rates to non-human biota.

Key findings

Tissue to whole organism conversion factors derived from site-specific data were generally within the range of international reference values, though up to an order of magnitude higher for group 2 elements, including radium.

Workplan for 2017–18

- Gamma spectrometry analysis of mussel shells
- Data analysis
- Write up of research paper

Planned project outputs and associated outcomes

The primary output for this project is a journal paper with site-specific tissue to whole organism conversion factors for a range of elements and wildlife groups.

The primary outcome for this project is wildlife dose modelling for the Ranger rehabilitation context using available site-specific data to demonstrate radiation protection of the environment against rehabilitation standards.

Planned communication activities

- Paper published in international and peer reviewed scientific journal
- Key findings published in annual technical report
- Presentations to key stakeholders on request
- Presentations to the broader scientific community

Project publications to date (if applicable)

Carpenter J, Orr B, Urban D & Grzechnik M 2016. Radiological assessment of freshwater ecosystem downstream of Ranger uranium mine. Report prepared under MoU 1516-0447.

Ranger – Rehabilitation

Flora and fauna (3 projects)

Project details					
Project title	Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria - Stage 1. Descriptive component				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Develop and monitor closure criteria				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 1	**Time-frame**	2
			Importance 2	**Time buffer**	D
Project number (if already commenced)	RES-2013-002	**Project commencement date**		1/9/2013	
		Estimated completion date		1/11/2016	
Project duration (months)	5	**Date required**		1/11/2018	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	R&L	**Reason for project delay (where applicable)**		Other priorities have impacted on the delivery time of this project	
Supporting team(s)	N/A				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**		140	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		0	

Aims

- Develop a timeline of landscape disturbances and change for Kakadu National Park, and in particular the Ranger mine site area (1950-2015).
- Characterise vegetation change for a 'stable' temporal envelope (1996-2015) using the aerial photography record.

- Characterise vegetation recovery using the aerial photography record, (a) immediately post BTEC from 1996, and (b) post Cyclone Monica (from 2006).
- Characterise vegetation trajectory under a disturbance regime (1950 – 1981) using the aerial photography record.

Background

It is important that closure criteria and our understanding of analogue sites for the Ranger mine site, are developed in the context of temporal change in the landscape and disturbance of the site. The Environmental Requirements refer specifically to revegetation under the primary environmental objectives for rehabilitation:

"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 Kakadu National Park, 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".

There are both spatial and temporal components in this objective that need to be addressed and a landscape ecology approach is an appropriate framework to do this by. The aerial photography record of the region provides a suitable dataset to analyse vegetation change and trajectories for the Ranger minesite and surrounds over a number of temporal phases spanning 1950-2016.

The previous vegetation analogue research provides some of the information required for informing terrestrial vegetation criteria (such as species lists), but it is limited in both spatial and temporal extent, providing snapshots across the landscape but not the whole story. A landscape approach, such as deriving measures from time series remote sensing, provides a total dataset to compare an area of interest with the surrounding landscape through time. This approach will capture the natural variability, change and disturbance which have not been analysed in the previous research.

The outputs from this project will provide an envelope of variability, or trajectory, in setting closure criteria and provide a continuous representation of the landscape rather than discrete sampling points both spatially and temporally.

Progress against plan

- Woody cover data sets have been created from aerial photo mosaics for 1950, 1964, 1976, 1978, 1981, 1984, 1987, 1991, and 2004.
- Woody cover data sets have been created from WorldView satellite imagery for 2010 and 2016.
- Descriptive statistics on tree cover, change in tree cover and fate attributes derived from landscape metrics have been compiled.
- A manuscript describing the methodology for creating the woody cover data sets has been drafted for submission to a peer-reviewed journal for publication.
- A manuscript describing the application of landscape and fate analysis metrics for woody cover change analysis has been drafted for submission to a peer-reviewed journal for publication.

Key findings

Time series analysis of the woody cover data sets shows that savanna woody cover is quite variable across the site both temporally and spatially. This variability is likely attributed to the presence of disturbance agents including fire, feral water buffalo and extreme weather events. Closure criteria relevant to vegetation will need to factor in the variability of woody cover in savanna and the impact of disturbance agents.

Workplan for 2017–18

Finalisation and submission of the following journal papers:

- Woody cover mapping method compared with traditional ecological methods.
- Landscape metrics tool box and application to savanna temporal.

Production and submission of the following journal papers:

- Decadal ecological change in the savanna surrounding Ranger uranium mine.
- The use of time series woody cover information to refine closure criteria.

Production of an internal report documenting in detail the data, methods, rule sets, tool boxes and validation processes.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Decadal time series analysis of woody cover change over the region surrounding the mine between 1950 and 2016.
- Journal publications describing the methodology used and products created, the analysis of change over time and how this can be used to refine closure criteria.
- Timeline infographic completed in collaboration with PAA. Made available for presentations and closure criteria technical working groups.

The outcomes that this project will achieve are:

- The characteristics of savanna habitat dynamics over a 'stable' temporal scale and the timeline of landscape changes and disturbances can be used to define trajectories for informing and reviewing closure criteria.

Planned communication activities

The primary communication activities for the project are:

- Timeline of landscape change
- Report to the Closure Criteria Working Group with key recommendations for setting vegetation closure criteria
- Plain language summary of the key findings and advice on when (timeframe) the revegetation may be on an agreed trajectory to meeting the ERs
- Conference presentation
- Journal papers

Project publications to date (if applicable)

No project publications to date.

