



Australian Government

Department of the Environment and Energy

Supervising Scientist

SUPERVISING SCIENTIST



Annual Technical Report
2017-18



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This report should be attributed as Supervising Scientist 2018. *Annual Technical Report 2017–18*, Commonwealth of Australia 2018.

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ISSN: 1440-3013 (Print)

ISSN: 2203-6075 (Online)

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

ABN 34190894983

Contact

Supervising Scientist Branch

Department of the Environment and Energy

Postal: GPO Box 461, Darwin NT 0801 Australia

Street: Pederson Road/Fenton Court, Eaton NT 0820 Australia

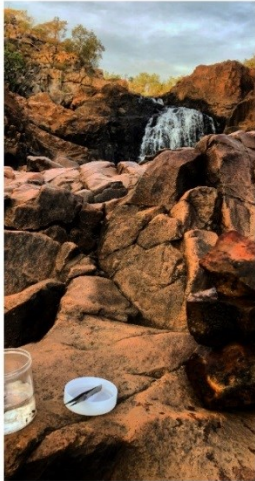
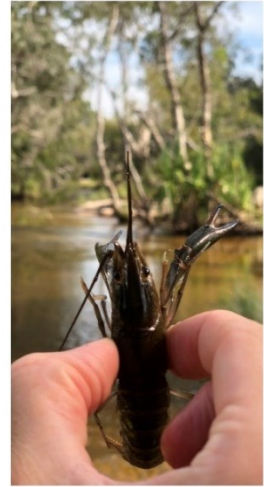
Telephone +61 8 8920 1100

Facsimile +61 8 8920 1199

environment.gov.au/science/supervising-scientist

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

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



Photos (clockwise spiral from top left): Sample preparation in laboratory, Performing fish surveys in visual observation boat, *Cherax quadricarinatus* (Red claw crayfish), *Gomphrena floribunda*, Checking fauna survey pit traps, *Carettochelys insculpta* (Pig-nosed turtle), Flying an Unmanned Aerial Vehicle, Collecting aquatic macroinvertebrates at Edith Falls Nitmiluk National Park, Counting fish in visual observation boat.

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SUPERVISING SCIENTIST'S OVERVIEW

2017-18 –was a busy and productive year for the Supervising Scientist Branch (SSB) with significant progress in a number of areas, and ongoing focus on the rehabilitation of the Ranger uranium mine.

Our environmental monitoring programs were successfully completed to the usual high standard and continue to show that people and the environment in the Alligator Rivers Region remain protected from the effects of uranium mining. Water quality in both Magela and Gulungul Creeks continues to improve compared to previous years, with no exceedances of the statutory water quality guidelines recorded in either creek during the reporting period. Our field monitoring team overcame some significant safety challenges associated with the increasing risk of crocodile attacks. However, in some cases this has driven advances in our monitoring techniques, such as the move from visual observation to videography methods for fish monitoring.

Our Revegetation and Landform team made significant progress in the development of leading-edge vegetation monitoring techniques using unmanned aerial vehicles. These techniques use hyperspectral cameras and laser scanners to measure a range of vegetation characteristics at a landscape-scale, capturing significantly more information than is possible with ground-based techniques. This technology will assist with the development of revegetation closure criteria, and provide the platform for monitoring to assess their achievement.

Progressive rehabilitation activities at Ranger mine continued through-out the year, including the backfill of Pit 1 and the transfer of mine tailings from the tailings storage facility to Pit 3. We worked closely with Energy Resources of Australia (ERA) and the regulatory agencies throughout the year, with a focus on tailings deposition in Pit 3. We commissioned an independent expert review of the process and are now contributing to the development of a new tailings deposition method that is expected to be implemented some time in 2018-19.

A key milestone in the rehabilitation process was the development and submission of ERA's Ranger Mine Closure Plan. We completed an assessment of the draft Plan in July 2017 and provided feedback to ERA and other members of the Ranger Minesite Technical Committee. ERA subsequently published a revised version of the Plan on 5 June 2018, which was still under assessment at the end of the 2017-18 reporting period.

To support our assessment of the Ranger Mine Closure Plan, we are developing a series of Rehabilitation Standards that quantify the rehabilitation objectives for Ranger mine. These Standards are non-binding, but will form the basis of the Supervising Scientist's advice on the closure criteria proposed by ERA and in time, on the success of rehabilitation. It is planned that the standards will be published at the same time as the Supervising Scientist's Ranger Mine Closure Plan Assessment Report in the second half of 2018.

Reflecting our continued focus on mine rehabilitation, the membership of the Alligator Rivers Region Technical Committee (ARRTC) was reviewed to better align the Committee with rehabilitation-related requirements. We were fortunate to appoint a number of new members renowned for their expertise in each of their relative disciplines.

The SSB and ERA research programs are guided by a set of Key Knowledge Needs (KKNs) that are based upon a comprehensive risk assessment process. The KKNs were reviewed and consolidated during 2017-18, and projects aiming to address each of them have been scoped and scheduled. As the required research is completed and endorsed by ARRTC, the KKNs will be progressively closed-out.

To enhance the research and technical assessment capability within our Branch, we have established a network external collaborators. Long-term agreements have been put in place to help ensure that key research and assessment outcomes are delivered within required timeframes. This includes the Centre for Mined Land Rehabilitation at the University of Queensland, the CSIRO and Charles Darwin University who is undertaking three Ranger-related projects through the National Environmental Science Program.

The peer review and external communication of our work remains a priority for the Branch. A number of staff presented at national and international forums and conferences throughout the year, with some staff contributing to the work of the International Atomic Energy Agency (IAEA) by attending expert missions. Additionally, we participated in a number events hosted by the IAEA and the OECD Nuclear Energy Agency, met with officials from the International Union for the Conservation of Nature and the International Council on Monuments and Sites and conducted technical exchange meetings in Germany with Wismut GmbH which is undertaking the world's largest uranium rehabilitation project. Locally, we once again hosted a stall at the Mahbilil Festival in Jabiru and continue to connect with local Aboriginal people through the staff at our Jabiru Field Station and ongoing engagement with the Gundjeihmi Aboriginal Corporation and the Northern Land Council.

Finally, I would like to thank all of the staff of SSB for their professionalism, dedication and hard work during 2017-18. Our achievements over the last year are a credit to all of them.

Keith Tayler

Supervising Scientist

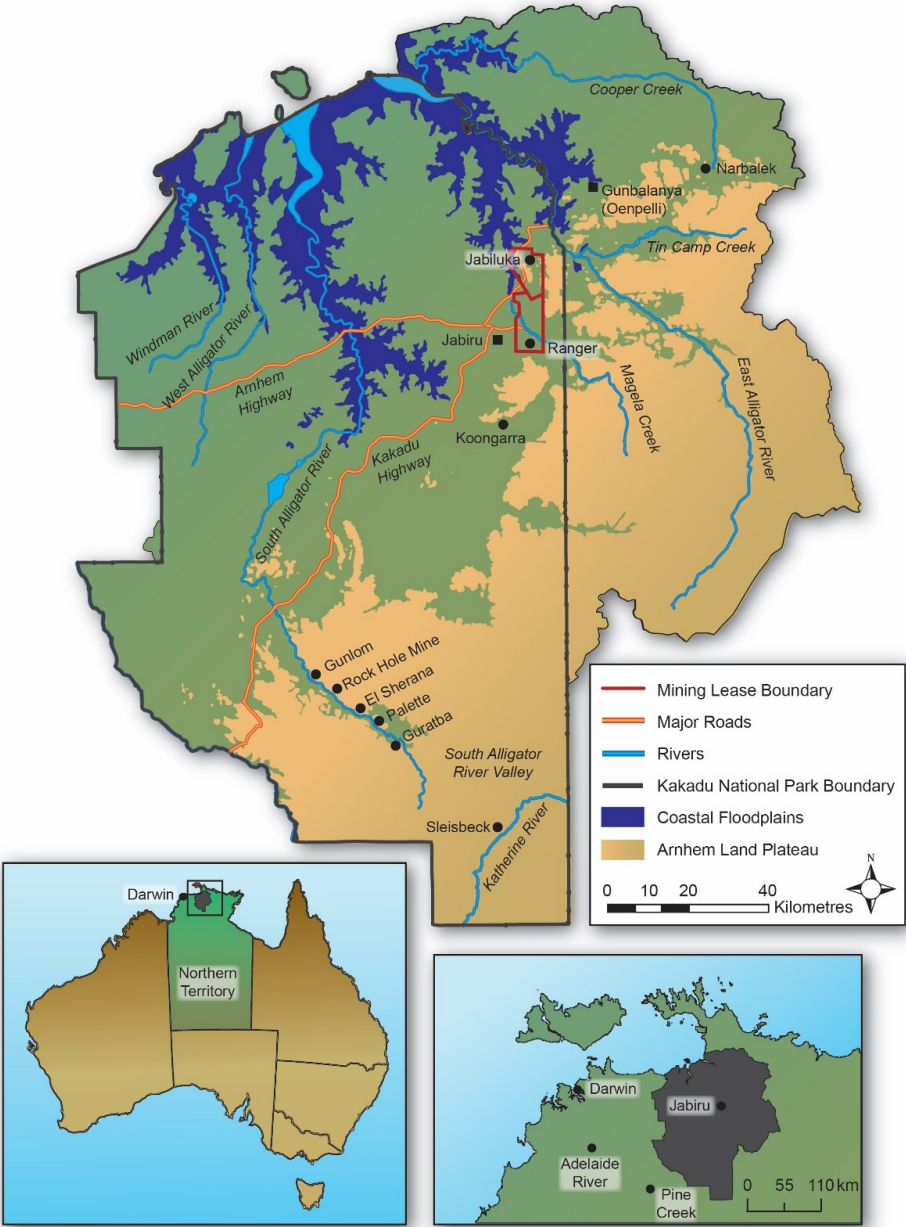


Figure 1 Alligator Rivers Region



SITE CODE	GULUNGUL SITE DESCRIPTION	SITE CODE	MAGELA SITE DESCRIPTION
GCNUS	Gulungul Creek new upstream	MCUGT	Magela Creek upstream
GCUS	Gulungul Creek upstream	MCDW	Magela Creek downstream
GCLB	Gulungul Creek lease boundary	G8210009	Magela Creek gauging station
GCDS	Gulungul Creek downstream		
GCT2GCC	Gulungul Creek confluence with Tributary 2		
GCT2RST	Gulungul Creek Tributary 2 Radon Springs Track		

Figure 2 Ranger minesite including location of water release points and SSB monitoring sites

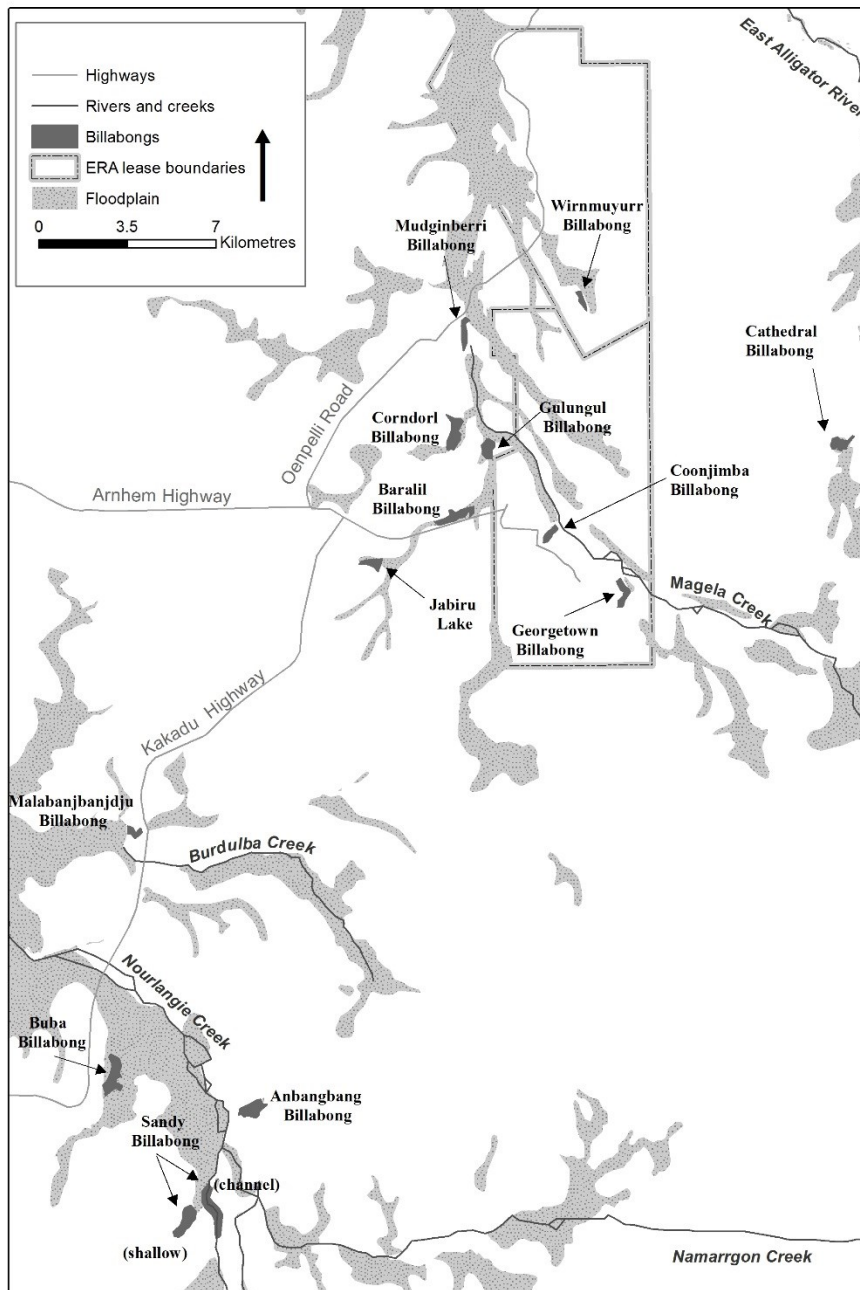


Figure 3 Location of waterbodies in the Supervising Scientist Branch's environmental research and monitoring programs.

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 Australian Department of the Environment and Energy. The SSB is situated within the Heritage, Reef and Marine Division.

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

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

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 1). The ARR extends into western Arnhem Land and includes the catchments of the West Alligator, South Alligator and East Alligator Rivers. The dual World Heritage listed Kakadu National Park lies entirely within the ARR, as do the Ranger, Jabiluka, Nabarlek and Koongarra uranium deposits.

The Ranger and Jabiluka uranium deposits are surrounded by, but remain separate from, Kakadu National Park. The Koongarra project area was incorporated into the Kakadu World Heritage area in 2011, and later incorporated into Kakadu National Park in 2013. Nabarlek is situated to the east of Kakadu National Park within Arnhem Land.

Ranger mine 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 for the 2017–18 reporting period.

1.3 The regulatory framework

The Authority to mine uranium at Ranger is issued under s41 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*, 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* (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 provides assurance to the public and other interested groups that the Alligator Rivers Region remains protected from the impacts of uranium mining. We do this through a range of activities designed to communicate the outcomes of the branch's supervision and assessment program, and results of research and monitoring activities. These communication and engagement activities provide the SSB with the opportunity to identify, understand and address stakeholder concerns, expectations and sensitivities relating to uranium mining in the ARR.

2.1 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (ARRAC) provides a forum for community liaison and engagement on uranium mining activities in the region. The committee comprises representatives of government and regulatory bodies, stakeholder organisations, and companies involved in uranium mining activities in the ARR.

The 48th ARRAC meeting was held in Jabiru in September 2017 and the 49th meeting took place in Darwin in April 2018. At these meetings the Committee was advised of the SSB's current activities, including updates on SSB's supervision, assessment and monitoring at Ranger, Jabiluka, Nabarlek and other sites in the ARR.

At the meetings Energy Resources of Australia Ltd (ERA) presented a broad overview of their activities at Ranger, including mine closure planning. The DPIR reported on their water quality check monitoring program, and reports were also presented by Committee members including the Northern Land Council, Cameco Australia Pty Ltd, Northern Territory Department of Health, and The Australian Radiation Protection and Nuclear Safety Agency. At the 49th meeting the Committee acknowledged Professor Charles Webb's 20 years of service in the role of ARRAC chair.

The minutes of ARRAC meetings are available on the Departments website at:

www.environment.gov.au/node/23143

2.2 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) advises the Assistant Minister for the Environment on the adequacy and appropriateness of the scientific research conducted by the SSB and ERA. 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.

The Minister for the Environment and Energy made changes to the Committee's membership which took effect on 1 November 2017. The committee consists of three former and seven new members, and possesses the expertise necessary to provide technical advice on themes related to the rehabilitation of the Ranger uranium mine.

The Committee convened at its 39th meeting in Darwin in December 2017. The meeting focussed on landform design for the Ranger site, including the establishment and long-term success of revegetation. The ARRTC endorsed the research currently being undertaken to inform landform design, including landform evolution modelling and the cumulative ecological risk assessment being undertaken collaboratively between the SSB the CSIRO. The ARRTC commended the development and evolution of the Key Knowledge Needs (KKNs), and alignment of these with the SSB's strategic 10 year plan.

The 40th ARRTC meeting was held in Darwin in May 2018, and included a field trip to the Ranger minesite. The meeting focussed on reviewing the research related to ecosystem restoration of the Ranger uranium mine, with particular focus on ERA's proposed revegetation closure criteria and the associated revegetation strategy. The Committee was also presented with an update on closure activities by ERA, and an update from the Supervising Scientist on its proposed 2018-19 research program.

The minutes of ARRTC meetings are available on the ARRTC website at:

www.environment.gov.au/science/supervising-scientist/communication/committees/arrtc/meetings

2.3 Communication with other stakeholders

Throughout 2017–18 SSB staff participated in a number of national and international conferences, meetings and technical working groups. At these events staff share the outcomes of the SSB's research and monitoring programs, whilst also benchmarking the programs against international leading practice. The work of the SSB is also routinely published in a range of scientific journals and on the Department of the Environment and Energy website. All reports and publications are available at:

www.environment.gov.au/science/supervising-scientist/publications.

TABLE 1 PRESENTATIONS AT NATIONAL AND INTERNATIONAL CONFERENCES**1 JULY 2017 TO 30 JUNE 2018**

Conference	Place/date (no. Papers)
Royal Australian Chemical Institute (RACI) Centenary Congress	Melbourne, Australia, 23–28 July 2017 (2 presentations)
World of Drones Congress 2017	Brisbane, Queensland 31 August – 1 September 2017 (1 panel discussion; 1 booth display)
Society for Environmental Toxicology and Chemistry (SETAC) Australasia Conference	Gold Coast, QLD, 4–6 September 2017 (4 presentations)
Society for Environmental Toxicology and Chemistry (SETAC) North America Focused Topic Meeting: Risk Assessment of Chemical Mixtures	6–8 September 2017, Denver, Colorado, USA (1 presentation)
Australian Society for Limnology (ASL) Conference	Sydney, NSW, 24-26 September 2017 (1 presentation)
International Atomic Energy (IAEA) Agency Regulatory Supervision of Legacy Sites	Bessines, France, 16-17 October 2017 (2 presentations)
International Atomic Energy (IAEA) Agency Uranium Mining Remediation Exchange Group	Bessines, France, 18-20 October 2017 (2 presentations)
Second Technical Meeting of the International Atomic Energy Agency (IAEA) Modelling and Data for Radiological Impact Assessments (MODARIA II) Scientific Program	Vienna, Austria, 30 October–3 November 2017 (working group participation)
EnviroMine2017- 5th International Seminar on Environmental Issues in Mining	Santiago, Chile, 8-10 November 2017 (1 presentation)
Aquatic Toxicology Symposium	San Francisco, USA, 4-7 June 2018 (1 presentation)
International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economic and Environmental Issues URAM 2018)	Vienna, Austria, 25-2 June 2018 (2 presentations)



Figure 4 The Supervising Scientist presented information on the regulation of uranium in Australia to staff from Wismut GmbH during a technical exchange mission in Chemnitz, Germany, 2018.

The SSB aims to engage with the local Aboriginal community wherever possible. This facilitates the transfer of both cultural and environmental knowledge and information between the traditional custodians of the land, and SSB staff. SSB participated in two pre-employment workshops for local aboriginal women and men, at Jabiru Field Station in September 2017 and June 2018. The attendees were familiarised with the laboratories and aquaculture facilities at the field station, and given practical demonstrations of water chemistry equipment and the use of macroinvertebrates for biological monitoring.

The SSB participated in a number of community activities in 2017-18, including the 2017 Mahbilil Wind Festival in Jabiru in August 2017, and World Wetlands Day in February 2018. The SSBs information marquee was equipped with a range of scientific posters and 'hands on' educational activities. These attracted visitors to the event and enabled SSB staff to engage and share information related to environmental monitoring and protection in the region. Local events are important opportunities for information exchange between SSB and local community members.

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*. 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 routine periodic minesite inspections (RPIs) and environmental audits. These processes allow stakeholders to review ERA's environmental performance and include assessment of environmental incidents and associated investigations, ensuring 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 the Ranger, Jabiluka and Nabarlek sites, providing a forum for the mining operators to discuss environmental management and regulatory issues with regulators and key stakeholders.

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 km² Ranger Project Area (RPA) and is adjacent to Magela Creek, a tributary of the East Alligator River.

Ranger is an open cut mine and has been producing uranium oxide (U₃O₈) via acid leach extraction since 1981. In accordance with current regulatory approvals, mining at Ranger ceased in 2012 and stockpiled ore will continue to be processed until 2021. Rehabilitation planning for Ranger has been underway for a number of years, with ERA submitting a draft Mine Closure Plan at the end of 2016 which was updated in 2018. 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 for permanent tailings disposal. Excavation of Orebody No 3 began in 1997 and mining in the pit, known as Pit 3, ceased in 2012. Pit 3 will also be utilised for permanent tailings disposal. Tailings deposition in Pit 3 commenced in February 2015 and will continue until all tailings have been relocated from the Tailings Storage Facility (TSF) into 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 Ranger 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 water quality using electrical conductivity (EC) as the key indicator, as shown in Table 2.

TABLE 2 WATER CLASSES AT THE RANGER MINE

Water class	Indicative EC range ($\mu\text{S}/\text{cm}$)
Release water	193–476
Pond water	1220–2380
Process water	18,800–34,900

The rainfall recorded at Jabiru Airport for the 2017–18 wet season was 1919 mm. This was above the annual average of 1550 mm (Figure 5).

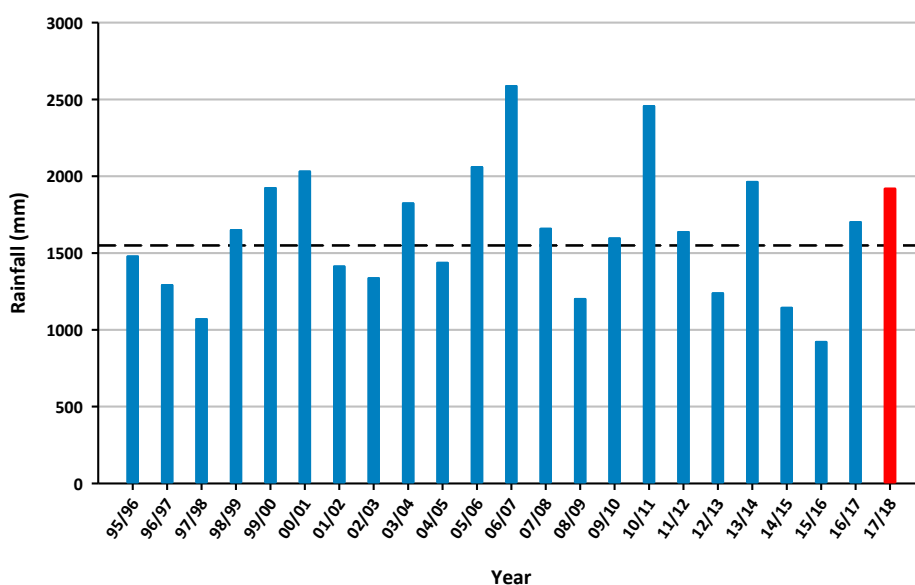


Figure 5 Annual (July - June) rainfall measured at Jabiru Airport from 1995 to 2018. Black dotted line indicates the average annual rainfall of 1550 mm.

Process water

Process water 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 and in Pit 3. (Figure 2). As part of the strategy to manage and reduce the process water inventory on-site, ERA constructed a brine concentrator water treatment plant in 2013. The plant produces good 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
2017-18	319	1828

The brine concentrator distillate is discharged from various locations around the site and ultimately reports to Magela Creek during the wet season or is 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. In January 2018, during a planned shutdown, ERA installed spin-clear cyclones and made other minor adjustments to the operation of the brine concentrators which contributed to distillate production at almost 100% of nominal capacity in 2017-2018. ERA is exploring other options to further optimise the performance of the brine concentrator, hoping to increase its capacity to 125% of nominal capacity.

Additional process water treatment strategies, such as the recommissioning of the High Density Sludge (HDS) treatment plant, are also being investigated by ERA. Metallurgical trials to confirm 'proof of concept' are currently underway and subject to feasibility assessment and refurbishment, commissioning is planned in the first quarter of 2019.

To further reduce the volume of process water on-site, a number of initiatives were implemented during 2017-18 to reduce inputs to the process water inventory.

Significant rainfall during February 2018 caused the pond water inventory to exceed storage capacity. ERA commenced intermittent transfer of excess pond water to the process water system via pumping, and engaging of the Retention Pond 2 (RP2) to Pit 3 spillway in accordance with the Ranger Water Management Plan. This additional input to the process water system commenced on 13 February 2018 and ceased at the start of March 2018. During this period approximately 550 ML of pond water was transferred from RP2 to Pit 3 comprising 370 ML actively pumped and approximately 180 ML transferred over the spillway. There was no impact to the off-site environment as a result of these on-site water transfers.

Pond water

Pond water is water that has been in contact with stockpiled mineralised material and operational areas at the site, other than those contained within the process water system. Pond water is stored in RP2, Retention Pond 3 (RP3), Retention Pond 6 (RP6) and parts of the Pit 1 catchment area (Figure 2). ERA has previously committed to

retaining pond water on-site unless it is treated prior to release. 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
2017-18	3392	2306

Permeate is discharged at various locations around the site, including the Corridor Creek Wetland Filter and RP1, ultimately reporting to Magela Creek during the wet season or irrigated on LAAs during the dry season. In May 2018 ERA commenced operation of two turbomisters on the eastern side of RP1 and intend to install an additional 12 turbo-misters later in 2018. These turbomisters are used to dispose of permeate and distillate during the dry season, with approximately 50-60% of the treated water travelling by overland flow through the RP1 land application area to RP1 with the remainder removed through evaporation.

In an effort to divert pond water inputs to the process water system though the 2017-18 wet season ERA has submitted an application to treat selected water sources through the Corridor Creek Wetland Filter and RP1. This proposal was assessed by the Ranger MTC with some concerns raised regarding water quality monitoring and potential impacts. ERA is currently reviewing options and intends to provide an updated application later in 2018.

From April 2018 to June 2018 pond water permeate produced from pond water treatment was discharged to Magela Creek at MG001 (Figure 2). Although no environmental impact was detected, the release of permeate at this location was not in accordance with the statutory requirements for the release of treated pond water. This incident is discussed further in section 3.1.3.1.

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 discharged 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 WATER RELEASE VOLUMES

Year	Volume (ML)
2013–14	1674
2014–15	772
2015–16	117
2016–17	1573
2017–18	1521

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 currently focussed on the deposition of tailings into Pit 3 for permanent disposal. Tailings deposition in Pit 1 was completed in 2008 and pit backfill commenced in 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 controlled wastes include disposal in the mine pits, incineration via turbo burning and off-site recycling. Non-hazardous wastes are disposed of either through disposal to landfill or off-site recycling. In 2016, an application to instate a new temporary controlled waste disposal site adjacent to Pit 3 was approved. This new site replaces the 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.

ERA is responsible for the development of closure criteria that can be used to demonstrate the achievement of the Environmental Requirements. In parallel with the development of the closure criteria, SSB is developing a suite of Rehabilitation Standards. These non-binding environmental 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, ecosystem restoration and radiation. They draw upon nearly 40 years of research conducted by the Branch to provide quantitative criteria that reflect the Environmental Requirements. The Standards also afford the highest level of ecosystem protection and will provide benchmarks against which the achievement of the rehabilitation objectives can be assessed. It is intended that the Standards will be updated in the future as additional relevant knowledge becomes available. Further information on the current status of the Standards is provided in Chapter 5.1.2.

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 the planning and implementation of 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 plan, with feedback provided to ERA and MTC members in July 2017. An updated plan was released publicly by ERA on 5 June 2018, which includes updates on the status of rehabilitation activities and addresses some of the feedback provided on the draft document by SSB and other stakeholders. SSB is reviewing the updated plan and intends to publish an Assessment Report by September 2018, 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 that 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 and the long-term protection of people and the environment in the Alligator Rivers Region.

The RMCP will be updated periodically during the rehabilitation process as additional information is obtained through planning, research and monitoring, and as rehabilitation activities are completed over time. A number of less complex rehabilitation activities will be approved within the RMCP itself (e.g. the mill deconstruction), whilst more technically-complex activities will require a stand-alone approval process that occurs externally to the RMCP. This stand-alone approval process will require the submission of specific applications that include all relevant information related to the particular activity (e.g. decommissioning of the Tailings Storage Facility).

The Department of Industry, Innovation and Science (DIIS) has been 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 using stand-alone applications. The Framework aims to 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 at the end of June 2018 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	8.46 Mm ³	9.82 Mm ³	14.29 Mm ³
Pit 1 Backfill	5.02 Mt	4.03 Mt	7.00 Mt
Annual process water treatment [*]	1.88 GL	1.83 GL	NA
Brine injection	82 ML	NA	NA

^{*} 12 Month rolling average from June 2017 – June 2018

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
Notification of change to Pit 3 operation	2018
Assessment of environmental impacts from deposition of tailings in Pit 3	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 disposal of tailings to -12 mRL	2017
Pit 1 backfill design	2017
Pit 1 final landform design	Still under assessment
TSF	
TSF east wall notching and reduction in TSF MOL	2018
Site-wide Solutes	
Surface water modelling	Still under assessment
Groundwater modelling	Still under assessment

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
Brine injection commenced (currently off-line since September 2016)	2016
Change to multi-point tailings deposition	2017
TSF	
Tailings dredging commenced	2016

3.1.2.4 Pit 1

Mining in Pit 1 ceased in 1995 and tailings transfer into 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 and a system of vertical ‘wick’ drains were installed to accelerate the consolidation and dewatering of the tailings. To enable conversion of the Pit 1 footprint from a process water catchment to a pond water catchment a low-permeability cap (i.e. compacted laterite) was placed on top of the waste rock in 2016. Incident rainfall and runoff from surrounding areas that report to the capped section of Pit 1 are now managed as pond water, provided the EC remains below 4,000 $\mu\text{S}/\text{cm}$.

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. A workshop was also held to address key concerns related to transport of contaminants from tailings into and through groundwater. On 1 February 2017 SSB publicly released its assessment report supporting the proposed final tailings level and concluding that the application demonstrated that the risk to Kakadu National Park from tailings stored in Pit 1 was low, compared to the cumulative risk associated with the whole rehabilitated minesite. This report included recommendations related to the Pit 1 backfill plan and for additional whole-of-site investigations, modelling and monitoring. 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 on 5 April 2017, subject to ERA addressing the Supervising Scientist’s recommendations.

A Pit 1 backfill plan was submitted by ERA for review in early February 2017 and was subsequently assessed and supported by SSB. ERA commenced backfill works in April 2017 in accordance with the backfill plan and in March 2018 submitted an application to proceed with placement of the final 6 million tonnes of backfill material, which is currently being assessed by the MTC. Following a review of the material movement schedule in May 2018, ERA have revised the estimated date for completion the Pit 1 backfill from early-2019 to mid-2020.

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. The drainage system was designed to enable removal and treatment of contaminated water displaced upwards during brine injection and contaminated water expressed downwards during tailings consolidation.

A number of projects are underway to transfer all tailings into Pit 3 for permanent disposal. This includes the deposition of mill tailings into Pit 3 rather than the TSF, and the transfer of tailings from the TSF to Pit 3 using a custom-built dredge. Brine injection into the waste rock underfill commenced in September 2015. The brine injection process has been suspended since September 2016 due to failure of the decant bore used to extract water from the under-bed drainage system in Pit 3. ERA is currently making arrangements to replace the decant bore and reactivate the under-bed drainage system. In the interim, brine produced from process water treatment is being recirculated within the process water system. ERA is monitoring process water quality to ensure that brine recirculation does not impact on its ability to treat the water.

The process water levels in Pit 3 and the TSF are currently managed in a closed circuit in order to ensure that the water in the TSF is the correct depth for the tailings dredge. In March 2017 ERA advised the MTC that a significant volume of water was required to be transferred from the TSF into Pit 3 in order to continue dredge operations in the TSF. The resultant increase of the water level in Pit 3 was expected to impact on tailings deposition in Pit 3, essentially requiring transition from a sub-aerial deposition method (tailings deposited on a dry 'beach') to a sub-aqueous deposition method (tailings deposited into the water column). Depositing tailings sub-aqueously increases the potential for the tailings to segregate based on particle size, which can lead to long-term issues with tailings settlement in the pit. To address concerns that 'sub-aqueous' tailings deposition might affect rehabilitation timeframes and environmental outcomes, SSB engaged a geotechnical engineer to undertake a detailed technical review of tailings deposition in Pit 3. The review found sub-aqueous tailings deposition may result in longer consolidation timeframes and provide a larger long-term groundwater contaminant source than previously predicted. Outcomes and recommendations from the review were provided to the regulatory authorities and ERA in October 2017 and in January 2018, a technical workshop was facilitated by ERA to address outstanding concerns regarding the potential environmental impacts of tailings deposition in Pit 3. The information presented by ERA at the workshop demonstrated that proposed changes to the tailings deposition strategy did not increase the risk to the environment. SSB subsequently advised regulatory authorities of its support for continued deposition of tailings in Pit 3, contingent upon ERA completing the action items agreed at the workshop and addressing SSB's recommendations on tailings management. Progress on the agreed actions and recommendations are tracked through regular stakeholder meetings including the Minesite Technical Committee and the Closure Consultative Forum.

3.1.2.6 Tailings Storage Facility

As indicated above, tailings currently stored in the TSF are being transferred to Pit 3. Advice provided by ERA indicates that tailings transfer is behind schedule, due to sub-optimal dredge performance. ERA is exploring options to increase the tailings dredging rate to ensure the transfer of tailings from the TSF to Pit 3 is completed on schedule in Q1 2021.

On 11 December 2017 ERA requested that the TSF maximum operating level (MOL) be reduced to assist with the ongoing management of tailings and process water transfers. The proposal amended the dry season MOL from RL 59.2 m to RL 49.61 m and the wet season MOL from RL 57.9 m to RL 48.23. SSB had no objections to this amendment but noted any proposed structural changes to the TSF would require additional assessment. This MOL reduction application was approved by DPIR on 5 January 2018.

On 7 February 2018 ERA submitted an application to notch the eastern embankment of the TSF. This notching to reduce the TSF crest height from RL 60.5 m to RL 51.0 was required to improve process water pumping rates to optimise the water balance between the TSF and Pit 3. This application was assessed and supported by SSB noting that the notching provided an opportunity for ERA to characterise potential contamination in the TSF embankment material to inform future decommissioning. ERA completed the construction of the notch in early June 2018.

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. The Ranger MTC met five times during the 2017–18 reporting period. Significant agenda items discussed at the meetings included the following:

- Pit 3 brine injection and tailings deposition
- process and pond water treatment initiatives and inventory forecasting
- Pit 1 water balance, contaminated groundwater management, tailings settlement monitoring and bulk backfill strategy
- GCT2 interception system review and the effectiveness of management and monitoring strategies for high EC events in Gulungul Creek
- environmental incidents and process safety implementation and oversight activities
- progressive tracking of rehabilitation works and performance, including TSF tailings dredging, brine injection and process water treatment.

The MTC meeting on the 28 November 2017 focussed on a review and discussion of tailings deposition in Pit 3 including changes to tailings deposition strategies proposed by ERA as discussed in Section 3.1.2.5 above.

3.1.3.2 Audits and inspections

The 2017 Annual Environmental Audit was conducted from 30 July– 4 August 2017 and focussed on ERA's management of major rehabilitation activities, including its ability to monitor key rehabilitation metrics. The selected rehabilitation activities included process and pond water management and treatment, tailings management and pit backfill processes.

The audit comprised 21 questions associated with these rehabilitation activities and the grading for each question was assigned based upon the status of management strategies in place, in consideration of potential consequences to the environment and/or rehabilitation and closure timeframes.

The audit found that generally ERA had appropriate strategies in place for managing major rehabilitation activities, with no non-conformances determined. Three conditional findings identified where improvements were needed:

- the implementation of recommendations from external validation and calibration of the site water balance model
- the update of procedures associated with brine injection
- the incorporation of new monitoring prisms into the site prism database to monitor Pit 3 geotechnical stability.

These three conditional findings have been followed up by stakeholders through the RPI process and have been satisfactorily addressed by ERA. The 2018 Annual Environmental Audit is scheduled for September 2018.

The 2018 Ranger RPI and audit program was agreed by stakeholders in December 2017. Each RPI in the program has a specific theme, aligned with relevant activities on-site (Table 10). RPIs were carried out as scheduled during the 2017–18 and Table 11 shows the focus areas for each of the RPIs.

TABLE 10 2018 RANGER ROUTINE PERIODIC INSPECTION PROGRAM

Month	Primary Focus
January	Fire management and Pit 1 backfill (completed)
February	Radiation management (completed)
March	Weed and land use management (completed)
April	TSF 6 monthly inspection, tailings and process water transfers
May	Surface and groundwater monitoring
June	Hydrocarbon and hazardous substances management
July	Rehabilitation activities and planning
August	TSF annual inspection
September	2018 Annual Environmental Audit
October	Waste management and disposal
November	Water treatment and management
December	Crushing, milling and processing circuits

TABLE 11 RANGER ROUTINE PERIODIC INSPECTIONS 2017-18

Month	Primary Focus
July 2017	2017 Annual Environmental Audit
August	TSF annual inspection
September	Bulk hydrocarbon and acid management, hazardous chemical storage and waste disposal and follow-up on reported environmental incidents for June-August 2017
October	Water management and release, wet season preparatory works, Pit 1 MBL bores, Pit 3 rim release sites and Djalkmara irrigation areas
November	Pit 1 backfill, Pit 3 tailings deposition and under bed drainage, TSF dredge improvements, process water treatment and brine recirculation, CCWLF mixing bund, southern boundary drainage line repair and reported incidents for September/October 2017.
December	Processing area inspection, leach tank bunding, high density sludge pilot plant, processing area dust monitoring, dust extraction interlock testing, asset integrity monitoring and reported incidents for November/December 2017
January 2018	Bulk material movement, Pit 1 backfill schedule and consolidation monitoring, discriminator calibration, fire management and 2018 burn program development. Reported incidents for December 2018.
February	Radiation management, 2017 radiation and atmospheric monitoring results, contamination monitoring and reported incidents for January/February 2018
March	Weed and land use management, weed spraying initiatives, current site revegetation trials, 2017-18 water management status and reported incidents for February 2018.
April	TSF post-wet season inspection, Pit 3 pumping infrastructure relocation, 2017 Annual Environmental Audit follow-up and reported incidents for March/April 2018.
May	Surface and groundwater monitoring, Pit 1 backfill status, TSF eastern wall notch construction and reported incidents for April/May 2018.
June	Bulk hydrocarbon and hazardous chemical management, water treatment plant interlocks, hazardous/non-hazardous waste disposal, and reported incidents for June 2018.