Project details					
Project title	Vegetation analogue review				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Develop and monitor closure criteria				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 1	**Time-frame** 2	
			Importance 2	**Time buffer** C	
Project number (if already commenced)	RES-2014-002	**Project commencement date**	1/2/2014		
		Estimated completion date	30/10/2017		
Project duration (months)	6	**Date required**	1/10/2018		
In-house or outsourced	Collaboration	**Actual completion date**	N/A		
Lead team	R&L	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	WASQ, UQ				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**	25		
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**	15		

Aims

- Review existing vegetation analogue research undertaken in relation to Ranger mine site and catalogue the data.
- Assess the existing vegetation analogue sites in the context of remote sensing imagery that provides a continuous dataset, and whether the full range of habitats have been characterised.
- Scale the existing species information to a comparable size for the rehabilitated area to provide appropriate closure criteria for species density.
- Undertake a preliminary assessment of understorey characteristics for analogue sites using existing ultra high resolution remotely sensed data (UAV derived).
- Produce a synthesis of the information from aims 1 and 2 to inform vegetation closure criteria.

Background

It is important that closure criteria for the Ranger mine site are developed based on an understanding of analogue sites in the surrounding area. Research on vegetation analogues has been undertaken in the past by SSB and ERA using traditional ecological methods predominantly at the plot scale (i.e. ground-based surveys). The output of this research has been identification of plant community types that has resulted in an agreed species list for rehabilitation. Other site assessments containing vegetation data (e.g. historical Northern Territory Government surveys) have not been included in the analogue research and analyses to date. More importantly, the research that has been undertaken has only focussed on shrubs (>1.5 m in height) and trees, as this is the immediate priority in early establishment of revegetation. Discussions held by the Flora and Fauna Technical Working Group (TWG) have highlighted the gap in knowledge on understorey, particularly in the existing analogue research.

A limitation of ground-based survey approaches is that only small samples of the landscape are measured, and the results may not be representative of the communities and habitats when viewed at a landscape scale. A landscape approach, such as deriving measures from remote sensing, provides continuous data to: derive measures for closure criteria; and to compare the rehabilitated mine site with the surrounding landscape. Using remote sensing data, spatial statistics and landscape metrics, the existing analogue sites and data can be compared in a landscape context and ensure the range of communities and habitats have been defined.

This project addresses development and agreement of closure criteria for revegetation and informs ongoing work on the establishment and sustainability of ecosystems on the mine landform post-decommissioning. There is also a link to the savanna trajectory project.

Progress against plan

- Existing vegetation analogue research in relation to Ranger mine site was collected, catalogued and analysed for consistency.
- The applicability of the datasets was assessed against the following parameters: whether it was collected adjacent to the mine; what type of substrate it occurred on; how variable the landform was; and whether there was appropriate imagery available.
- Rarefaction curves for existing species data were calculated to demonstrate the likelihood of species numbers that should be present beyond the plots sampled and are able to be used to scale species numbers per vegetation community.
- Initial attempts have been made to contextualise the high-resolution remote sensing data across the Ranger lease area with the Georgetown analogue vegetation classes. However, due to some of the wetter environments (rainforest and paperbark communities) not occurring in the analogue area, the classification accuracy across the broader area was low.

Key findings

- The comprehensive data of shrubs and tree (>1.5 m in height) from 2010 survey the Georgetown analogue area, which coincided with WorldView-2 imagery, was determined to be the most appropriate to develop interim closure criteria.
- The Georgetown analogue area vegetation grouped into three vegetation classes, described using Bray-Curtis similarity and cluster analysis. These three vegetation communities were

clearly separated by average distance to waterways, suggesting underlying water gradients have a strong effect on observed vegetation patterns.

Workplan for 2017–18

- Use species information from existing analogue research and scale to develop closure criteria for the rehabilitated area.
- Preliminary assessment of understorey characteristics using existing UUAV data over an analogue site.
- Collation and analysis of fire history data for the analogues.
- Synthesis of information from above activities and communication activities.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Accessible catalogue of existing analogue data.
- Landscape scale map of vegetation communities derived from the existing analogue data (if possible using RFC approach).
- Synthesis report and journal publication on information derived from the aims of this project.
- Communication outputs as outlined in the planned communication activities section below.

The outcomes that this project will achieve are:

- Integration of existing analogue data with larger scale dataset to ensure robustness of the data underpinning closure criteria.
- Communication products for analogue-trajectory approach to closure criteria and expectations of landscape using analogue sites that stakeholders are familiar with.
- Refined closure criteria for relative abundance at the scale of the rehabilitation area.
- Scoping and plan to undertake a study on understorey to derive information for closure criteria specific to understorey.

Planned communication activities

The primary communication activities for the project are:

- Synthesis report on the vegetation analogue research review and analysis of existing data using remotely sensed imagery.
- Presentation to the Flora and Fauna Technical Working Group.
- Plain language summary of the research and the implications for vegetation closure criteria and monitoring.
- Stakeholder communication product on expected outcomes for revegetation (infographic).

Project publications to date (if applicable)

No project publications to date.

Project details					
Project title	Developing monitoring methods for revegetation using RPAS: Jabiluka revegetation				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Active		
What business need does this project inform?	Monitoring of relevant flora closure criteria				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 1	**Time-frame** 3	
			Importance 3	**Time buffer** D	
Project number (if already commenced)	RES-2014-003	**Project commencement date**	1/7/2014		
		Estimated completion date	1/10/2018		
Project duration (months)	24	**Date required**	1/10/2018		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	R&L	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)					
Project manager	Whiteside, Tim	**Project total estimated internal resources (person weeks)**	32		
Project sponsor	Bartolo, Renee	**Project total estimated collaborator resources (person weeks)**	0		

Aims

- The testing and development of methods for efficient and accurate monitoring of the success of mine site rehabilitation using RPAS technologies.
- To identify variables that can be measured that relate to relevant closure criteria.
- To monitor and analyse the success of the revegetation effort on the Jabiluka minesite using time series data.