3.1.3.3 Environmental incidents

During 2017–18, 23 environmental incidents had been reported by ERA to stakeholders. Most of these incidents related to minor process water and waste liquor spills within the processing area and minor tailings line leaks between the processing facilities and the TSF or Pit 3. The number of reported incidents has increased slightly from the 18 incidents reported in 2016–17.

All incidents were investigated by SSB through the RPI process and were considered to have been resolved satisfactorily and did not result in off-site impacts.

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 and tailings related incidents are comparable to the number reported in 2016–17, however hydrocarbon incidents increased from three in 2016–17 to eight in 2017–18.

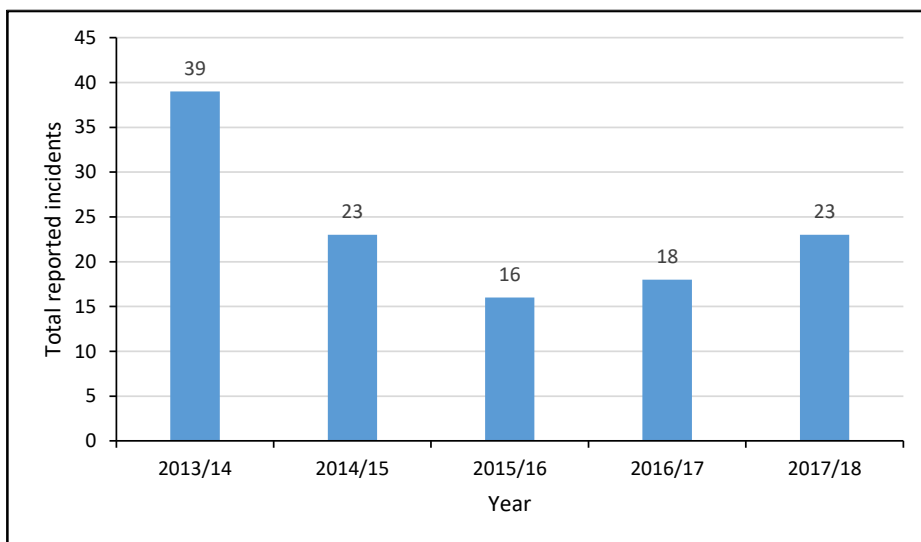


Figure 6 Ranger mine reported environmental incidents by year

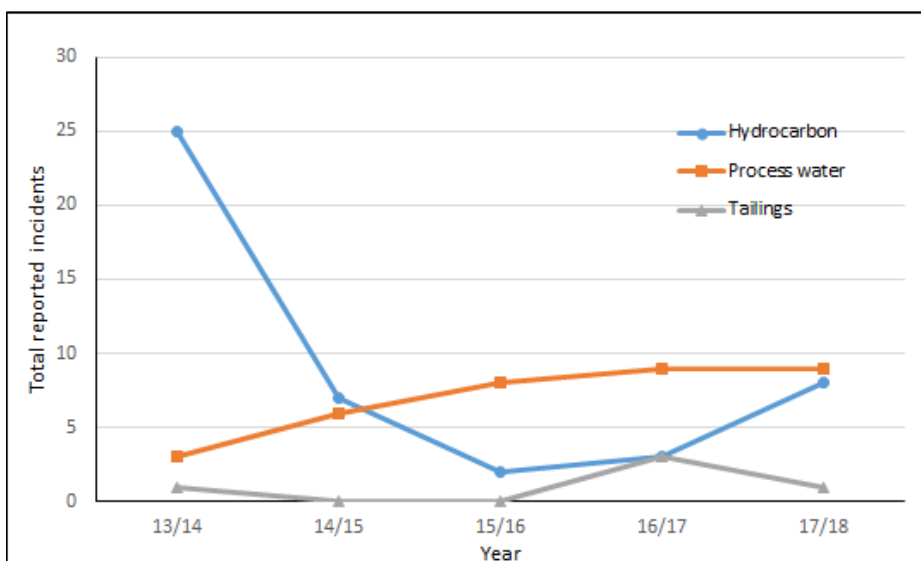


Figure 7 Hydrocarbon, process water and tailings incidents by year

3.1.3.4 Significant incidents

No incidents requiring formal investigation by SSB have been reported during 2017–18, however three notable incidents were reported:

- On 14 December 2017 ERA became aware that the scrubber and ventilation interlock tests on Ball Mill 2 had not been undertaken in accordance with the requirements of the Ranger Authorisation 0108. Atmospheric monitoring showed that the dust control systems remained effective during the period of non-compliance with statutory testing requirements.
- On 3 February 2018 while transporting sulfuric acid to site, a minor quantity (less than 2 L) of acid spilt onto the Kakadu Highway. The spilt acid was cleaned up and the contaminated soil was disposed at the Ranger minesite.
- Between 12 April 2018 and 7 June 2018 a total of 215.1 ML of pond water permeate (treated pond water), was discharged to Magela Creek at release point MG001 (Figure 2) contrary to the discharge locations stipulated in the Ranger Water Quality Objectives (WQOs) discussed in Section 4.1. Continuous monitoring by SSB confirmed that electrical conductivity at the downstream compliance point MCDW (Figure 2) remained below the WQOs EC investigation trigger levels during the release period, confirming that this discharge did not cause any impact to the ecosystem downstream of the RPA.

Stakeholders followed up on these incidents through the RPI process and were satisfied with the remediation activities undertaken and improved control strategies implemented to minimise the risk of re-occurrence.

Table 12 provides a summary of the significant incidents that have occurred since 2013.

TABLE 12 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 m3 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 <i>Environment Protection Biodiversity and Conservation Act 1999</i> . SSB and NT Government identified deficiencies in ERA's fire management system, which was subsequently audited in 2016.

3.1.4 Radiation protection

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 in a year)
- Limit to workers (100 mSv over 5 years with a maximum of 50 mSv in any one year).

In addition, ARPANSA has recommended a reference level of 5 mSv in a year to distinguish between designated and non-designated workers at Australian uranium mines. Designated workers are those who could potentially receive an occupational radiation dose above the reference level. These workers are monitored more intensely than the non-designated workers. It is ERA's responsibility to monitor radiation doses and to ensure that radiation exposures to both workers and the general public from operations at Ranger are as low as reasonably achievable, taking into account economic and societal factors.

Dose constraints for the Ranger operation are revised annually and detailed in ERA's Annual Radiation and Atmospheric Monitoring Report. The 2017 dose constraints for Ranger mine are listed in Table 14.

TABLE 13 2017 ANNUAL RADIATION DOSE CONSTRAINTS FOR RANGER MINE

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

3.1.4.1 Radiation 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 2017 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 13. For designated workers there was a slight increase in the mean effective dose for 2017 when compared to 2016 as shown in Table 14. This increase is attributed to increased non-routine operational activities in 2017, associated with the processing area tank inspection and refurbishment program. For non-designated workers, the 2017 dose was comparable to the 2016 dose as shown in Table 15.

TABLE 14 2017 DESIGNATED WORKER DOSE (mSV)

	2017	2016
Occupational dose limit	20	20
Mean annual effective dose (% of dose limit)	1.28 (6.4%)	1.14 (5.7%)
Maximum annual effective dose (% dose limit)	3.96 (19.8%)	4.14 (20.7%)

TABLE 15 2017 NON-DESIGNATED WORKER DOSE (mSV)

	2017	2016
Occupational dose limit	20	20
Mean annual effective dose (% of dose limit)	0.14 (0.7%)	0.15 (0.8%)
Maximum annual effective dose (% dose limit)	1.13 (5.7%)	1.07 (5.4%)

3.1.4.2 Radiation 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.

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 negligible and does not currently pose a public health risk (typically contributing less than 5% of the public dose limit). Accordingly, 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 16 provides a summary of annual average radon progeny potential alpha energy concentration (PAEC) in air and estimated doses to the public in 2017. The mine-derived annual dose from radon progeny in air has been estimated to be 0.023 mSv at Jabiru town which is 2.3% of the public dose limit of 1 mSv in a year and comparable to the 2016 dose of 0.018 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 16 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN

	2017	2016
Annual average PAEC [$\mu\text{J m}^{-3}$]	0.045	0.043
Total annual dose [mSv]	0.436	0.348
Mine-derived dose* [mSv]	0.023	0.018

*The radon progeny PAEC difference used in the mine-derived dose calculation was 0.009 $\mu\text{J}/\text{m}^3$ for 2016 and 0.018 $\mu\text{J}/\text{m}^3$ for 2015

ERA uses high volume air samplers to monitor airborne concentrations of LLAA in the township of Jabiru and at Jabiru East. Table 17 provides a summary of the annual average LLAA radionuclide concentration reported by ERA and the total and mine-derived doses to the public at Jabiru estimated by SSB. 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_α^{-1} , breathing rate of 0.75 $\text{m}^3 \text{h}^{-1}$ and assumed full year occupancy of 8,760 hours.

TABLE 17 LLAA RADIONUCLIDE CONCENTRATIONS IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN IN 2017

	2017	2016
Annual average concentration ($\text{Bq}_\alpha^{-1}\text{m}^{-3}$)	1.3×10^{-4}	1.4×10^{-4}
Total annual dose (mSv)	0.006	0.006
Mine-derived dose* (mSv)	3.2×10^{-4}	3×10^{-4}

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

The mine-derived dose from dust-bound LLAA radionuclides has been estimated by assuming that the ratio of mine-derived 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-derived 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-derived to total dose ratio for dust should be less than that for radon progeny.

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 at least August 2024.

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 at the Djarr Djarr exploration camp site in 2007, 2008 and 2010, resulting in significant vegetation mortality.

The results of vegetation surveys carried out by ERA during October 2015 were provided to stakeholders in February 2018. These results showed that plant mortality rates for vegetation planted in 2013 were around 50%, increasing to around 80% for vegetation planted in 2014. The 2015 survey also demonstrated that natural recruitment is occurring, contributing up to 85% of the total number of stems at the site. Another revegetation survey is planned by ERA later in 2018 to assess the 5-year survival rates of vegetation planted in 2013.

ERA uses herbicide to actively manage weeds at the Jabiluka mineral lease. The survey results for the 2017-18 weed spraying season indicate that both Djarr Djarr and Jabiluka show a decrease in weed density, compared to the 2016-17 survey. This is in part attributed to the early cessation of 2017-18 wet season rains, allowing access for

weed management activities prior to the seeding period for many of the weed species. To improve weed management outcomes during 2017-18, and over future wet seasons, a weed spraying unit has been relocated to the Jabiluka site, with herbicide and fuel transported to the site as needed using a helicopter. In 2017-18, 321 hours of weed spraying activities have been undertaken at the Jabiluka and Djarr Djarr sites.

ERA undertakes annual fuel-reduction burning around the Djarr Djarr and Jabiluka sites to reduce the effects of wildfires on the revegetated areas. In January 2018 ERA successfully undertook a mid-wet season burn at the Djarr Djarr site to remove fuel load and minimise impacts from early dry season wildfires that regularly occur in the Mudginberri Billabong region. In May 2018, controlled burns was conducted around the perimeter of the Jabiluka rehabilitated area to protect the site revegetation with a follow up burn conducted at the end of June 2018. The total area burnt in the Jabiluka lease area in 2017 was 243 Ha.

3.2.1.2 Water management and monitoring

The Jabiluka site lies to the west of Ngarradj Creek and is in the headwaters of three sub-catchments. These sub-catchments are termed the southern, central and northern tributaries of Ngarradj Creek. The Interim Water Management Pond (IWMP) at the Jabiluka site was removed in 2013 and the area was recontoured and revegetated. ERA continues to monitor water quality in groundwater and surface waters upstream and downstream of the Jabiluka site in accordance with the Jabiluka Authorisation. Overall, the monitoring results reported during the 2017-18 wet season remain within historical ranges reported in previous wet seasons, and there has not been any evidence of off-site environmental impacts. 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. Given the low environmental risk posed by the site, SSB ceased water quality monitoring prior to the 2015–16 wet season.

During 2017–18, ERA progressed consultation with GAC regarding sampling the Mine Valley bores located to the west of Jabiluka. ERA is accountable for the collection of samples from the Mine Valley bores. The data and interpretation of groundwater in mine valley will be incorporated into future Jabiluka Wet Season Reports and inform the future groundwater monitoring program.

3.2.2 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 three times during 2017–18 and these meetings focussed on the ongoing progress of revegetation, weed control activities and fire management.

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

season to allow stakeholder discussion of any potential issues identified during the most recent inspection.

The 2017 pre-wet season inspection was conducted on 17 November 2017 and focussed on landform stability, general vegetation health and the status of groundwater and surface water monitoring sites. No outstanding wet season preparative actions were identified during the inspection. The 2018 post-wet season inspection was conducted on 27 April 2018 with no significant impacts observed from the higher than average rainfall that occurred during the 2017-18 wet season. Stakeholders noted that the wet season burning and early dry season weed spraying at Djarr Djarr had contributed to a noticeable reduction in weeds observed on-site.

No environmental incidents have been reported for Jabiluka during 2017–18.

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 oxide 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. In early 2018 UEL changed their name to DevEx Resources (DevEx) and are expanding their exploration focus within the ARR to include targets other than uranium.

Since 2008, DevEx has undertaken extensive exploration on the Nabarlek lease and has assumed responsibility for management of the rehabilitated areas at 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 SSB, the regulator and key stakeholders including the NLC.

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 DevEx 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. A review of tube stock planting techniques and timing was undertaken by DevEx in 2017 to identify more effective methods to increase survival rates. This review identified that undertaking plantings early in the wet season to improve water availability would assist in decreasing early tubestock mortality. Feral animals and wild cattle are believed to contribute to tube stock mortality with DevEx looking to repair the mine perimeter fence and in consultation with local ranger groups, implement a program to eradicate these animals within this fenced area during 2018.

A weed spraying campaign was undertaken early in the 2017-18 wet season with follow up weed spraying scheduled for March-April 2018. Access to the site in 2018 was delayed until May 2018 due to late wet season rainfall and the washout of a river crossing on the main Nabarlek access road. Annual fire management activities are undertaken in conjunction with the local DMED Rangers from Oenpelli, as recommended during the 2015 stakeholder audit and usually occur concurrently with weed spraying activities on-site. Due to the late access to the site in 2018, consultation with the DMED Rangers identified that cool burns would commence in May 2018, with limited weed spraying undertaken prior commencing these burns.

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. The mapping will be undertaken again in the future to enable temporal assessment of weed density and distribution across the lease, helping to demonstrate the effectiveness of DevEx's weed management program. Weed mapping scheduled for 2018 was not undertaken due to the late site access discussed above. Observations on the ground in 2018 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. During 2018-19 DevEx intends to evaluate the use of residual herbicides to selectively target mission grass which is particularly prevalent in the more open areas on-site.

3.3.1.2 Water management and monitoring

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

In August 2016 DevEx 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. In October 2017 DevEx undertook further water sampling from monitoring and surface water sites with results reported in the 2018 Mining Management Plan.

At the beginning of the 2016-17 wet season SSB deployed three continuous EC sensors, one in Kadjirikamarnda Creek downstream of the former minesite, and two in Cooper Creek at sites upstream and downstream of the former minesite. The EC measurements were consistent with DevEx monitoring data and provide a baseline of current seasonal EC trends which can be used to assess changes over time. EC sensors were redeployed for the 2017-18 season and showed similar trends to the previous season. SSB will continue to monitor EC at Nabarlek in 2018-19.

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 contributes about one quarter of the total radon flux from the rehabilitated minesite and historically, the majority 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 DevEx undertook a program of shallow drilling in the RAA to further characterise the radioactivity profile in the area. 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. The preferred remediation option being considered by DevEx involves burial of the radiologically contaminated material at the current location and placement of a rock cover with water diversion earthworks to minimise future erosion. SSB conducted a LiDAR survey of the RAA using a UAV in June 2018 to assist with the remediation activities and material placement.

3.3.2 Exploration

The Mining Management Plan for the 2017 dry season works was submitted by DevEx on 28 June 2017 and following assessment, SSB supported the acceptance of this updated Mining Management Plan on 2 September 2017. During October 2017, DevEx undertook non-invasive exploration activities comprising ground gravity and radon-in-soil surveys. The 2017 stakeholder site inspection was conducted on 20 October 2017 to coincide with these exploration activities. The Mining Management Plan for 2018 dry season works was submitted on 18 July 2018 and is currently under assessment. The proposed work program for 2018 includes further geophysical surveying which will inform a small drilling program later in 2018.

3.3.3 Assessment activities

The 2017 stakeholder site inspection was conducted on 20 October 2017 and focused on an assessment of the former camp, the status of weed management and follow up on remedial works identified during the 2016 site visit. During this inspection the escalated Category 2 non-compliances from the 2015 audit were closed off with stakeholders noting significant improvements in hydrocarbon and hazardous waste management. Additionally, stakeholders noted matters raised during the 2016 inspection regarding the disposal of exploration samples had been satisfactorily addressed by DevEx. The 2017 site inspection identified two open exploration drill holes requiring remediation and that several bores used for groundwater sampling required repairs including new caps. There were no environmental incidents reported for Nabarlek during 2017–18.

A Nabarlek MTC meeting was held on 31 May 2018 and focussed on the ongoing progress of revegetation and weed management, and possible remediation strategies for the RAA and other outstanding disturbed areas on-site.

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.

In June 2016 a review of the monitoring data for the containment facility, commissioned by Parks Australia, recommended minor improvements to annual management activities, reporting of monitoring data and minor earthworks to restrict pooling of water on the surface of the facility.

An audit of the containment facility was conducted by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) on 30 May 2018 conjointly with an inspection of the facility by SSB staff. The need to monitor and if required, repair surface cracks on the containment and ongoing management of annual mission grass were the main findings from this inspection. A UAV LiDAR survey of the containment facility conducted by SSB on 26 June 2018 will assist in identifying the effectiveness of remediation activities undertaken to restrict the pooling of water on the surface of the facility. Bushfires had been through the area in 2017-18, impacting on revegetation in some areas at the containment facility but fortunately not damaging monitoring equipment. Continuation of a program of late wet season/early dry season low intensity burns to reduce fuel load and protect monitoring equipment was also recommended from the SSB inspection.

3.4.2 Uranium exploration projects

3.4.2.1 Cameco/Vimy Resources Arnhem Project and Wellington Range – King River Joint Venture Project

On 1 March 2018 Cameco entered into an agreement with Vimy Resources Limited to acquire Cameco's ARR exploration projects with Cameco effectively ceasing its exploration activities in the region.

No exploration activity was undertaken by Cameco in the ARR during 2017 prior to transfer of the tenements to Vimy Resources, 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 inspection of the Myra, Kukalak and Cadell Project and the Arnhem Projects was undertaken by stakeholders from 28-30 August 2017 to assess

compliance with their relevant closure requirements. No significant outstanding rehabilitation activities were identified during this inspection. Stakeholders noted the advanced status of revegetation of the rehabilitated drill sites. On 27 October 2017 Cameco submitted an application for closure of the Arnhem Project. Following a review of historical audit and inspection records in conjunction with the rehabilitation report supplied as part of the closure application, SSB concluded there was no outstanding rehabilitation requirements and supported closure of project.

On 20 June 2018, Vimy Resources submitted a MMP for their 2018 dry season exploration program which includes the re-establishment of the King River camp, construction of groundwater bores to source water for exploration and camp activities, and the drilling of up to 30 RC drill holes.

3.4.2.2 DevEx West Arnhem Joint Venture

As discussed in Section 3.3 UEL changed their name to DevEx in early 2018. No changes to the companies ARR projects occurred as a result of this name change.

The 2017 inspection of DevEx West Arnhem joint venture was undertaken in conjunction with the Nabarlek site inspection on 20 October 2017. As discussed in Section 3.3.3, two Category 2 non-compliances identified during the 2015 Audit were closed off and the inspection identified two open exploration drill holes requiring remediation and that several bores used for groundwater sampling required repairs including new caps.

The Mining Management Plan for the 2017 dry season works was submitted by DevEx on 20 July 2017 and SSB supported the acceptance of this updated Mining Management Plan on 02 September 2017. The exploration program proposed for 2017 involved ground gravity and radon-in-soil surveys. Due to resource constraints these activities were not undertaken in 2017 and were rescheduled for 2018. The 2018 MMP describing this continuation of non-invasive exploration was submitted on 26 June 2018 and is currently under assessment.

3.4.2.3 Alligator Energy Tin Camp Creek Project and Beatrice Project

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

Due to the non-invasive nature of the proposed exploration and limited time on-site, SSB has not undertaken any site inspections or audits of these projects during the 2017–18 reporting period.

The 2018 MMP for the Tin Camp Creek and Beatrice Project were submitted on 20 June 2018 and following review the SSB recommended acceptance to DPIR on 31 July 2018. The 2018 work program comprises further surface sample collection and geophysical surveys during a small campaign scheduled for later in 2018

3.4.2.4 UXA Resources Nabarlek Group Project

No exploration activities were proposed or carried out at this site during 2017 or are proposed in 2018, so SSB has not undertaken any site inspections or audits during the 2017–18 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 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. No environmental impacts from Ranger mine's operations to the off-site environment were reported from SSB's monitoring undertaken to date, including during the 2017–18 wet season.

The dates of wet season flow commencement and cessation, since the 2009–10 wet season, are shown in Table 18.

TABLE 18 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
2017-18	15 Nov 2017	12 Jul 2018	240	3 Jan 2018	18 Jun 2018	166

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 2017–18 wet season indicates that there have been no observed environmental impacts from operations at Ranger uranium mine in the off-site 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 recent wet seasons (Figure 8).

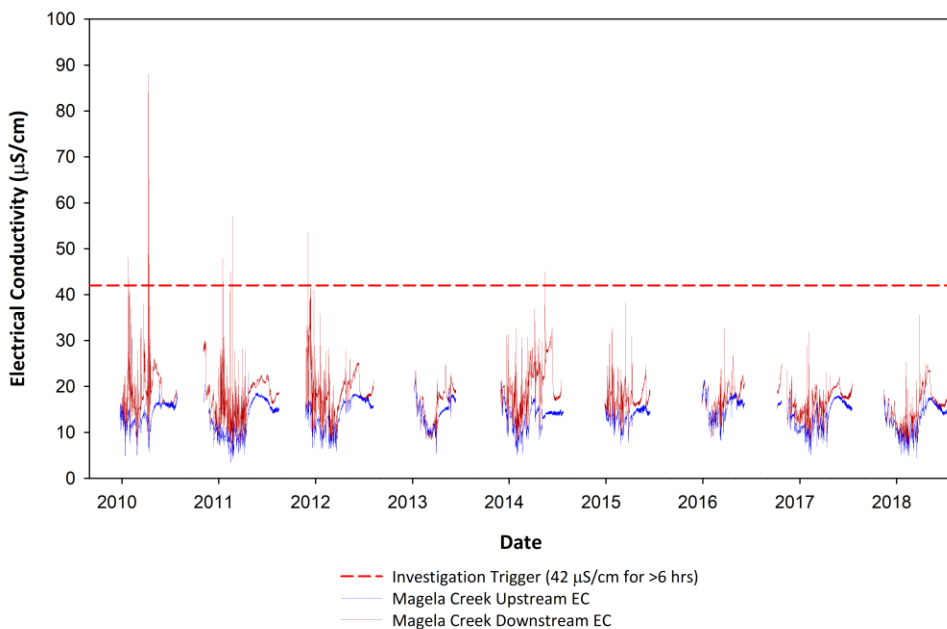


Figure 8 Magela Creek electrical conductivity (EC) data measured during the wet season 2009-18.

Throughout the 2017-18 wet season, the conductivity in Magela Creek remained well below the Investigation Trigger value (Figure 9). An increase in conductivity was observed towards the end of March with the onset of recessional flows and increased groundwater contribution, which is known to have a higher EC than the rainfall driven surface water flow. The drop in EC observed at the downstream site during mid-May coincided with the cessation of discharge from Georgetown Billabong into Magela Creek. SSB monitoring shows that all water quality objectives for Magela Creek were met during the 2017–18 wet season.

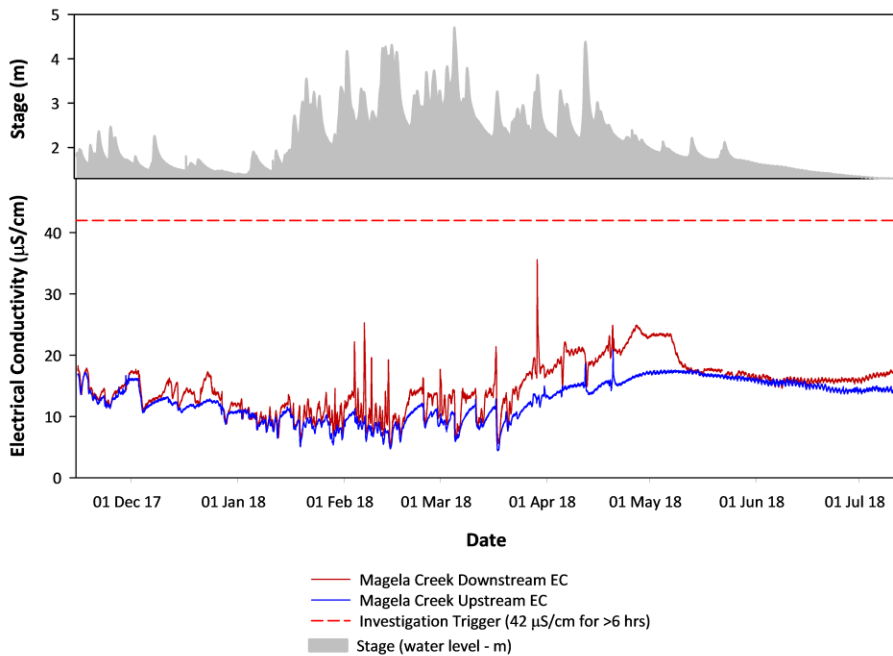


Figure 9 Magela Creek electrical conductivity (EC) and water level (stage) data measured during the 2017–18 wet season.

Compliance with the ^{226}Ra Limit of 3 mBq/L is assessed by calculating the difference in the geometric mean of ^{226}Ra concentrations measured at the Magela upstream and downstream sites for the entire season. ^{226}Ra concentrations in Magela Creek over the 2017-18 wet season were below the Limit (Figure 10).

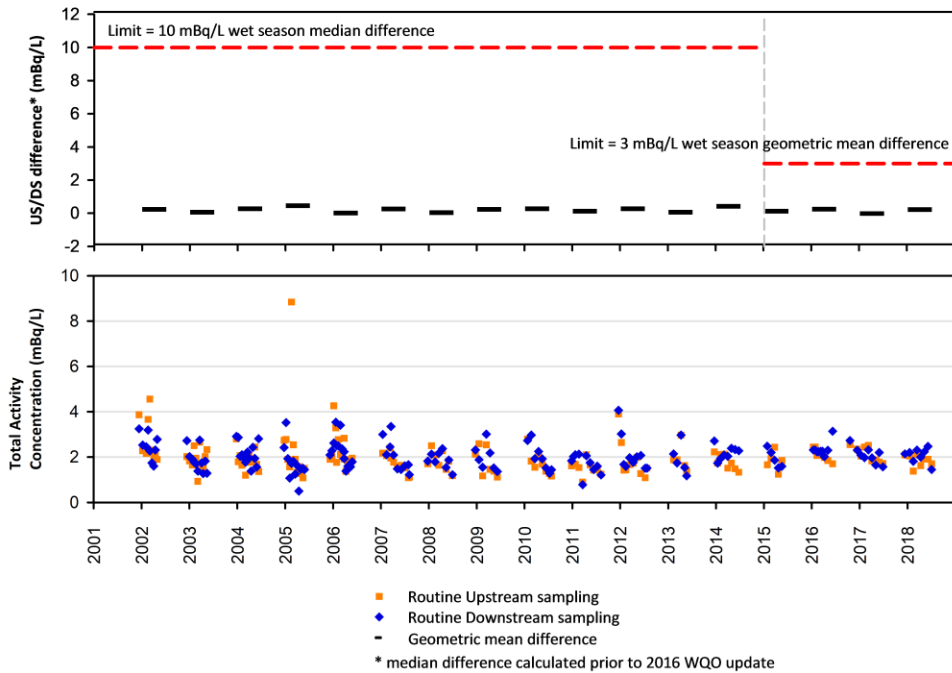


Figure 10 Magela Creek upstream and downstream ^{226}Ra data.

Biological monitoring

Toxicity monitoring

Work, health and safety concerns when operating in high flowing waters in Magela and Gulungul creeks resulted in a reduction in the number of in situ toxicity monitoring tests undertaken during the 2017-18 wet season (compared to previous seasons). Seven in situ toxicity tests were conducted in Magela Creek, spanning the period 24 November 2017 to 10 April 2018.

For the 2017–18 wet season, snail egg production in 5 out of 7 tests was higher at the downstream site compared to the upstream site (Figure 11). Analysis Of Variance (ANOVA) testing showed egg difference values between the sites were not significantly different for the 2017–18 wet season compared to all previous wet seasons.

Higher downstream egg production observed in the 2017–18 wet season is a pattern typical of toxicity monitoring in Magela Creek over many years, and has been associated with either slightly elevated EC and/or higher water temperature at the downstream site compared to the upstream site. These observations and hypotheses have been the subject of ongoing research by SSB (see Project RES-2017-028 reported in Appendix 2).

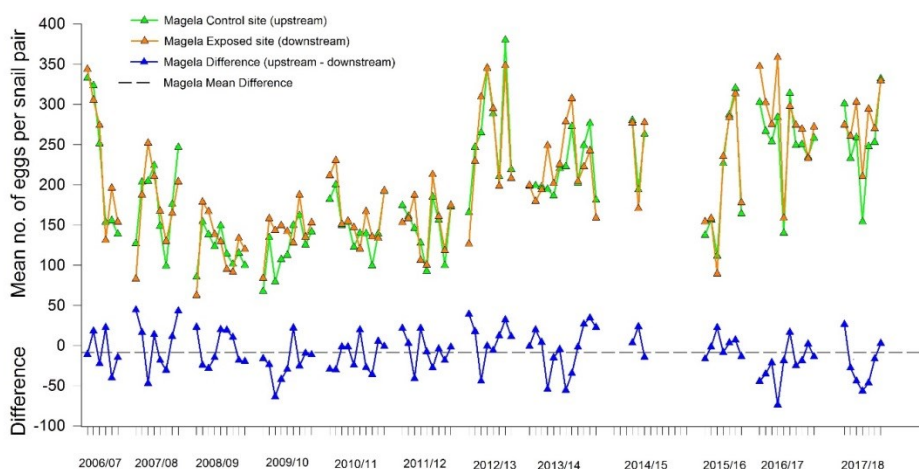


Figure 11 Time series of in-situ snail egg production data from toxicity monitoring tests conducted in Magela Creek.

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. SSB monitors the bioaccumulation of ^{226}Ra in mussels by measuring ^{226}Ra activity 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 12).

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.

Freshwater mussels were collected from Mudginberri Billabong in October 2017. Figure 12 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 2017 were within the range of previously measured values, though at the lower end of the range for mussels aged 3 to 6 years.

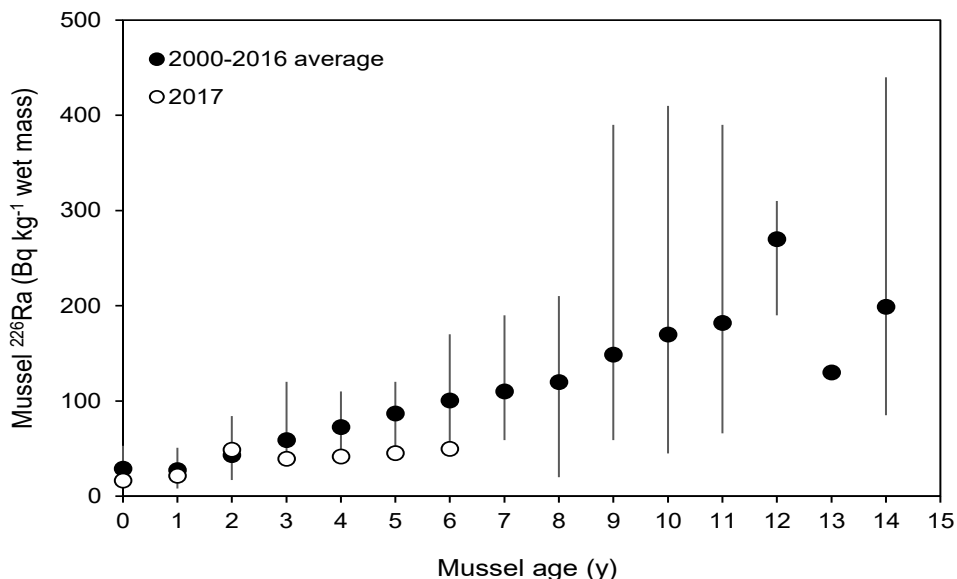


Figure 12 Flesh ^{226}Ra activity concentrations in mussels collected from Mudginberri Billabong.

The annual committed effective dose from ^{226}Ra in mussels has been calculated to be 0.07 mSv for a 10-year-old child who eats 2 kg (wet mass) of mussel flesh based on the 2017 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 2016 has been calculated as 0.12 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.

4.1.2 Early detection monitoring in Gulungul Creek

Monitoring undertaken in Gulungul Creek during the 2017–18 wet season showed no observable environmental impacts from operations at Ranger mine in the off-site 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, upstream and downstream monitoring locations on Gulungul Creek were adjusted to better assess the mine derived inputs into Gulungul Creek. The former downstream site (GCDS) was relocated to the lease boundary (GCLB) and a new upstream site was installed (GCNUS), which is used as the control site for the SSB monitoring program.

The EC measured in Gulungul Creek during the 2017-18 wet season indicates a continued improvement in water quality since the 2013-14 wet season (Figure 13).

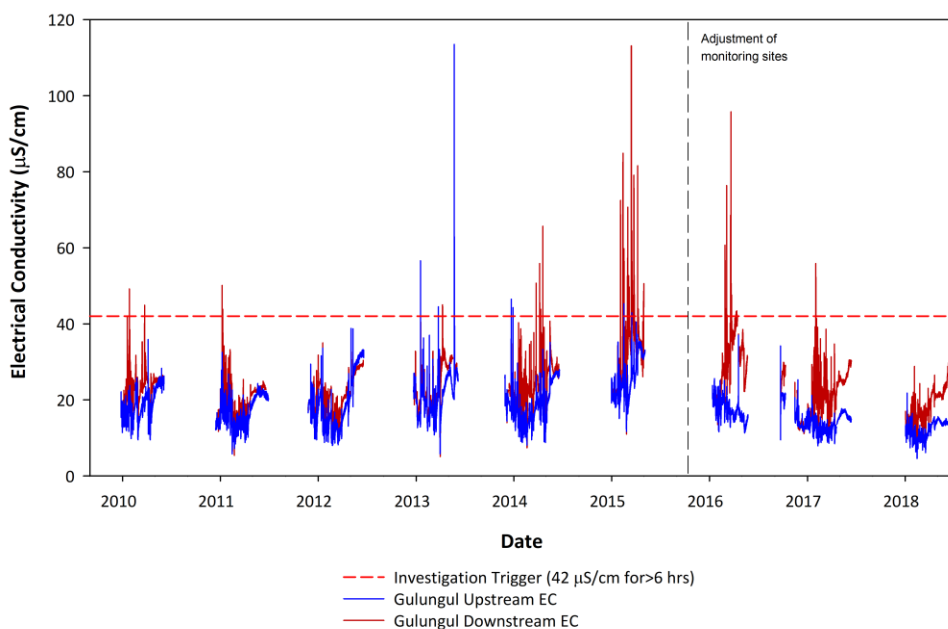


Figure 13 Gulungul Creek electrical conductivity (EC) data measured during the wet season.

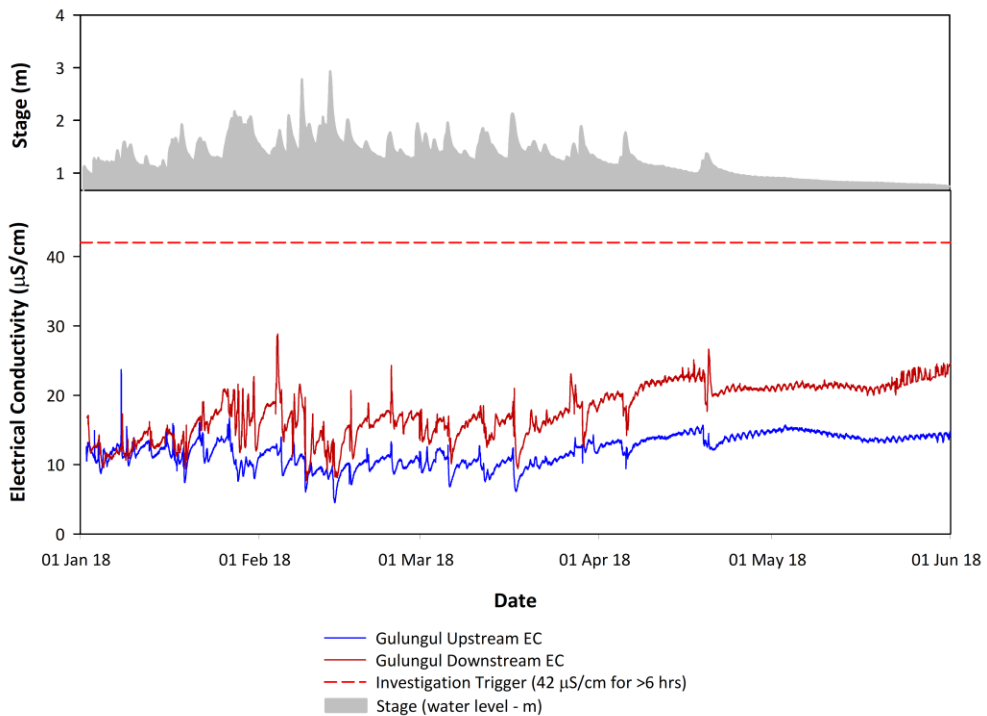


Figure 14 Gulungul Creek electrical conductivity (EC) and water level (stage) data measured during the 2017–18 wet season.