Background

Monitoring minesite rehabilitation requires the assessment of indicators including those relevant to vegetation establishment and erosion. For the rehabilitated Ranger minesite, the impact of disturbances such as fire, weeds and cyclones also need to be measured and modelled. To help

make such assessments, data and information on these indicators is required at a suitable frequency and scale that can measure rehabilitation success.

RPAS technologies allow the acquisition of data that meet the frequency and scale requirements. The products from the analysis of RPAS data can be used to monitor changes in surface conditions, and vegetation growth.

The recent rehabilitation efforts at Jabiluka minesite provide an area for the testing RPAS techniques for data collection and analysis. The methods developed here will then be applied to the Ranger minesite as rehabilitation work progresses.

Progress against plan

To date, ten missions have been conducted over Jabiluka minesite. Data have been processed and analysed for all flights.

Key findings

Analysis shows an overall increase of woody cover on the site during the time frame. Fate analysis metrics show that while the number of plants intially decreased, the size of the surviving plants increased. Also of note was the number of volunteer plants being detected.

Workplan for 2017–18

- Ongoing collection of data at Jabiluka
- Processing and analysis of data sets
- Documentation including peer-reviewed publication

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Analysis of a time-series of RPAS imagery over Jabiluka minesite showing revegetation progress.
- An established set of methods for monitoring with RPAS technologies relevant to the assessment of particular vegetation closure criteria detailed in an IR.
- A journal article detailing the data collection and analysis method.
- A journal article highlighting the time-series analysis.

The outcomes that this project will achieve are:

- Cost effective and timely methods for measuring and assessing biophysical indicators that can be used to monitor the performance of rehabilitation against the relevant closure criteria.
- An understanding of the resource requirements to undertake such monitoring programs.
- Strategic capability to implement monitoring programs.

Planned communication activities

The primary communication activities for the project are:

- Conference presentations

- Journal papers
- Communication product developed with the PAA team on monitoring revegetation with RPAS imagery
- Reporting and presentations to key stakeholders as necessary

Project publications to date (if applicable)

Whiteside, T & Bartolo, R. 2016, Monitoring the vegetation success of a rehabilitated mine site using multispectral UAV imagery, presented at UAS4RS: Unmanned Aerial Systems for Remote Sensing Applications Conference 2016, Brisbane, 17-18 February 2016.

Whiteside, T & Bartolo, R. 2016, Robust and repeatable ruleset development for hierarchical object-based monitoring of revegetation using high spatial and temporal resolution UAS data, presented at 6th International Conference on Geographic Object-based Image Analysis (GEOBIA 2016), Enschede, The Netherlands, 14-16 September 2016. Online proceedings not yet available.

Ranger – Rehabilitation

CC theme: Groundwater (3 projects)

Project details					
Project title	Groundwater - Pit 1 Transmissivity Assessment				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Active		
What business need does this project inform?	An improved characterisation of zones that could provide a preferential pathway for COPC movement to be incorporated into the seasonal solute egress modelling.				
Closure criteria theme (if applicable)	Groundwater	**Project Priority**	**Relevance** 2	**Time-frame** 2	
			Importance 2	**Time buffer** D	
Project number (if already commenced)	To be confirmed	**Project commencement date**	2/5/2016		
		Estimated completion date	20/2/2020		
Project duration (months)	43	**Date required**	20/2/2020		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	S&M	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	N/A				
Project manager	Baker, Peter	**Project total estimated internal resources (person weeks)**	35		
Project sponsor	Turner, Kate	**Project total estimated collaborator resources (person weeks)**	0		

Aims

- To characterise the MBL zone for the use in seasonal solute egress modelling.
- To characterise the carbonate between Pit 1 and Pit 3 to determine whether hydraulic connection exists between the two pits.

Background

The MBL zone has been identified as a potential pathway for COPCs from the tailings in Pit 3 to move towards Corridor Creek. The current modelling indicates that while this will occur, the

timing and concentrations are insufficient to markedly increase COPC concentration when compared to that derived from the waste rock.

Initial analysis of the groundwater chemistry data indicates preferential pathways exist in the MBL zone and that the fluxes in groundwater identified by this analysis are quite variable. Recent pumping of the MBL bore has provided a dataset that indicates that the hydraulic conductivity in the MBL zone is at least an order of magnitude greater than that used in the groundwater model.

Consequently, a detailed characterisation of the MBL zone to determine the nature and distribution of 'higher' hydraulic conductivity that will allow COPCs into Corridor Creek, Georgetown Billabong and beyond, is required.

This project will also investigate, through characterisation, whether the carbonate between Pit 1 and Pit 3 can provide a pathway into the surface water systems as the area returns to pre-mining conditions.

Progress against plan

- Initial pumping test results have been analysed and hydraulic conductivities calculated.
- Compilation of groundwater chemistry data nearly compiled and initial analysis commenced.

Key findings

Nil to report

Workplan for 2017–18

Complete analysis of the geology, hydrogeology, geochemistry and current pump test results to characterise in detail the MBL zone and determine whether further primary data acquisition is required.

Planned project outputs and associated outcomes

The outputs for this project include:

- A hydrogeological and geochemical data set for the Pit area.
- A hydrogeological characterisation of the MBL zone.
- A transmissivity assessment of the MBL zone and the carbonate between Pit 1 and Pit 3.