Throughout the 2017-18 wet season, the conductivity in Gulungul Creek remained well below the Investigation Trigger value (Figure 14). The slightly higher EC recorded at the downstream monitoring location can be attributed to the flushing of solutes from the shallow aquifer system to the west and south of the minesite. ERA actively manages water quality in the Gulungul catchment, which has significantly improved the water quality in Gulungul Creek over recent years, and enabled water quality objectives in Gulungul Creek to be maintained for the 2017-18 wet season.

^{226}Ra concentrations in Gulungul Creek over the 2017-18 wet season were well below the Limit (3 mBq/L calculated difference) (Figure 15).

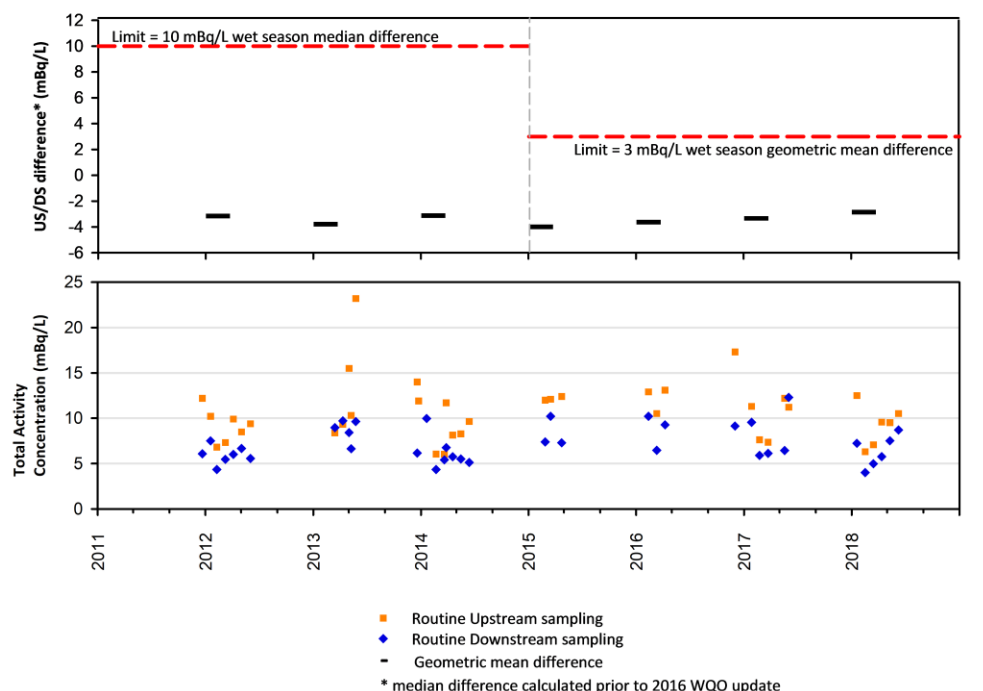


Figure 15 Gulungul Creek upstream and downstream ²²⁶Ra data.

Upper Gulungul Catchment Investigation

Since the 2012-13 wet season, water quality measured at the original Gulungul Creek upstream control site, GCUS (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. Investigations conducted by ERA concluded that the elevated EC was due to irrigation activities in the Corridor Creek application area.

Figure 16 compares the EC measured at GCUS and at the new upstream control site, GCNUS, for the 2017-18 wet season. The data show that the EC at GCUS continues to be elevated compared to GCNUS, indicating ongoing input of solutes between the two sites. Continuous monitoring loggers deployed in the upper Gulungul tributary (GCTS) to detect and track changes in the solute plume originating from the Corridor Creek Land Application Area (CCLAA) showed no change in electrical conductivity at monitored sites between the 2016-17 and 2017-18 wet seasons. This suggests the solute plume in the shallow aquifer is still present and discharging to the low lying area to the south of the CCLAA during the wet season when groundwater levels are elevated. SSB will continue to monitor this area in the 2018-19 wet season.

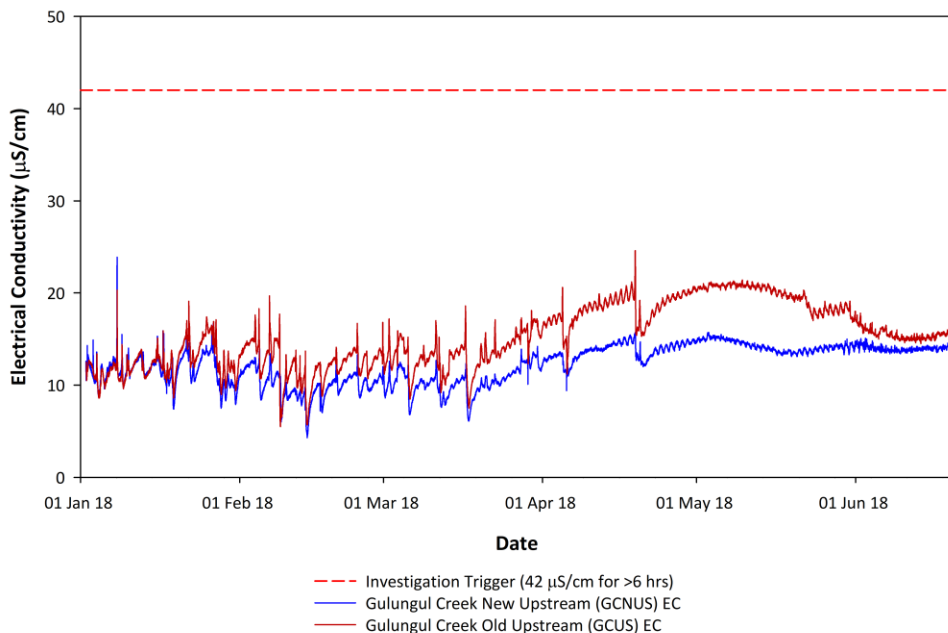


Figure 16 Comparison of EC values measured in Gulungul Creek upstream of the mine, at the existing control site (old upstream) and the new investigation-site (new upstream).

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. 136 ML of water was extracted by the interception system during the 2017–18 wet season.

SSB continues to monitor the EC 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. The average EC of the base flow in GCT2 has continued to decline in 2017-18, leading to the observed improvement in water quality in Gulungul Creek downstream of the minesite during the 2017-18 wet season (Figure 17). SSB will continue to measure the EC at GCT2RST during the 2018-19 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.

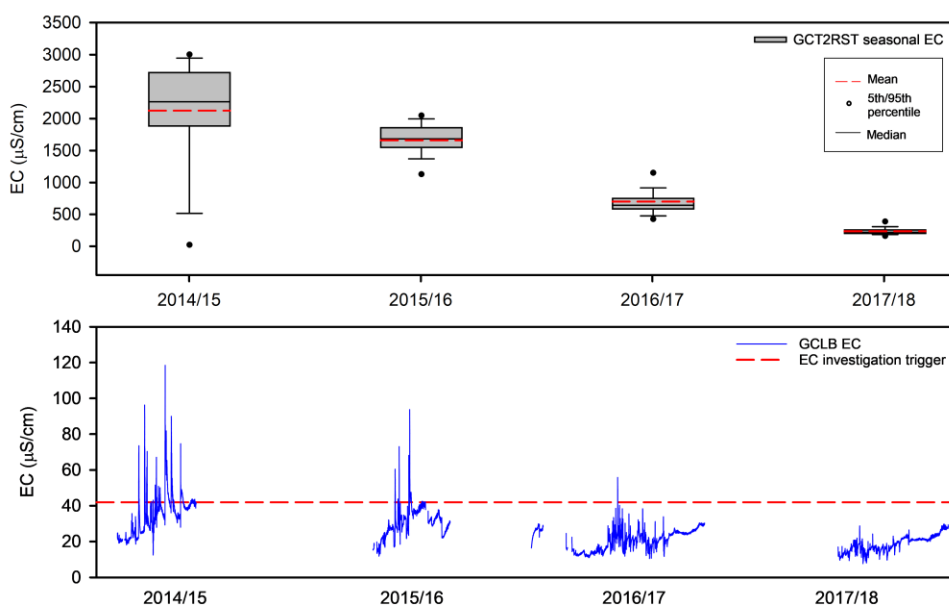


Figure 17 Electrical conductivity measured within Gulungul Creek Tributary 2 (GCT2RST) (above) and Gulungul Creek downstream compliance site (GCLB).

Biological monitoring

Toxicity monitoring

Three sites are included in toxicity monitoring in Gulungul Creek: upstream and downstream sites tested since 2009–10 (GCUS and GCDS respectively), and midstream site (GCLB) included since 2015 to measure any water quality-related effects arising from contaminated surface water in the GCT2 tributary. Work, health and safety concerns when operating in high flowing waters in Gulungul Creek resulted in a reduction in the number of in situ toxicity tests undertaken during the 2017-18 wet season (compared to previous seasons). Four in situ toxicity tests were conducted in Gulungul Creek, spanning the period 19 January 2017 to 27 March 2018. Figure 18 shows data for just the upstream and downstream sites, while Figure 19 shows data for all three sites. The first test included only two sites, upstream and midstream (GCUS and GCLB respectively), because the downstream site could not be accessed (Figure 19). The second and fourth tests included all three sites (GCUS, GCLB and GCDS) and the third test was invalid due to a crocodile attack on the snail tubs at GCUS (Figure 19).

Results from the routine GCUS and GCDS sites comparison show higher egg production at the downstream site compared to the upstream site, which has also been observed in previous years (and in adjacent Magela Creek – see Figure 11 above).

Analysis Of Variance (ANOVA) could not be performed as there were only two valid tests for this site.

Egg production at the midstream and downstream sites were greater than that measured at the upstream site, as observed in previous years, and egg production at midstream and downstream sites were similar (Figure 19). Analysis Of Variance (ANOVA) testing showed egg difference values between GCUS and GCLB sites were not significantly different for the 2017–18 wet season compared to difference values for the same sites for the three previous wet seasons.

Similar and elevated snail egg production at GCLB and GCDS sites compared to GCUS reflects slightly elevated, and similar, EC at the midstream and downstream sites relative to the upstream site (i.e. lack of significant discharge of contaminated water from GCT2 tributary), as reported in an external publication (see reference in Project summary RES-2015-018, Appendix 2).

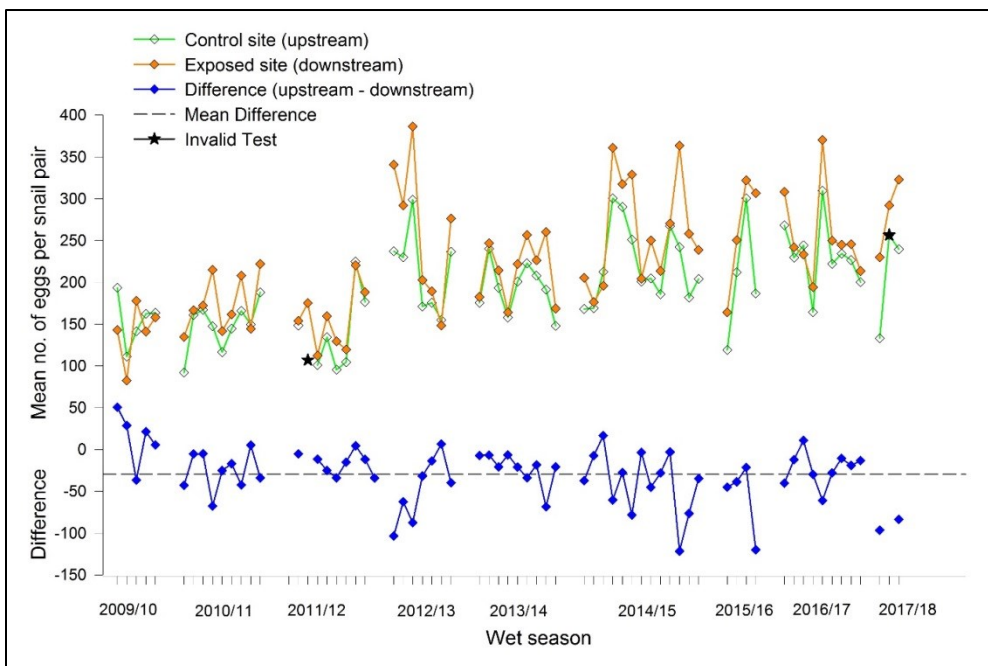


Figure 18 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek

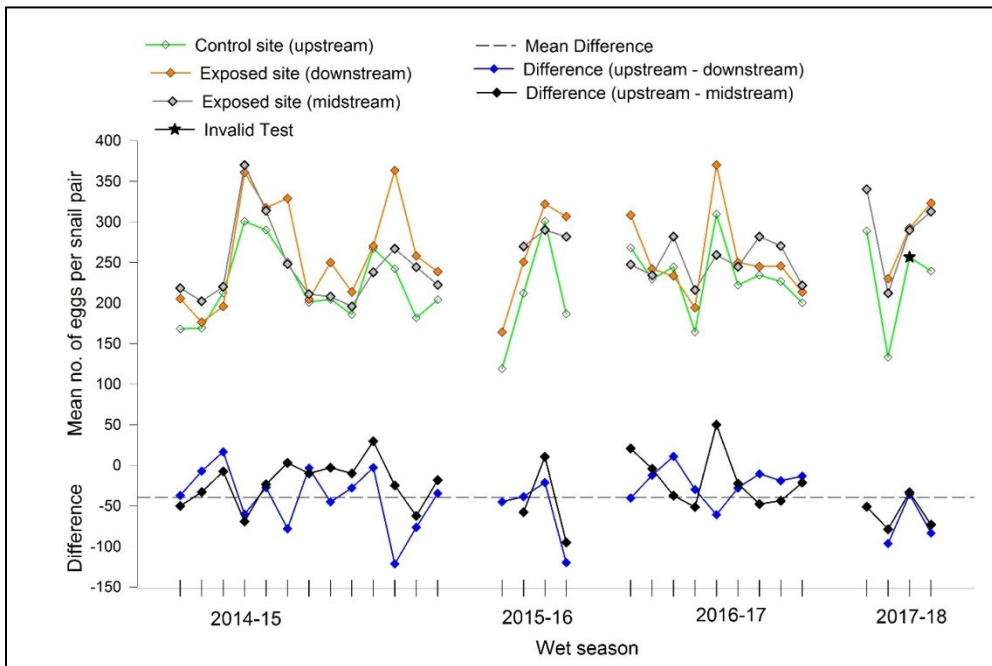


Figure 19 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek since 2015.

4.1.3. Ecosystem monitoring

Macroinvertebrate communities

During the recession flow period of each wet season, macroinvertebrate communities are sampled in Magela and Gulungul creeks at sites upstream and downstream of the mine, and at the same paired site configuration in control sites, Burdulba and Nourlangie creeks. In 2015 and thereafter, an additional site located downstream of the GCT2 confluence with Gulungul Creek (GCT2GCC), was included in the annual sampling regime. This additional site was established in response to discharge of contaminated water from GCT2 tributary to Gulungul creek, downstream of the confluence, during the 2014–15 wet season. Details of the statistical methods undertaken on the annual data were last described in the Supervising Scientist Annual Report for 2014-15 (pp 44–49) and are not repeated here.

Results for two components of this monitoring study are reported:

1. At the time of the last (2016-17) Annual Technical Report, only results for 2017 sampling in Magela and Gulungul creeks were available. For the current report, results for the full 2017 dataset (i.e. addition of control stream data from Burdulba and Nourlangie creeks) can be reported.
2. For the 2017–18 wet season, only samples and analyses from the ‘exposed’ creeks, Magela and Gulungul creeks, are available for analysis and reporting.

Results for the full 2017 dataset

Compilation of, and analyses for, the full macroinvertebrate dataset from 1988 to 2017 has been completed. Multi-factor ANOVA is applied to the replicate, paired-site dissimilarity values shown in Figure 20 to test for changes between exposed and control streams over time. The ANOVA showed no significant change from the before (pre 2017) to the after (2017) periods in the magnitude of upstream-downstream dissimilarity between the control and exposed streams ($p=0.988$ and $p=0.870$ for BA and BA*Exposure interaction respectively). This result is unsurprising given that the dissimilarity values for all four creeks for 2017 plot at similar values to those recorded in most previous years (Figure 20).

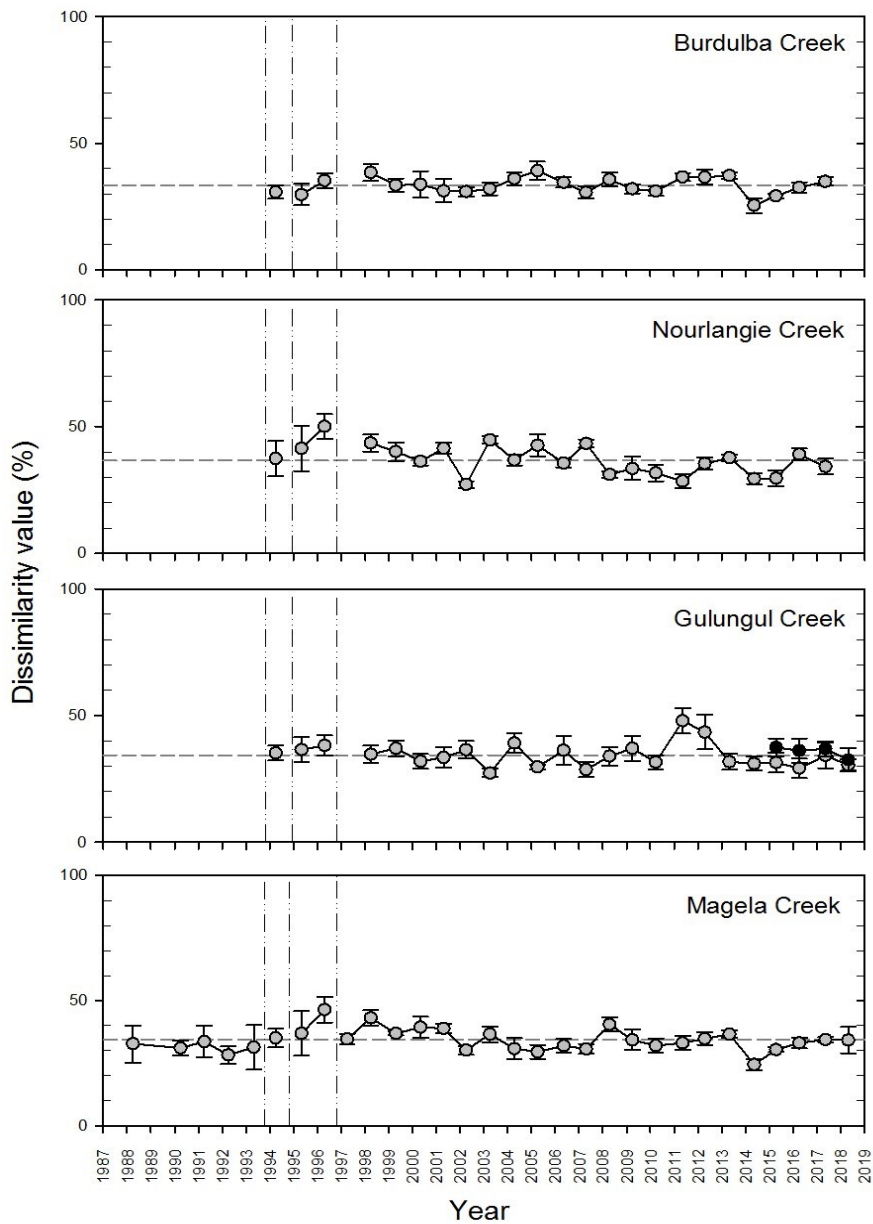


Figure 20 Paired upstream-downstream Bray-Curtis dissimilarity values using family-level (log transformed) data for macroinvertebrate community structure.

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 ($\pm$ standard error) of the 5 possible (randomly-selected) pairwise comparisons of upstream-downstream replicate samples within each stream.

Graphical ordination methods can also be used to infer potential impact if points associated with exposed sites sit well outside of points representing reference sites. Figure 21 shows the multivariate ordination derived using replicate within-site macroinvertebrate data. Data points are displayed in terms of the sites sampled in Magela and Gulungul creeks downstream (including GCT2GCC) of Ranger mine for each year of study (to 2017), relative to Magela and Gulungul upstream (control) sites for 2017, and all other control sites sampled up to 2017 (previous years Magela and Gulungul upstream sites, all sites in Burdulba and Nourlangie). Samples close to one another in the ordination indicate a similar community structure. Data points associated with the 2017 Gulungul and Magela downstream sites (including GCT2GCC) are generally interspersed among the points representing the control sites, indicating that these ‘exposed’ sites have macroinvertebrate communities that are similar to those occurring at control sites.

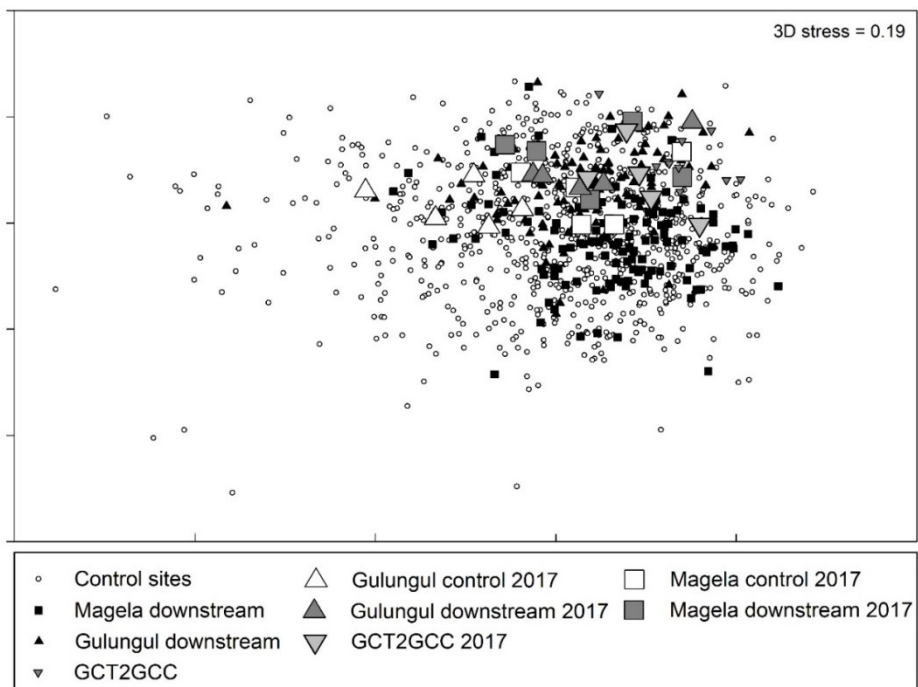


Figure 21 Ordination plot (axis 1 and 2) of macroinvertebrate community structure.

Results for exposed streams, 2017–18 wet season

A modified ANOVA model was run to examine the exposed creeks, Magela and Gulungul, to determine if any change in the dissimilarities associated with just these streams over time (Figure 20) has occurred. The ANOVA showed no significant change from the before (pre 2018) to after (2018) periods in the magnitude of upstream-downstream dissimilarity across both ‘exposed’ streams and this was

consistent between both streams. A more sensitive multivariate-ANOVA (PERMANOVA) was applied to the actual replicate macroinvertebrate community structure data associated with Magela and Gulungul creeks. This analysis also showed no significant difference between the downstream data from 2018 with downstream data from previous years, and no significant difference between the upstream data separately from 2018 with upstream data from previous years. Again, this result is unsurprising given that the dissimilarity values for both creeks for 2018 plot at similar values to those recorded in most previous years (Figure 20).

Figure 22 shows the multivariate ordination using replicate within-site macroinvertebrate data Magela and Gulungul creeks sampled downstream (including GCT2GCC) of Ranger mine for each year of study (to 2018), relative to Magela and Gulungul upstream (control) sites for 2018, and all other control sites sampled prior to 2017 (previous years Magela and Gulungul sites, all sites in Burdulba and Nourlangie). Data points associated with the 2018 Gulungul and Magela downstream sites (including GCT2GCC) are generally interspersed among the points representing the control sites, indicating that these 'exposed' sites have macroinvertebrate communities that are similar to those occurring at control sites. One Magela downstream site had higher diversity and abundance causing it to be an outlier in the ordination.

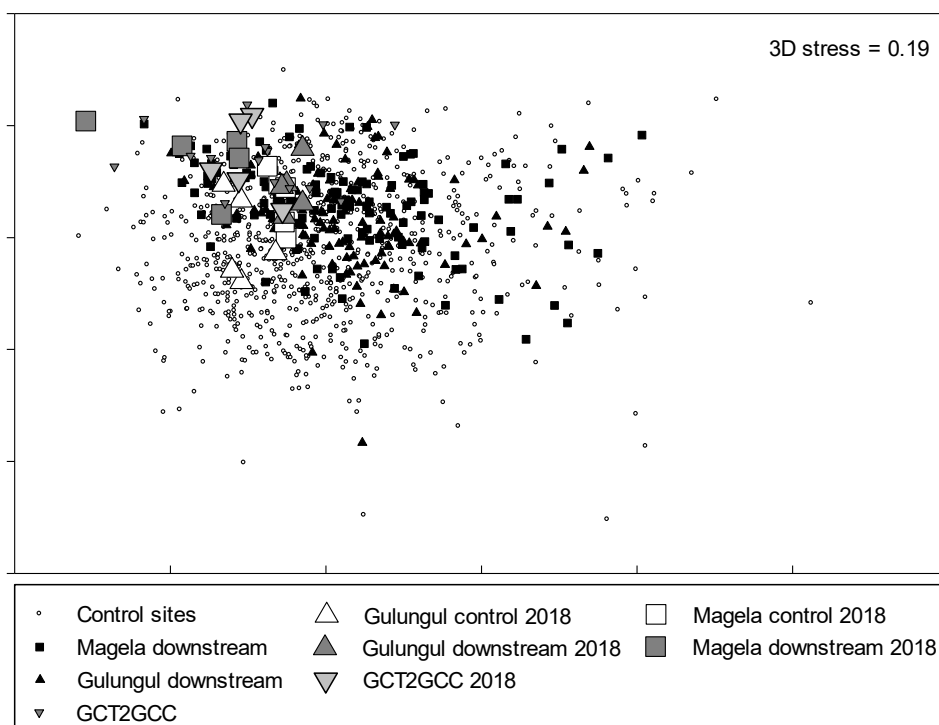


Figure 22 Ordination plot (axis 1 and 2) of macroinvertebrate community structure.

These collective results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2018 have not adversely affected macroinvertebrate communities. 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 2017-18 wet season, however, no high EC events at GCT2GCC were recorded. The dissimilarity values for the 2017-18 wet season are more comparable with dissimilarity values for most previous years Gulungul upstream downstream pairing (Figure 20). It is quite likely that macroinvertebrate communities have responded to water quality changes over the past four year period and now reflect improved water quality in Gulungul Creek in general.

Fish communities

Fish communities in shallow lowland billabongs are traditionally assessed for mining-related impacts every two years. The increased frequency of crocodile-human interactions has led to a reassessment of the risk associated with the sampling methodology used for this program. As a result, this program will no longer occur in its current form. A research project will be undertaken to develop alternative methods for assessing fish communities in shallow billabongs.

Fish communities in deep channel billabongs are assessed for impacts annually. Changes in data collection methodology from visual observations to videography commenced in 2016 due to safety concerns. 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). Imagery for 2018 was collected in May with analysis of the data completed.

Annual mean paired-site dissimilarity for 2018 was similar to 2017 and all previous years (Figure 23). Whilst not provided here, the results also indicated that there was no significant difference in rainbowfish abundance between Mudginberri Billabong and Sandy Billabong. With higher than average rainfall and stream discharge recorded for the 2017-18 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 results is required before conclusions can be drawn. This validation will arise from side by side comparisons of data collected using traditional visual observations and videography, conducted in August 2017 and 2018, and to be repeated in August 2019.

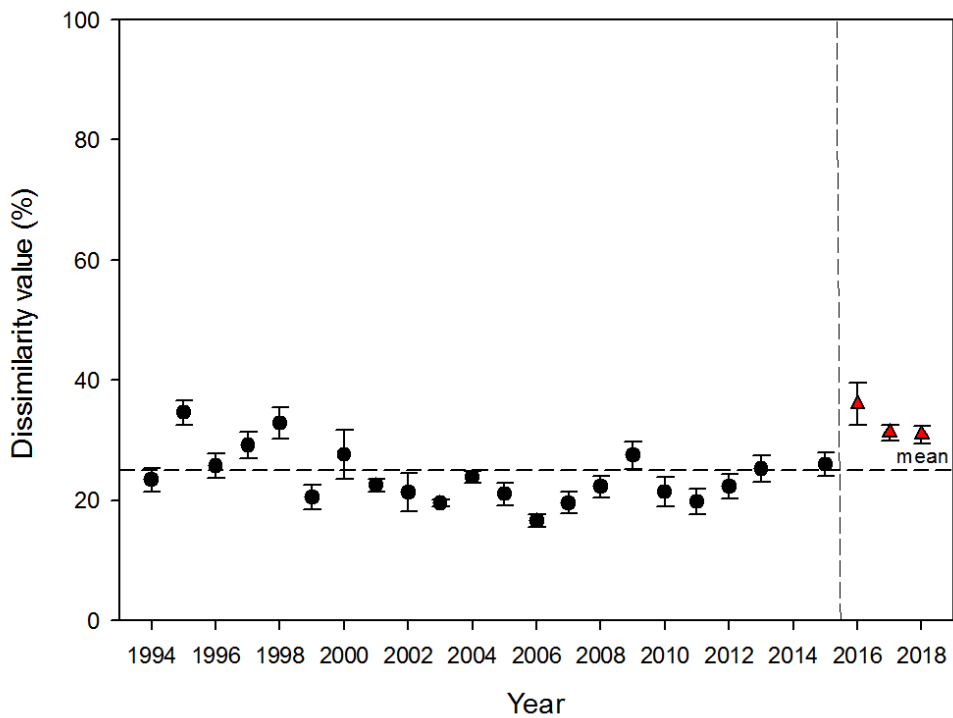


Figure 23 Paired control-exposed dissimilarity values for fish community structure.

Dissimilarity values calculated using the Bray-Curtis measure, for community structure of fish in Mudginberri ('exposed') and Sandy ('control') Billabongs. Values are means ($\pm$ 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).

5 RESEARCH

5.1 Introduction

The Environmental Research Institute of the Supervising Scientist (ERISS) within 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.

5.1.1 Overview of the 2017-18 research program

The 2017–18 SSB research program was endorsed by ARRTC at its 38th meeting in May 2017, following an extensive revision of the KKNs and a subsequent work planning process. The endorsed research program included 54 research projects and eight monitoring projects, and is reviewed quarterly to assess progress and review priorities. Of the research projects, 29 were new projects, while 25 were continuing projects.

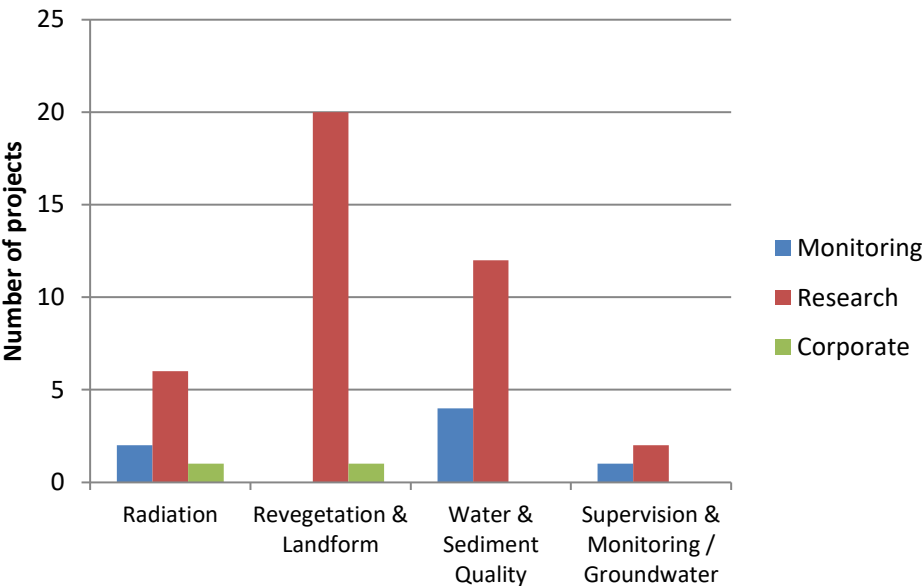
Based on the 10-year planning process (described in the 2016-17 ATR), the proposed program represented a significant increase in workload from previous years, where research project numbers have typically been around 30-33. Most of the increased project load could be attributed to:

- i. significant additional projects focusing on vegetation and landform aspects relating to revegetation. This is in recognition of the general lack of quantitative scientific data and sound knowledge for certain aspects of revegetation, which are needed to properly inform closure criteria, in addition to the relatively long lead times required to acquire such data; and
- ii. inclusion, for the first time, of dedicated groundwater research projects.

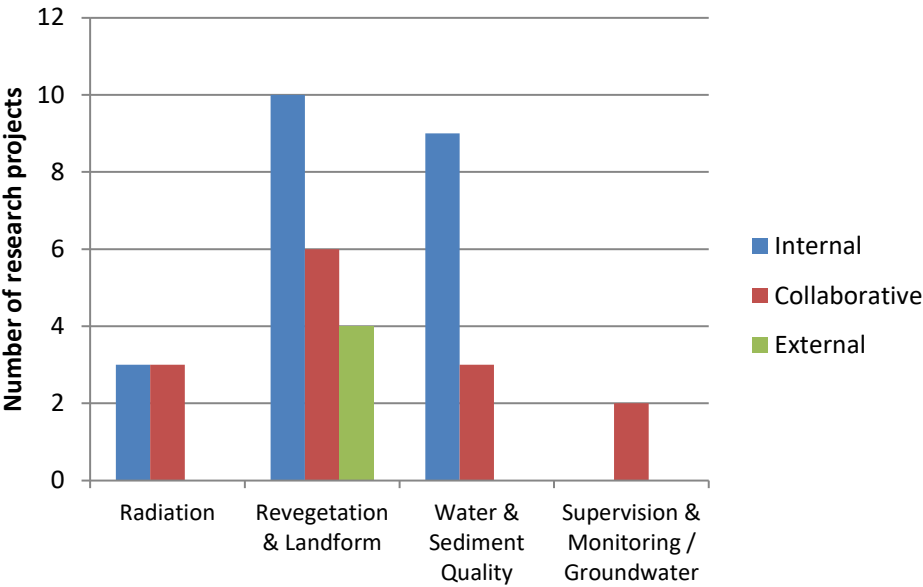
Since the program was endorsed, some projects were unexpectedly carried over into 2017-18, while there has also been a revision and consolidation of the groundwater projects associated with the transfer of their management from the Office of Water Science to SSB. More recently, a number of new projects have been proposed, with some already commenced. These new projects represent a mix of high priority projects and formalisation of activities that were not previously framed as projects. As of July 2018, of the projects scheduled to be commenced, continued or completed in 2017-18, 48 are active, 13 were proposed to commence prior to July 2018, nine have been completed, and one has been superseded. Figure 24 provides various perspectives on the work program, particularly for the research program. Summaries of the status of current research are provided in sections 5.2 to 5.4.

With ERA expecting to submit its landform and revegetation plan in 2018, the Landform and some of the Ecosystem restoration projects (i.e. those related to landform properties that will enable the establishment of a sustainable vegetation community) are of highest priority at this point in time. 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. As such, 27 of the current projects involve 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.

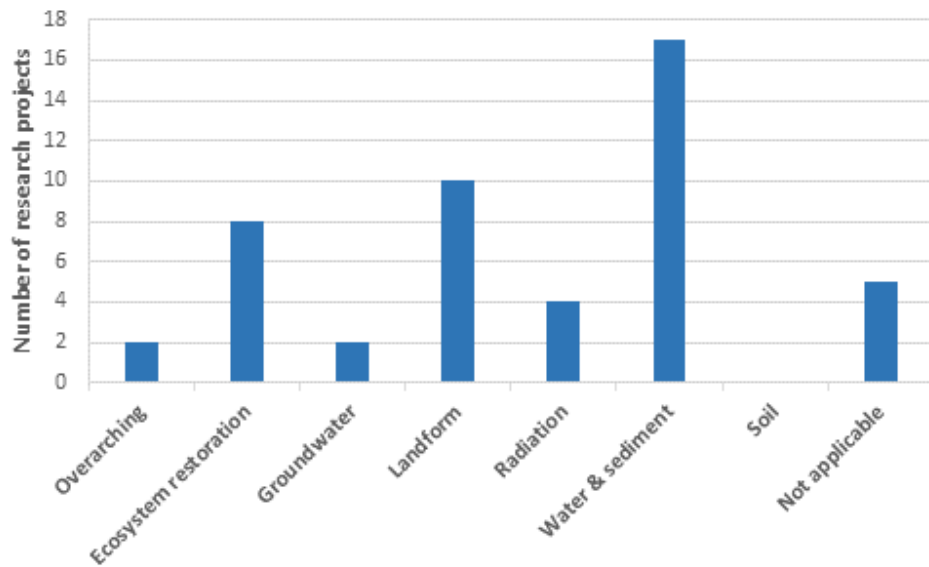
Staff of ERISS have also continued to draft the Rehabilitation Standards (see section 5.1.2, below) and assist the Supervision and Monitoring team with the consolidation of the KKNs. The KKN consolidation process is being undertaken to more closely align the scientific research being undertaken by both SSB and ERA with the Ranger Environmental Requirements, avoid repetition and simplify the way in which the knowledge needs are structured. The consolidation process to date has reduced the total number of KKNs across the five rehabilitation themes (i.e. Water and Sediments, Landform, Ecosystem Restoration, Radiation and Cross-themes) from 125 to 32.