The outcomes from this study will be:

- An improved understanding of the preferential pathways through the MBL zone that can be incorporated into the seasonal solute egress modelling to provide greater confidence in the model predictions.
- An improved understanding of the role of the carbonate in groundwater movement between Pit 1 and Pit 3 and its ability, if any, to transmit COPC from the tailings in Pit 1 into the broader groundwater system.

- The results of this project could also help improve the siting of monitoring bores for model validation and early warning monitoring of potential impacts.

Planned communication activities

- Presentation to ARRTC and ARRAC
- Technical reports
- Journal paper

Project publications to date (if applicable)

There are no publications for this project to date.

Project details					
Project title	Groundwater - Pit 3 Transmissivity Assessment				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Active		
What business need does this project inform?	An improved characterisation of zones that could provide a preferential pathway for COPC movement to be incorporated into the seasonal solute egress modelling.				
Closure criteria theme (if applicable)	Groundwater	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	To be advised	**Project commencement date**	20/2/2017		
		Estimated completion date	22/12/2017		
Project duration (months)	10	**Date required**	22/12/2017		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	S&M	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)					
Project manager	Baker, Peter	**Project total estimated internal resources (person weeks)**	14		
Project sponsor	Turner, Kate	**Project total estimated collaborator resources (person weeks)**	0		

Aims

- Determine whether COPCs from the tailings deposited in Pit 3 can be transmitted through the fracture zone in the north face.
- Determine the role of the carbonate in the south face of Pit 3 and its role in groundwater movement in the Pit 3 area.
- Obtain a better understanding of the recharge pathways.

Background

The north face of Pit 3 appears to be a zone where groundwater is currently leaking into Pit 3 since current groundwater gradients are towards the pit. This zone is likely to be in direct contact with tailings deposited in Pit 3. Characterisation (e.g. distribution, hydraulic properties) of this

zone is required and will likely include long-term pumping tests in the area between Pit 3 and Magela Creek.

Whilst the carbonate in the south face is not expected to provide a pathway, understanding recharge pathways for, and the age of groundwater within, this carbonate will provide a greater understanding of how groundwater can move through the minesite area. This may involve the drilling of additional bores to allow tracer testing of if water samples can still be obtained age dating of the groundwater.

Progress against plan

Initial compilation of hydrogeological and geochemical data in the Pit 3 has commenced.

Key findings

Nil to report

Workplan for 2017–18

- September 2017 - Compilation of all data associated with the fracture zone in the north face and the carbonate in the south face.
- December 2017 – Complete analysis as to the role of the fault zone in COPC movement and the role of the carbonate in how groundwater may enter and move through and around Pit 3. This will help determine whether futher primary data acquisition is required.

Planned project outputs and associated outcomes

The outputs for this project include:

- A hydrogeological and groundwater chemistry dataset for the Pit 3 area.
- A transmissivity assessment of the fracture zone in the north face of Pit 3.
- A better understanding of the recharge pathways and the role of the carbonate in groundwater movement in and around Pit 3.

The outcomes from this study will be:

- Confirmation as to the role, if any, of the fracture zone in the movement of COPCs from the tailings in Pit 3 and an improved understanding of recharge pathways particularly in regards the role of the carbonate in facilitating groundwater movement.
- Whether further primary data acquisition is required to understand these processes.
- The results of this project can be used in the development of seasonal groundwater egress models to increase confidence in the results.
- The results of this project could also help improve the siting of monitoring bores for model validation and early warning monitoring of potential impacts.

Planned communication activities

- Presentations to ARRTC and ARRAC
- Technical report(s)
- Journal paper

Project publications to date (if applicable)

There are no publications for this project to date.

Project details			
Project title	Groundwater - Time series analysis of groundwater levels		
SSB function	Research	**Site**	Ranger
Project category	Monitoring of closure criteria	**Project status**	Proposed
What business need does this project inform?	An improved understanding of seasonal groundwater movement over time to improve future groundwater modelling and monitoring regimes.		

Closure criteria theme (if applicable)	Groundwater	**Project Priority**	**Relevance** 1	**Time-frame**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	To be advised	**Project commencement date**			27/2/2017
		Estimated completion date			29/9/2017
Project duration (months)	6	**Date required**			29/9/2017
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	S&M	**Reason for project delay (where applicable)**			Access to the SURFER contouring package has only recently be obtained.
Supporting team(s)	N/A				
Project manager	Baker, Peter	**Project total estimated internal resources (person weeks)**			5
Project sponsor	Turner, Kate	**Project total estimated collaborator resources (person weeks)**			0

Aims

- To develop a set of historical and current potentiometric maps by formation, aquifer, surface catchment for each season (where possible).
- To develop an improved understanding of potential variations in groundwater flow across the Ranger area to better inform future groundwater modelling and location of groundwater monitoring sites.

Background

At present there is no 'complete' set nor detailed analysis of the potentiometric surface from pre-mining to the current day. Analysis of this information will provide a better understanding of potential variations in groundwater flow across the area particularly as to why there is a change in vertical flow direction in some areas i.e. a swapping of downwards movement to upward movement. This project will also assist in better quantifying groundwater recharge and its temporal variation. Maps will be produced for the whole Ranger Project Area by formation, aquifer, surface catchment for each season if possible. This is needed to provide a better understanding as to what the groundwater flow regime could look like post closure but also, given the current groundwater model is calibrated only using data from 2005-6, provide better surety as to the models predictions by allowing comparison against a broader data set.