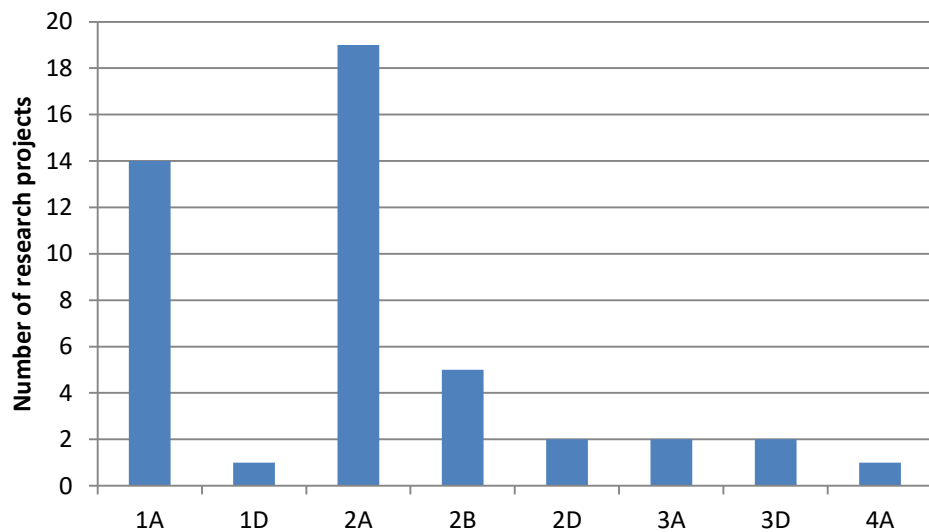
A. Research projects by SSB team and project type



B. Research projects by SSB team and method of delivery



C. Research projects by closure theme



D. Research projects by priority (1–4 represents decreasing order of importance, A–D represents decreasing urgency)

Figure 24 (A B C D) Summary plots of active projects as at March 2018. Note – completed and proposed projects are not included in the plots.

Three projects related to Ranger rehabilitation have been included in the National Environmental Science Program (NESP) Northern Australia Environmental Resources (NAER) Hub's version 4 research plan, commencing in 2018. The projects, all of which are being led by researchers at Charles Darwin University, are:

- *Ecology and sensitivity of riparian vegetation* (Ecosystem restoration closure theme) – The project is designed to fill knowledge gaps relating to the potential groundwater dependence of riparian ecosystems within the Ranger minesite area, and to quantify risks posed to those ecosystems from surface and groundwater egress of mine-related contaminants;
- *Rehabilitation of faunal assemblages at Ranger Uranium Mine* (Ecosystem restoration closure theme) – The project is designed to inform development of criteria that signify the successful recolonisation of fauna at the rehabilitated Ranger uranium mine, and provide valuable information on the performance of different revegetation practices in terms of broader ecosystem restoration.
- *Effects of surface and groundwater egress of mining-related solutes on aquatic ecological connectivity, Magela Creek* (Water and sediment closure theme) – The project is designed to assist SSB in assessing the extent to which water quality criteria relevant to off-site impacts, set for Ranger rehabilitation, are being met.

These projects represent a significant resource investment for NESP that will provide valuable information for SSB and ERA on the Ranger rehabilitation.

Updates on all of the SSB water quality, biological and atmospheric monitoring activities for the 2017–18 period were provided in previous sections of this report. Highlights of the progress made in the SSB research program are provided below in sections 5.2 to 5.4.

5.1.2 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.

Details of the Rehabilitation Standards are provided in Table 19. A rehabilitation standard for herbicides was discontinued due to the fact that herbicide use for weed control will most likely be a shorter term practice associated with the post-rehabilitation active management phase rather than a long-term closure issue. However, water quality limits for herbicides might still be required as part of the post-rehabilitation water quality compliance program. Also, rather than draft a rehabilitation standard for contaminants of potential concern in soils, SSB is likely to instead rely on an independent review of soil closure criteria proposed by ERA.

The Rehabilitation Standards have been provided to the Minesite Technical Committee (MTC) for review, and will be published on the SSB website in September 2018.

TABLE 19 PROGRESS OF THE SUPERVISING SCIENTIST'S REHABILITATION STANDARDS AS AT JUNE 2018.

Closure theme	Rehabilitation standard	Status
Water and sediment	Magnesium (surface water)	90% Completed
	Uranium and Manganese (surface water)	90% Completed
	Uranium (sediment)	In Draft
	Ammonia (surface water)	90% Completed
	Nutrients (surface water)	In Draft
	Turbidity and sedimentation (surface water)	In Draft
	Sulfate – acid sulphate soils (surface water)	90% Completed
	Other metals (surface water)	90% Completed
Landform	Landform – stability and erosion	90% Completed
Ecosystem restoration	Ecosystem restoration	90% Completed
Radiation	Environmental Radiation Protection	90% Completed
	Public Radiation Protection	90% Completed

5.2 Water and Sediment Quality

The Water and Sediment Quality (WASQ) team has developed Rehabilitation Standards for the key contaminants of potential concern for receiving waters, including standards for magnesium, uranium, manganese, sulfate, ammonia and for other metals of potential concern in tailings and brines. Standards for uranium in sediments, nutrients and turbidity are also currently being developed.

Active project work undertaken in the reporting period included:

1. Acceptance of a journal manuscript on the influence of pH on ammonia toxicity to local freshwater species.
2. Submission of a journal manuscript documenting the toxicity of contaminated waters from Gulungul Creek Tributary 2 in 2015 - 2016.
3. Assessment of the toxicity of mixtures of contaminants of potential concern (both at their operational limits and also as they occur in minesite waters) to local freshwater species.
4. Development of standard acute and chronic toxicity test protocols for freshwater mussel species, deriving 24-hour and 14-day toxicity estimates for ammonia using larval and juvenile mussels. The sensitivity of the mussels to magnesium is currently being assessed.

5. Further refinement of the chronic 7-day fish test protocol to fully replace the 96-h acute protocol which had a mortality endpoint. A reference data set for chronic uranium toxicity to the fry larvae can then be established.
6. In collaboration with Macquarie University, development of a DNA library for aquatic macroinvertebrates in the ARR has commenced. This library will be used as a biomonitoring tool to detect potential mine-related changes to macroinvertebrate communities.
7. Re-analysis of data from a mesocosm study conducted in 2002 has provided additional candidate magnesium guideline values for phytoplankton and zooplankton communities. These results are being prepared for journal publications with the guideline values being incorporated into the (surface water) magnesium rehabilitation standard.
8. Changes to fish communities in Mudginberri Billabong downstream of Ranger have been assessed annually by way of comparison to a reference channel billabong (Sandy, in Nourlangie Ck catchment). Since the change from visual survey to videography methods that commenced in 2016, there is a need to calibrate the comparative metrics used to assess similarity between the two billabong types. Method comparison is being conducted over three consecutive years in crocodile-free environments to quantify the change in data collection methods.
9. A PhD project commenced in 2017 to characterise the chemistry and biota of the dry season, saturated, subsurface sands of Magela Creek. Sampling sites are located across a gradient of reference and mine-water contaminated (near Coonjimba Billabong confluence) sands to assess risks and determine thresholds of biological effects. These results will inform assessments of saline water egress to the creeks during and following minesite rehabilitation.

5.3 Revegetation and Landform

The Revegetation and Landform (R&L) team has developed Rehabilitation Standards for erosion and containment of tailings in relation to the final landform, which are currently in review. Rehabilitation Standards for ecosystem restoration have also been developed.

Active project work undertaken in the reporting period included:

1. Publication of a journal manuscript on defining the importance of ecological processes for monitoring aquatic habitats for conservation and rehabilitation objectives.
2. Submission of a journal manuscript on the impact of ripelines on the final rehabilitated landform. Reviewer's comments are being addressed prior to publication.
3. Application of 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. Publication of a journal manuscript on the development and use of synthetic rainfall datasets and presentation of a paper on applying climate change analogues to assess long-term landform stability presented at an international conference. The Bureau of Meteorology also completed a review of the methodology.

4. Publication of a journal manuscript on mapping magnesium surface salts from saline mine discharge with airborne hyperspectral data.
5. Completion by Dr Peter Bayliss from CSIRO of the cumulative ecological risk assessment (CERA) to examine on-site cumulative risks to revegetation. The report is currently undergoing external review and it is anticipated the work will be published in the peer-reviewed literature. Further work is planned to commence in the coming months to address off-site cumulative risks to aquatic ecosystems.
6. Acceptance of a journal manuscript on the methods for using multispectral data collected using Remotely Piloted Aircraft (RPAS) for monitoring minesite revegetation.
7. Decommissioning of older Remotely Piloted Aircraft (RPA) and replacement with Tuff Wing (fixed-wing) and DJI M600 (heavy-lift multi-rotors) platforms. LiDAR and hyperspectral sensors have been integrated on the DJI M600s and are operational. These sensors are being used to further develop methods to measure and monitor vegetation and erosion.
8. Collaborative work with the Centre for Mined Land Rehabilitation (CMLR) and in particular Associate Professor Peter Erskine, on projects to inform the Ecosystem Restoration Rehabilitation Standard has continued.
9. Commencement of a collaboration with the University of Tasmania (Professor David Bowman and Dr Lynda Prior) to undertake an analysis on the inference of potential drivers of change in woody cover in savanna surrounding Ranger uranium mine. Results will inform the Ecosystem Restoration Rehabilitation Standards.
10. Collaborative work with the University of Newcastle (Associate Professor Greg Hancock) to calibrate the predictions of suspended sediment load by the CAESAR-Lisflood model at the catchment scale.
11. Collaborative work with the University of Hull (Professor Tom Coulthard) to finalise enhancements to the CAESAR-Lisflood model, including a sensitivity analysis of model parameters, development of enhanced vegetation shear stress parameters and the development of a capacity to model sub-surface layers beneath the surface layer.
12. A collaborative study with Dr Monishka Narayan and Professor Ken Evans (Charles Darwin University) modelling the evolution of the pre-mine Ranger landform has been completed and has been submitted to the journal *Geomorphology* for peer review.

5.4 Radiation

The Radiation team has developed Rehabilitation Standards for radiation protection of the public and the environment for the Ranger 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 (UNSCEAR).

Active project work undertaken in the reporting period included:

1. Assessment of radiation doses to Aboriginal people living at Manaburduma camp (Jabiru) and Mudginberri community from operations at Ranger mine.
2. Publication of a journal manuscript on dispersion modelling of radon-222 from the Ranger final landform.
3. Publication of a journal manuscript on factors to convert radionuclide activity concentrations from tissue-specific to whole organism to support wildlife dose assessments for the Ranger final landform.
4. Submission of a journal manuscript on whole organism concentration ratios for freshwater wildlife and a proposed water radiological quality guideline value for protecting freshwater ecosystems after rehabilitation of the Ranger mine.
5. Collaborative work with the Australian National University on developing new radiochemistry methods for measuring actinium-227 and protactinium-231 in environmental samples.
6. Ongoing involvement in the IAEA Modelling and Data for Radiological Impact Assessments (MODARIA II) scientific program to ensure research of the Radiation team, which provides the scientific basis for demonstrating achievement of rehabilitation standards for the Ranger mine, aligns with world's best practice standards for radiation protection of people and the environment.

5.5 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 RPA-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.

APPENDIX 1

SUPERVISING SCIENTIST PUBLICATIONS

FOR THE PERIOD JULY 2017 TO JUNE 2018

- Bartolo RE, Harford AJ, Humphrey CL, George AK. & van Dam RA 2018. Defining the importance of ecological processes for monitoring aquatic habitats for conservation and rehabilitation objectives at the Ranger uranium mine, Kakadu Region, Australia. *Marine and Freshwater Research* 69, 1026-1046.
- Bayliss P, Finlayson CM, Innes J, Norman-López A, Bartolo RE, Harford AJ, Pettit NE, Humphrey CL, van Dam RA, Dutra LXC, Woodward E, Ligtermoet E, Steven A, Chariton A & Williams DK 2017. An integrated risk-assessment framework for multiple threats to floodplain values in the Kakadu Region, Australia, under a changing climate. *Marine and Freshwater Research* 69, 1159-1185.
- Doering C 2018. Radiation Doses to Aboriginal people living near Ranger uranium mine. Internal Report 655, Supervising Scientist, Darwin.
- Doering C, McMaster SA & Johansen MP 2018. Modelling the dispersion of radon-222 from a landform covered by low uranium grade waste rock. *Journal of Environmental Radioactivity* 192, 498-504.
- Doering C, Medley P, Orr B & Urban D 2018. Whole organism to tissue concentration ratios derived from an Australian tropical dataset. *Journal of Environmental Radioactivity*, 189, 31-39.
- Erskine W, Saynor MJ, Boyden JM & Evans KG 2017. Sediment fluxes and sinks for Magela Creek, Northern Territory, Australia. *Marine and Freshwater Research* 69, 1018-1025.
- Erskine W, Turner L, Rose T, Saynor M & Webb A 2017. Bedform maintenance and pool destratification by the new environmental flows on the Snowy River downstream of the Jindabyne Dam, New South Wales. In *Journal and proceedings of the royal society of New South Wales*. Royal Society of New South Wales, 150, no 465/466, 152-171.
- Hirth GA, Johansen MP, Carpenter JG, Bollhöfer A & Beresford NA 2017. Whole-organism concentration ratios in wildlife inhabiting Australian uranium mining environments. *Journal of Environmental Radioactivity*, 178-179, 385-393.
- Humphrey C, Bishop K & Dostine P 2018. Vulnerability of fish and macroinvertebrates to key threats in streams of the Kakadu region, northern Australia: assemblage dynamics, existing assessments and knowledge needs. *Marine and Freshwater Research*.69, 1092-1109.

- Humphrey CL & Chandler L 2018. Use of field-effects information to inform surface water guideline values for magnesium sulfate in Magela Creek. Supervising Scientist Report 212, Supervising Scientist, Darwin NT.
- Kleinhenz LS, Trenfield MA, Mooney TJ, Humphrey CL, van Dam RA, Nuggeoda D & Harford AJ 2018. Acute Ammonia Toxicity to the Larvae (Glochidia) of the Tropical Australian Freshwater Mussel *Velesunio* spp. Using a Modified Toxicity Test Protocol. *Environmental toxicology and chemistry*. In press
- Lucas R, Finlayson CM, Bartolo RE, Rogers K, Mitchell A, Woodroffe CD, Asbridge E & Ens E 2017. Historical perspectives on the mangroves of Kakadu National Park. *Marine and Freshwater Research* 69, 1047-1063.
- Mooney TJ, Pease C, Trenfield MA, van Dam RA & Harford AJ 2018. Modelling the pH-ammonia toxicity relationship for *Hydra viridissima* in soft waters with low ionic concentrations. *Environmental toxicology and chemistry* 37(4), 1189-1196.
- Peters A, Merrington G, Schlekot C, De Schampheleere K, Stauber J, Batley G, Harford A, van Dam RA, Pease C, Mooney T, Warne M, Hickey C, Glazebrook P, Chapman J, Smith R & Krassoi R 2018. Validation of the nickel biotic ligand model for locally relevant species in Australian freshwaters. *Environmental Toxicology and Chemistry*. In press.
- Pettit NE, Bayliss P & Bartolo RE 2016. Dynamics of plant communities and the impact of saltwater intrusion on the floodplains of Kakadu National Park. *Marine and Freshwater Research* 69, 1124-1133.
- Pfitzer KS, Harford AJ, Whiteside TG & Bartolo RE 2018. Mapping magnesium sulfate salts from saline mine discharge with airborne hyperspectral data. *Science of The Total Environment*, 640-641, 1259-1271.
- Supervising Scientist 2018. *Annual Technical Report 2016–17*, Commonwealth of Australia, Darwin.
- Sutcliffe B, Chariton AA, Harford AJ, Hose GC, Greenfield P, Midgley DJ & Paulsen IT 2018. Diverse fungal lineages in subtropical ponds are altered by sediment-bound copper. *Fungal Ecology* 34, 28-42.
- 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*. 19(8), 3323-3341.
- Sutcliffe B, Chariton AA, Harford AJ, Hose GC, Stephenson S, Greenfield P, Midgley DJ & Paulsen IT 2018. Insights from the Genomes of Microbes Thriving in Uranium-Enriched Sediments. *Microbial ecology* 75(4), 970-984.
- 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(4), 765-777.

- Verdon-Kidd DC, Hancock GR & Lowry JB 2017. A 507-year rainfall and runoff reconstruction for the Monsoonal North West, Australia derived from remote paleoclimate archives. *Global and Planetary Change* 158, 21-35.
- Whiteside Timothy G & Bartolo Renée E 2018. A robust object-based woody cover extraction technique for monitoring mine site revegetation at scale in the monsoonal tropics using multispectral RPAS imagery from different sensors. *International Journal of Applied Earth Observation and Geoinformation* 73, 300-312.

APPENDIX 2 SUMMARIES OF RESEARCH PROJECTS ACTIVE OR COMPLETED IN 2017–2018

Ranger–Operational phase (and decommissioning)

1 Research (8 projects)

Ranger - Rehabilitation

1 Closure criteria theme: Cross-themes (4 projects)

2 Closure criteria theme: Water and sediment (12 projects)

3 Closure criteria theme: Landform (10 projects)

4 Closure criteria theme: Radiation (4 projects)

5 Closure criteria theme: Ecosystem restoration (12 projects)

Other sites

1 Monitoring (1 project)

RANGER

Operational phase (and decommissioning)

1 Research

Ranger – Operational phase (and decommissioning)

Research projects (8 projects)

Project details					
Project title	Developing videography-based methods for monitoring fish communities (CDU and SSB)				
SSB function	Research	Site	Ranger		
Project category	Operational phase	Project status	Active		
What business need does this project inform?	Continual improvement of monitoring programs and laboratory ecotoxicity testing.				
Key Knowledge Needs (KKN)	WS11A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?				
Closure criteria theme (if applicable)	Water and Sediment	Relevance	2	Time-frame	2
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2013-016	Project commencement date	01/03/2013		
		Estimated completion date	10/12/2019		
Project duration (months)	36	Date required	30/06/2019		
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 previous 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 was conducted in two channel billabongs by SSB between 1994 and 2015 (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 was analysed in order to derive the necessary subset of data required for the same paired-billabong comparisons as used for the previous method. On the basis of this analysis, the protocol was refined and implemented for 2017 imagery. Comparative (side-by-side) observer-based and videographic imagery was acquired in 2017 to assess the implications of the change in methodology. These comparative studies will be repeated in 2018 and 2019.

Progress against plan

- Fish videography has replaced the previous visual census method, following trials and validation of methodology. 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 will be undertaken in May 2018.

- SSB staff are competent in the identification of fish from the videos. Additional staff will be trained in fish identification and counting metrics for videography.
- Data have been collected for the videography method comparison study, with an additional two years of data required to fully calibrate the new technique. This has involved conducting side-by-side fish surveys using both the visual census and the videography methods in crocodile-free environments (Gunlom and Edith falls).

Key findings

- Methods and design for the new videography sampling method were reported in the 2016-17 Annual Technical Report. The videography method utilises stationary, unbaited cameras, in both surface and benthic orientation, capturing relative species abundance data that is comparable to the data arising from the previous method.
- Results arising from the new methodology are a suitable replacement for those reported for fish community structure in the channel billabongs monitoring project (MON-1989-001). Results from the 2017 channel billabong monitoring are reported in the Environmental Monitoring section of the current (2017-18) Annual Technical Report.

Workplan for 2018-19

June-July 2018:

- Collect imagery from Mudginberri and Sandy billabongs using the same design as 2016 (basis of continuing monitoring technique). (Depending upon recessionary flow conditions this imagery may be collected earlier than July 2018).

July 2018:

- Undertake side-by-side comparisons of the two monitoring techniques in crocodile-free locations (Gunlom, Edith Falls).

October-December 2018:

- Prepare data for subsequent reports and publications.

Planned project outputs and associated outcomes

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

The outcomes of this project include 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

- 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 AJ, 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 Direct Toxicity Assessment data to evaluate multiple single toxicant water quality limits (including the magnesium 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 magnesium at different Mg:Ca ratios.		
Key Knowledge Needs (KKN)	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures and modifying factors?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	2
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2015-018	Project commencement date	01/03/2015
		Estimated completion date	30/06/2017
Project duration (months)	6	Date required	01/12/2016
In-house or outsourced	Internal	Actual completion date	08/08/2017
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)	24
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 of pond waters (RP2, Pit 3 and Djalkmara) was due to U and not Mg or Mn. Site groupings of specific water qualities have been determined, and these have been used to inform the

selection of sites for DTA testing in a subsequent project (RES-2017-001) that is assessing the toxicity of mixtures from contemporary mine-site water types.