Progress against plan

This project suffered intial delays due to the inability to get access to appropriate contouring software. Recently this has been addressed. An assessment will be made at end of August as to whether completion timeline can be met.

Key findings

Nil to report.

Workplan for 2017–18

- July 2017: Develop a groundwater database to confirm bore screening intervals, what aquifers/formation are monitored, to provide a consistent historical dataset and production of potentiometric maps.
- December 2017: Complete analysis of groundwater trends.

Planned project outputs and associated outcomes

The outputs for this project include:

- Groundwater database with locations, screened intervals and groundwater kevels.
- A time series of potentiometric maps from pre-mining to the current day.
- A better estimation of groundwater recharge spatially and temporally.

The outcomes from this study will be:

- An improved understanding of how the groundwater system has responded to the different perturbations across the life of the mine. This will provide information to inform what the groundwater system will look like post closure.
- The results of this project can be used in the development of seasonal groundwater egress models to increase confidence in the results.
- The results of this project could also help improve the siting of monitoring bores for model validation and early warning monitoring of potential impacts.

Planned communication activities

Presentation to ARRTC and ARRAC

Project publications to date (if applicable)

There are no publications for this project to date.

OTHER SITES

1 Research

2 Monitoring

Other sites

Monitoring (1 project)

Project details					
Project title	Radiation monitoring at the El Sherana containment facility				
SSB function	Monitoring	**Site**	South Alligator Valley		
Project category	Other	**Project status**	Active		
What business need does this project inform?	Protecting the health of Aboriginals and other members of the regional community				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 2	**Time-frame**	1/ongoing
			Importance 2	**Time buffer**	A
Project number (if already commenced)	MON-2013-006	**Project commencement date**	1/7/2012		
		Estimated completion date	30/6/2026		
Project duration (months)	168	**Date required**	1/7/2026		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	ENRAD	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	N/A				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**	100		
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**	0		

Aims

- To measure radon exhalation fluxes and gamma dose rates on the El Sherana containment facility every two years.
- To detect any changes in radiological conditions on the containment which may indicate issues with structural integrity of the facility.

Background

The El Sherana containment is a near-surface radioactive waste disposal facility. It contains around 22,000 tonnes of contaminated mining wastes that were removed from historic uranium

mines that operated in the South Alligator Valley during the 1950s and 1960s and were subsequently abandoned when mining became uneconomic. The El Sherana containment is managed by Parks Australia and regulated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). A condition of the licence issued to Parks Australia by ARPANSA is that radiological conditions at the containment must be measured at least once every two years. Supervising Scientist currently undertakes radon exhalation and gamma dose rate monitoring at the containment on behalf of Parks Australia.

Progress against plan

- Baseline measurements conducted at the site in 2007.
- Routine radon exhalation and gamma dose rate measurements made at the containment in 2010, 2012, 2013, 2015 and 2017.

Key findings

- No change in gamma dose rates at the site compared to baseline values.
- Radon-222 exhalation flux densities have typically been higher than baseline values and variable between years, showing a decreasing trend since 2012.
- Gamma and radon levels measured in June 2017 were consistent with baseline values.
- Radiation risk to members of the public from the containment is presently negligible.

Workplan for 2017–18

- July 2017-September 2017: Field work to measure radon exhalation fluxes and gamma dose rates.
- October 2017-December 2017: Data analysis, interpretation and write up of results.

Planned project outputs and associated outcomes

The output from this project is an additional and updated radiological monitoring dataset for the El Sherana containment facility.

The outcomes from this study will be:

- Assurance that there have been no changes in radiological conditions at the facility.
- Assurance that there is negligible radiation risk to members of the public from the facility.

Planned communication activities

- Internal report for each set of measurement results provided to Parks Australia
- Key findings published in annual technical report
- Presentations to key stakeholders on request

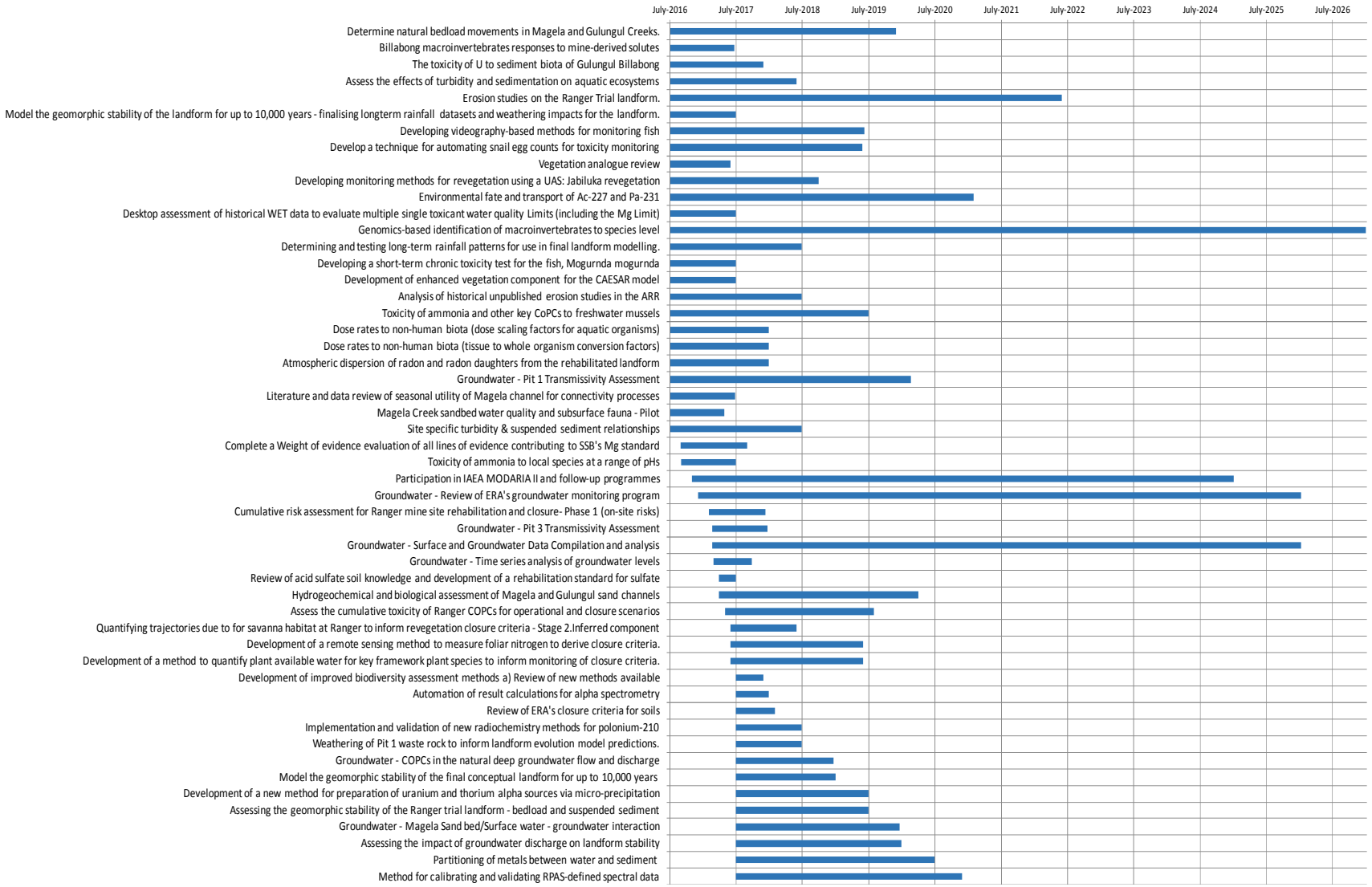
Project publications to date (if applicable)

Doering C, Bollhöfer A, Ryan B, Sellwood J, Fox T & Pfitzner J 2011. Baseline and post-construction radiological conditions at El Sherana airstrip containment, South Alligator River valley, Australia. Internal Report 592, June, Supervising Scientist, Darwin.

Bollhöfer A, Doering C, Medley, P & da Costa L 2013. Assessment of expected maximum doses from the El Sherana airstrip containment, South Alligator River valley, Australia. Internal Report 618, July, Supervising Scientist, Darwin.

Bollhöfer A, Doering C & Fox G 2015. Gamma dose rates and 222Rn activity flux densities at the El Sherana containment. Internal Report 642, July, Supervising Scientist, Darwin.

APPENDIX 3 SUPERVISING SCIENTIST BRANCH DRAFT RESEARCH PROJECT SCHEDULE, 2016-2026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Determine natural bedload movements in Magela and Gulungul Creeks.
Billabong macroinvertebrates responses to mine-derived solutes
The toxicity of U to sediment biota of Gulungul Billabong
Assess the effects of turbidity and sedimentation on aquatic ecosystems
Erosion studies on the Ranger Trial landform.
Model the geomorphic stability of the landform for up to 10,000 years - finalising longterm rainfall datasets and weathering impacts for the landform.
Developing videography-based methods for monitoring fish
Develop a technique for automating snail egg counts for toxicity monitoring
Vegetation analogue review
Developing monitoring methods for revegetation using a UAS: Jabiluka revegetation
Environmental fate and transport of Ac-227 and Pa-231
Desktop assessment of historical WET data to evaluate multiple single toxicant water quality Limits (including the Mg Limit)
Genomics-based identification of macroinvertebrates to species level
Determining and testing long-term rainfall patterns for use in final landform modelling.
Developing a short-term chronic toxicity test for the fish, Mogurnda mogurnda
Development of enhanced vegetation component for the CAESAR model
Analysis of historical unpublished erosion studies in the ARR
Toxicity of ammonia and other key CoPCs to freshwater mussels
Dose rates to non-human biota (dose scaling factors for aquatic organisms)
Dose rates to non-human biota (tissue to whole organism conversion factors)
Atmospheric dispersion of radon and radon daughters from the rehabilitated landform
Groundwater - Pit 1 Transmissivity Assessment
Literature and data review of seasonal utility of Magela channel for connectivity processes
Magela Creek sandbed water quality and subsurface fauna - Pilot
Site specific turbidity & suspended sediment relationships
Complete a Weight of evidence evaluation of all lines of evidence contributing to SSB's Mg standard
Toxicity of ammonia to local species at a range of pHs
Participation in IAEA MODARIA II and follow-up programmes
Groundwater - Review of ERA's groundwater monitoring program
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 1 (on-site risks)
Groundwater - Pit 3 Transmissivity Assessment
Groundwater - Surface and Groundwater Data Compilation and analysis
Groundwater - Time series analysis of groundwater levels
Review of acid sulfate soil knowledge and development of a rehabilitation standard for sulfate
Hydrogeochemical and biological assessment of Magela and Gulungul sand channels
Assess the cumulative toxicity of Ranger COPCs for operational and closure scenarios
Quantifying trajectories due to for savanna habitat at Ranger to inform revegetation closure criteria - Stage 2.Inferred component
Development of a remote sensing method to measure foliar nitrogen to derive closure criteria.
Development of a method to quantify plant available water for key framework plant species to inform monitoring of closure criteria.
Development of improved biodiversity assessment methods a) Review of new methods available
Automation of result calculations for alpha spectrometry
Review of ERA's closure criteria for soils
Implementation and validation of new radiochemistry methods for polonium-210
Weathering of Pit 1 waste rock to inform landform evolution model predictions.
Groundwater - COPCs in the natural deep groundwater flow and discharge
Model the geomorphic stability of the final conceptual landform for up to 10,000 years
Development of a new method for preparation of uranium and thorium alpha sources via micro-precipitation
Assessing the geomorphic stability of the Ranger trial landform - bedload and suspended sediment
Groundwater - Magela Sand bed/Surface water - groundwater interaction
Assessing the impact of groundwater discharge on landform stability
Partitioning of metals between water and sediment
Method for calibrating and validating RPAS-defined spectral data


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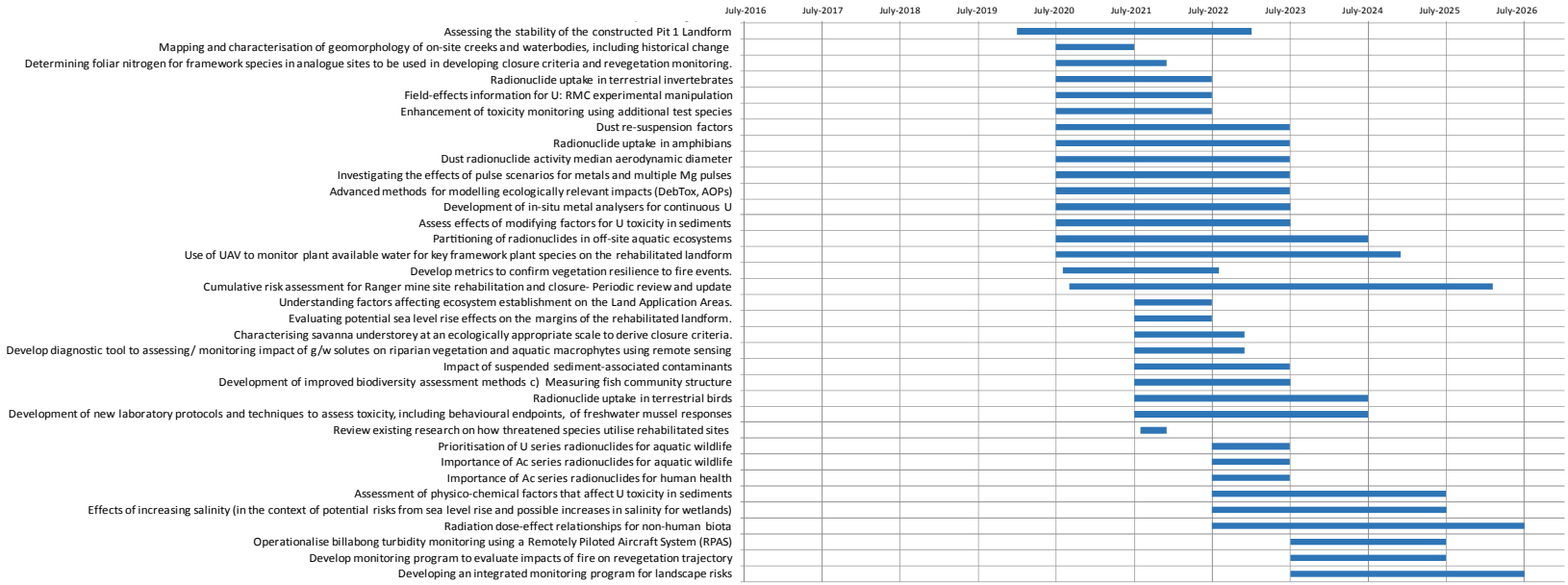
Assess effects of stressors other than mine-derived CoPCs, both alone or as modifiers of CoPC toxicity
Development of improved biodiversity assessment methods b) Macroinvertebrate communities: response measurement and diagnostics
Characterisation and assessment of the risk of herbicides to the aquatic environment
Establishing vegetation analogue plots and deriving closure criteria at an ecologically appropriate scale.
Characterising savanna understorey to derive closure criteria
Quantitative assessment of ecosystem establishment on trial landform waste rock
Review the current best practices for chemical and biological monitoring
Determining substrate representativeness of the Trial Landform with respect to the final landform.
Identification and mapping of Groundwater Dependent Ecosystems (GDEs)
Groundwater - Djalkmarra Sands Transmissivity Assessment
Water balance assessment in the final landform
Groundwater - Reactive transport modelling and analysis Mg/Ca
Determining how compaction within the final landform may impact ecosystem establishment.
Quantifying changes in riparian habitat at Ranger to inform long term monitoring and/or closure criteria
Development of method for monitoring of gully formation on the rehabilitated landform using stereopsis and LiDAR
Hydrodynamic modelling of Magela Creek
Effect of mine derived suspended sediments (cf natural suspended sediments) on the growth of juvenile mussels
Salt-turbidity interaction and altered ecological processes
Expand the monitoring timeframe for biodiversity assessment beyond recessional flow
Radionuclide uptake in terrestrial vegetation
Quantification of background sedimentation rates in on-site billabongs
Radionuclide uptake in small proliferators
Radon progeny equilibrium factors
Radon progeny activity median aerodynamic diameter
'Seasonal sensitivity' (to Mg) profile for organisms in the creek channel
The development of salt tolerance in aquatic organisms
Direct effects of suspended sediment on tropical freshwater biota
Ecohydrology and sensitivity of riparian flora – fine-scale mapping of groundwater use by riparian vegetation, pot trials of selected species
Development of improved biodiversity assessment methods e) Phytoplankton populations using in-situ flow cytometry
Seasonal changes in water physico-chemistry of reference billabongs (establish new baseline post last full characterisation in late 1979s/early 1980s)
Use of DGTs for U (and other) measurement
Water balance assessment of the Trial Landform
Effects of g/water egress to ecological connectivity: New phases identified from 2016-17 scoping study
Acute and chronic toxicity of CoPCs to local wildlife
Publication of biological monitoring results to date
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 2 (off site risks)
Groundwater - Contaminant plume migration TSF area
Developing UAV-based remote sensing techniques for measuring U counts on the rehabilitated landform.
Determining closure criteria for recolonisation of fauna
Quantifying changes to vegetation at Nabarlek.
Determining tolerance of framework plant species to contaminants and effects of long-term exposure to plant growth and health.
Improved understanding of sources and magnitude of sources of weeds on-site and off site using remote sensing
Impact of different salinity levels on the behaviour of suspended sediment
Development of improved biodiversity assessment methods d) Assess and incoporate new remote sensing technology, i.e automated water craft
Surveying and monitoring of the constructed Pit 1 Landform
Development of improved biodiversity assessment methods f) Metagenomics for routine monitoring of the biogeochemistry of sediments
Groundwater - Predicting nutrient concentrations in the creeks
Investigation into the Mudginberri agriculture trial area.
Fire history of analogue sites
Assessing the stability of the constructed Pit 1 Landform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Assessing the stability of the constructed Pit 1 Landform
Mapping and characterisation of geomorphology of on-site creeks and waterbodies, including historical change
Determining foliar nitrogen for framework species in analogue sites to be used in developing closure criteria and revegetation monitoring.
Radionuclide uptake in terrestrial invertebrates
Field-effects information for U: RMC experimental manipulation
Enhancement of toxicity monitoring using additional test species
Dust re-suspension factors
Radionuclide uptake in amphibians
Dust radionuclide activity median aerodynamic diameter
Investigating the effects of pulse scenarios for metals and multiple Mg pulses
Advanced methods for modelling ecologically relevant impacts (DebTox, AOPs)
Development of in-situ metal analysers for continuous U
Assess effects of modifying factors for U toxicity in sediments
Partitioning of radionuclides in off-site aquatic ecosystems
Use of UAV to monitor plant available water for key framework plant species on the rehabilitated landform
Develop metrics to confirm vegetation resilience to fire events.
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Periodic review and update
Understanding factors affecting ecosystem establishment on the Land Application Areas.
Evaluating potential sea level rise effects on the margins of the rehabilitated landform.
Characterising savanna understorey at an ecologically appropriate scale to derive closure criteria.
Develop diagnostic tool to assessing/ monitoring impact of g/w solutes on riparian vegetation and aquatic macrophytes using remote sensing
Impact of suspended sediment-associated contaminants
Development of improved biodiversity assessment methods c) Measuring fish community structure
Radionuclide uptake in terrestrial birds
Development of new laboratory protocols and techniques to assess toxicity, including behavioural endpoints, of freshwater mussel responses
Review existing research on how threatened species utilise rehabilitated sites
Prioritisation of U series radionuclides for aquatic wildlife
Importance of Ac series radionuclides for aquatic wildlife
Importance of Ac series radionuclides for human health
Assessment of physico-chemical factors that affect U toxicity in sediments
Effects of increasing salinity (in the context of potential risks from sea level rise and possible increases in salinity for wetlands)
Radiation dose-effect relationships for non-human biota
Operationalise billabong turbidity monitoring using a Remotely Piloted Aircraft System (RPAS)
Develop monitoring program to evaluate impacts of fire on revegetation trajectory
Developing an integrated monitoring program for landscape risks

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
Bq (becquerel)	SI unit for the activity of a radioactive substance in decays per second [s^{-1}].
CC (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).
CCLAA	Corridor Creek Land Application Area
CCWG	Closure Criteria Working Group
CDU	Charles Darwin University
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.
DPIR	Northern Territory Department of Primary Industry and Energy (formerly Northern Territory Department of Mines and Energy)
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.
EC (electrical conductivity)	A measure of the total concentration of salts dissolved in water.

ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
ERs	Environmental Requirements
GCT2	Gulungul Creek Tributary 2
GCUS	Gulungul Creek Upstream (upstream monitoring site)
GDEs	Groundwater dependent ecosystems
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.
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'
IT	Information Technology
IWMP	Interim Water Management Pond
JFS	Jabiru Field Station
KKN	Key Knowledge Needs
LAA	Land Application Area
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
mRL	Reduced Level metres
MTC	Minesite Technical Committee
NT	Northern Territory
ore	A type of rock that bears minerals, or metals, which can be extracted.
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.
RPA	Ranger Project Area
RPAS	Remotely Piloted Aircraft System
RPI	Routine Periodic Inspection
RP1	Retention Pond 1
RP2	Retention Pond 2
RP3	Retention Pond 3
RP6	Retention Pond 6
RUM	Ranger uranium mine. The name of a mine in Kakadu National Park, run by Energy Resources of Australia Ltd.
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.
SSB	Supervising Scientist Branch. A Branch of the Heritage, Reef and Marine Division, Department of the Environment and Energy.
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
UAV	Unmanned Aerial Vehicle
UEL	Uranium Equities Ltd
U	Uranium. The product mined from the Ranger uranium mine.
WTP	Water Treatment Plants
WQGV	Water Quality Guideline Value