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary outputs for the project are the analysis of the historical DTA data provided relevant additional context for the GCT2 toxicity assessment conducted in 2015. To this end, the results of the present project were included in the Internal Report and a subsequent paper submitted to the journal *Integrated Environmental Assessment and Management* (see Publications below).

The outcomes of this project include an 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 has been submitted.

Project publications to date (if applicable)

Data have assisted in the derivation of the rehabilitation standard for Mg.

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..

Trenfield M, Harford A, Mooney T, Ellis M, Humphrey C and van Dam R. In press. Integrating laboratory and field studies to assess impacts of discharge from a uranium mine and validate a water quality limit for magnesium. *Integrated Environmental Assessment and Management*.

Project details			
Project title	Genomics-based identification of freshwater macroinvertebrates to species level		
SSB function	Research	Site	All
Project category	Operational phase	Project status	Active
What business need does this project inform?	Continual improvement of monitoring programs and laboratory ecotoxicity testing.		
Key Knowledge Needs (KKN)	WS11A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	2
		Time-frame	2
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2015-019	Project commencement date	01/04/2015
		Estimated completion date	30/06/2019
Project duration (months)	60	Date required	30/06/2019
In-house or outsourced	Collaboration	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	N/A
Supporting team(s)	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 three freshwater insect orders, caddisflies (Trichoptera), mayflies (Ephemeroptera), and Dipteran family, Chironomidae. Material for this study is being drawn from NT Top End streams, including the ARR. Other macroinvertebrate groups will be analysed after these three initial groups have been well described locally.

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 has been established.
- A first 'test' batch of specimens (100) has been sent to Macquarie University where they are being processed for DNA sequencing.

Key findings

- There are no key findings to report.

Workplan for 2018-19

With collaborators from Macquarie University and NT Government, the development of a regional, baseline DNA barcode library for freshwater NT invertebrates.

- Provide material (600 macroinvertebrate samples) to Macquarie University collaborators for genetic analysis.
- Genetic analysis 80% complete for macroinvertebrate samples by June 2019.

Planned project outputs and associated outcomes

The primary outputs for the project are initial proof of concept, viz development of a regional, baseline DNA barcode library for caddisflies (Trichoptera), mayflies (Ephemeroptera) and non-biting midges (Diptera: Chironomidae). Once a DNA library for these three groups has been established, additional groups (Odonata, Coleoptera and Hemiptera) will be included to expand this library.

The outcomes of this project include accurate and cost effective species-level identifications of freshwater macroinvertebrates used as indicators of water quality in the ARR.

Planned communication activities

- Standard corporate and grant reporting requirements.
- Contributions to Supervising Scientist Annual Technical Report.
- Reports/presentations as necessary to ARRTC, ARRAC and other key stakeholders.
- Journal publication.
- Conference and workshop presentations.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Toxicity of ammonia and other key contaminants of potential concern (COPCs) to freshwater mussels		
SSB function	Research	Site	Ranger
Project category	Operational phase	Project status	Active
What business need does this project inform?	Informing SSB's rehabilitation standards and, potentially, ERA's final closure criteria through the provision of environmental protection thresholds for ammonia and other Contaminants of Potential Concern (COPCs) in water.		
Key Knowledge Needs (KKN)	WS6A. What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	2
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2015-025	Project commencement date	01/09/2015
		Estimated completion date	04/04/2020
Project duration (months)	42	Date required	30/12/2018
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)	4

Aims

- To complete the collation and review of available information on freshwater mussel culturing and toxicity testing.
- To collect mussels (*Velesunio* spp.) and develop a culturing method for the species (larvae and juvenile stages).
- To develop standardised acute and chronic test methods for the species.

- To conduct ammonia toxicity testing using the species and publish results.
- To conduct toxicity testing with other COPCs.

Background

An assessment of ammonia toxicity has recently been undertaken in order to develop a site-specific water quality Guideline Value (GV) for the Ranger uranium mine. This GV replaces an interim ammonia GV that 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 *Villosa* (both genera of freshwater mussel) were the most sensitive to the effects of ammonia. Freshwater 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 (Augsburger et al. 2003). Two species of hyriid freshwater mussels (*Velesunio* spp.) 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 the 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 mainly 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

- Adult female *Velesunio* spp. have been collected from multiple local creek and billabong sites as a source of larvae.
- Toxicity testing has been carried out with *Velesunio* larvae and ammonia, uranium and magnesium using an acute test method, while chronic exposure tests with magnesium, ammonia and uranium have also been conducted using newly-metamorphosed juveniles.
- Method development for both the acute and chronic toxicity test is complete.
- A study on differential toxicity response of *Velesunio* spp. populations from different sites has been conducted using acute copper toxicity testing.
- A journal paper describing the acute toxicity test method has been published.
- Journal papers describing the chronic toxicity test method, the genetic work and the toxicity of both uranium and magnesium to *Velesunio* spp. are being drafted.

Key findings

- DNA analyses show that what was thought to be a single mussel species is actually at least two different species which in early studies are showing differences in sensitivity.
- 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 are moderately sensitive to magnesium with a 24-h LC50 of 278 mg/L MgSO₄. This places it as the third most sensitive species of SSB's suite of local species to magnesium at a 9:1 Mg:Ca ratio.
- 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. Juvenile mussels are more sensitive to magnesium than the larvae with a 50% reduction in growth observed at 204-227 mg/L MgSO₄.

Workplan for 2018-19

July-December 2018:

- Finish acute toxicity testing of copper for genetics study.
- Finish acute and chronic toxicity testing of COPCs (U).
- Complete writing up and publication of 4-5 journal articles.

January-June 2019:

- Submission of final thesis mid February 2019.

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 estimates for mine-related COPCs: ammonia, U, Mn and Mg.
- At least four journal papers and a PhD thesis.

The outcomes of this project include increased confidence in site-specific GVs that are used to inform operational water quality limits, rehabilitation standards and, potentially, closure criteria for rehabilitation.

Planned communication activities

- 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 collaborating university (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.
- Kleinhenz L, Nugegoda D, Trenfield MA, van Dam RA, Humphrey C, Harford A. 2017. Chronic toxicity of ammonia to the tropical freshwater mussel *Velesunio* spp. Proceedings of the SETAC – Australasia Conference, 4-6 September 2017, Gold Coast, Australia.
- Kleinhenz LS, Trenfield MA, Mooney TJ, Humphrey CL, van Dam RA, Nugegoda D, Harford AJ. 2018. Acute ammonia toxicity to the larvae (glochidia) of the tropical Australian freshwater mussel *Velesunio* spp. using a modified toxicity test protocol. Environmental toxicology and chemistry Volume 37, Issue 8, p. 2175-2187.

Project details			
Project title	Developing a short-term chronic toxicity test for the fish, <i>Mogurnda mogurnda</i>		
SSB function	Research	Site	Other
Project category	Operational phase	Project status	Active
What business need does this project inform?	Continual improvement of monitoring programs and laboratory ecotoxicity testing.		
Key Knowledge Needs (KKN)	WS11A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2015-028	Project commencement date	01/06/2015
		Revised completion date	02/11/2018
Project duration (months)	6	Date required	30/12/2018
In-house or outsourced	Internal	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	Further testing required to finalise 28d protocol. Some writing and testing expected in 18-19
Supporting team(s)	N/A		
Project manager	Pease, Ceiwen	Project total estimated internal resources (person weeks)	15
Project sponsor	Harford, Andrew	Project total estimated collaborator resources (person weeks)	0

Aims

- To develop a short term (7 d) chronic toxicity test for *Mogurnda mogurnda* incorporating sub-lethal (growth) endpoints.
- To 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 Guideline Values (GV) for Magela and Gulungul creeks adjacent to Ranger uranium mine. The current routine toxicity test protocol 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 shorter, more cost-effective 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 7-d test method has been developed.
- Acceptability criteria for initial fish size and also growth rate have been established.
- Two toxicity tests have been completed for ammonia and three for uranium. Testing is currently underway applying the new method for Direct Toxicity Assessments (DTAs) of mine site waters. The 7-d test will be compared with a revised 28 d test in Magela Creek water to determine whether the longer exposure time results in a more sensitive response.
- There was some concern that there was inbreeding depression within SSB's in-house population due to non-replenishment of fish stock. To redress this, new fish were collected from Radon Springs and are being used for testing.

Key findings

- A chronic sub-lethal toxicity test method has been successfully developed for *M. mogurnda*. The 7-d EC50 of 1416 $\mu\text{g L}^{-1}$ U with upper and lower confidence limits (UCL, LCL) of 1050 and 1919 $\mu\text{g L}^{-1}$ is comparable with the EC50 derived by Cheng et al's (2010) earlier 28-d test of 1130 (LCL:1020, UCL: 1240) $\mu\text{g L}^{-1}$. Some modifications have been made to the method developed by Cheng et al (2010) and as such, the 7-d method will be compared to a revised version of the 28-d method.

Workplan for 2018-19

September-November 2018:

- Two tests comparing the 28 d and 7 d method will be undertaken using uranium as a toxicant.

December 2018:

- A standard operating procedure (SOP) detailing the new 7 d test method will be completed by the end of December 2018.
- A peer reviewed publication detailing the new method and the comparison between the sensitivity to U of the chronic 28 d and 7 d, and 96 h acute, tests will be completed by the end of December 2018.

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*.
- A SOP and subsequent peer-reviewed journal paper describing the new methodology.

The outcomes of this project include 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

- Presentation at the annual SETAC Australasia conference.
- A peer reviewed journal article.
- Annual reporting of results in the Supervising Scientist website.
- Reports and presentations for ARRTC and ARRAC meetings.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Develop a technique for automating snail egg counts for toxicity testing and monitoring		
SSB function	Research	Site	Ranger
Project category	Operational phase	Project status	Active
What business need does this project inform?	Improve the accuracy and efficiency of the snail reproduction response used in toxicity monitoring program and laboratory ecotoxicity testing.		
Key Knowledge Needs (KKN)	WS11A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	2
		Time-frame	2
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2012-006	Project commencement date	31/10/2017
		Estimated completion date	31/05/2019
Project duration (months)	10	Date required	31/05/2019
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	Jansen, Andrew	Project total estimated internal resources (person weeks)	40
Project sponsor	Humphrey, Chris	Project total estimated collaborator resources (person weeks)	0

Aims

- To develop an automated method for counting freshwater snail eggs within an egg mass. This will improve the efficiency and accuracy of this sub-lethal, reproductive endpoint used in field toxicity monitoring and laboratory testing.

Background

The snail, *Amerianna cumingi*, is currently used by the Supervising Scientist Branch for in-situ monitoring in Magela and Gulungul creeks. *A. cumingi* is also one of six local

species that is used in routine laboratory toxicity testing to derive water quality guidelines for Magela and Gulungul creeks adjacent to Ranger uranium mine. The endpoint used for both tests is reproduction, with the number of eggs laid by the snails after 96 hours counted and recorded manually under a dissecting microscope. This is a time consuming process, particularly considering that each replicate pair of snails can produce more than 200 eggs in the exposure period. The development of a new, automated method for counting snail eggs will improve the speed and accuracy of counting, ensuring the toxicity estimates derived from these tests are more efficient and reliable.

Progress against plan

- An egg-laying surface lying within the cylindrical egg chambers and which can be removed and laid flat for digital image analysis has successfully been developed. Laboratory testing has determined that the egg-laying surface - a thin and flexible clear polycarbonate plastic - does not interfere with *A. cumingi* egg production.
- A photographic platform has been engineered to capture high resolution images of egg masses on the egg-laying surfaces. This uses a macro lens attached to a tripod-mounted SLR camera, pointed towards egg masses which are suspended in a glass tank filled with water. A light box is positioned an appropriate distance behind the glass tank to illuminate the snail eggs.
- Progress has been made using the computer image software eCognition to automate counting. The software can successfully recognise and count number of egg masses, eggs and embryos. Further refinement of the software is needed to account for damaged eggs and remove potential artefacts in the imagery.
- One field test has been performed to test the new method while more tests are planned.

Key findings

- A suitable egg-laying substrate has been identified which does not interfere with *A. cumingi* fecundity.
- It is possible to capture high resolution images of all egg masses on the new egg-laying surface.
- Current progress with digital image analysis software indicates automation of egg counting will be possible.

Workplan for 2018-19

- Refinement of the method for automating snail egg counts will continue over the 2018-19 period. This will include trials in both the laboratory and field..

Planned project outputs and associated outcomes

The primary outputs for this project are:

- An internal report describing the new methodology.
- A paper in the Supervising Scientist Annual Technical Report.
- Annual reporting to ARRTC and ARRAC.

The outcomes that this project will achieve include increased efficiency and accuracy of in-situ monitoring and toxicity testing using the snail reproduction response.

Planned communication activities

- Presentation at the annual SETAC Australasia conference.
- Reports/presentations to key stakeholders as appropriate.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Retrospective estimate of radiation dose to long-term residents of the Jabiru-Mudginberri area from Ranger uranium mine		
SSB function	Research	Site	Ranger
Project category	Operational phase	Project status	Completed
What business need does this project inform?	Protecting the health of resident Aboriginal people and other members of the regional community from potential exposures to radiation.		
Key Knowledge Needs (KKN)	N/A		
Closure criteria theme (if applicable)	N/A	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	EXT-2017-014	Project commencement date	15/08/2017
		Revised completion date	31/12/2017
Project duration (months)	3	Date required	31/10/2017
In-house or outsourced	Commercial	Actual completion date	05/02/2018
Lead team	ENRAD	Reason for project delay (where applicable)	Delayed due to insufficient staff resources and competing priorities.
Supporting team(s)	N/A		
Project manager	Doering, Che	Project total estimated internal resources (person weeks)	5
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	0

Aims

- To estimate the radiation dose to long-term Aboriginal residents of the Jabiru-Mudginberri area.

Background

The NT Department of Health undertook a study of cancer risk factors for long-term residents of the Jabiru-Mudginberri area and requested that SSB retrospectively estimate the mine-related radiation dose to this cohort.

Progress against plan

- Mine-related radiation doses from potential exposure pathways were estimated.
- Internal report published and provided to the NT Department of Health.

Key findings

- Potential radiation doses were low and well below statutory dose limits.
- The main exposure pathway was radon.
- Exposures from dust and bush foods were negligible.

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary output for this project will be an estimate of radiation dose to Aboriginal people living near the Ranger uranium mine.

The outcome of this project includes public assurance that mine-related doses to Aboriginal people during the operational phase of the Ranger uranium mine have been within statutory limits and do not pose an unacceptable health risk.

Planned communication activities

- Internal report with details of the dose assessment methods and results.

Project publications to date (if applicable)

Doering C 2018. Radiation doses to Aboriginal people living near Ranger uranium mine. Internal Report 655, Supervising Scientist, Darwin.

Project details					
Project title	In situ responses of <i>Amerianna cumingi</i> to environmental variables (including EC and temperature)				
SSB function	Research	Site	Ranger		
Project category	Operational phase	Project status	Active		
What business need does this project inform?	Improved interpretation of snail egg-laying response in SSB’s toxicity monitoring program.				
Key Knowledge Needs (KKN)	WS11A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?				
Closure criteria theme (if applicable)	Water and Sediment	Relevance	3	Time-frame	1
		Project Priority Importance	3	Time buffer	A
Project number (if allocated)	RES-2017-028	Project commencement date	21/11/2017		
		Estimated completion date	24/12/2019		
Project duration (months)	25	Date required	31/12/2018		
In-house or outsourced	Internal	Actual completion date	N/A		
Lead team	WASQ	Reason for project delay (where applicable)	N/A		
Supporting team(s)					
Project manager	Mooney, Tom	Project total estimated internal resources (person weeks)	5		
Project sponsor	Humphrey, Chris	Project total estimated collaborator resources (person weeks)	0		

Aims

- To provide snail egg response data over an extended electrical conductivity range to that normally available in routine toxicity monitoring in Magela and Gulungul creeks, by deploying snails closer to a mine water release point.
- To provide a greater understanding of the extent to which environmental variables affect snail egg production and thereby improve interpretation of in situ toxicity monitoring results.

Background

In situ toxicity monitoring occurs routinely to biologically assess water quality at the compliance boundaries in Magela and Gulungul creeks. Egg production of the freshwater snail, *Amerianna cumingi*, is used as the test endpoint. The electrical conductivity (EC) at the compliance boundaries rarely exceeds guidelines values. Therefore, tests are typically conducted in waters of low EC. This has constrained our understanding of the snail's response in situ to ECs between approximately 10 and 30 $\mu\text{S cm}^{-1}$. This project will provide data that expands the EC range snails are exposed to by deploying snails closer to a mine water release point. A desktop review of water quality between MG001 and MG009 indicated that the MG001 site was the most appropriate site for additional toxicity monitoring. This site had the highest and most sustained elevation in EC throughout the wet season. Data on snail egg production obtained at this site will provide greater information to interpret in situ toxicity monitoring results. This information will be important post rehabilitation, where there is potential for unmanaged movement of contaminants offsite through contaminated surface and ground water sources.

Additionally, snail egg production can be affected by environmental determinants other than EC, including water temperature. Understanding the extent to which environmental variables affect snail egg production will provide more robust interpretation of in situ snail toxicity monitoring results. These data are collected as part of the routine toxicity monitoring. Therefore, additional data collection at MG001 will build on existing data and associated results reported previously in Humphrey & Ellis (2014; 2015).

Progress against plan

- Over the 2017-18 wet season six tests were completed in Magela Creek which incorporated the additional site at MG001. In two of the six tests snails were exposed to elevated EC (up 100 $\mu\text{S/cm}$) at MG001. The elevated EC occurred under pulse scenarios and was not sustained for the test durations. More data is required before conclusions can be made.

Key findings

- Nil to date because field exposures to date have not provided sufficient sustained elevated ECs to draw conclusions.

Workplan for 2018-19

- Continue in situ toxicity testing incorporating additional site at MG001.

Planned project outputs and associated outcomes

The output for this project will be results published in a peer-reviewed journal.

The outcome for this project will be data on snail egg production obtained at this site will provide greater information to interpret in-situ toxicity monitoring results. This information will be important post-rehabilitation, where there is potential for

unmanaged movement of contaminants offsite through contaminated surface and ground water sources.

Planned communication activities

- Standard reporting requirements.
- Reporting and presentations to key stakeholders as necessary.
- Journal publication.
- Conference and workshop presentations.

Project publications to date (if applicable)

No project publications to date.

RANGER

Rehabilitation

- 1 Closure Criteria theme: Cross-themes**
- 2 Closure Criteria theme: Water and sediment**
- 3 Closure Criteria theme: Landform**
- 4 Closure Criteria theme: Radiation**
- 5 Closure Criteria theme: Ecosystem restoration**

Ranger – Rehabilitation

CC theme: Cross-themes (4 projects)

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	Completed		
What business need does this project inform?	This project informs 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.				
Key Knowledge Needs (KKN)	CT1A. What are the cumulative risks to the success of rehabilitation and to the offsite environment?				
Closure criteria theme (if applicable)	Cross-themes	Relevance	1	Time-frame	1
		Project Priority Importance	1	Time buffer	A
Project number (if allocated)	RES-2016-014	Project commencement date	02/02/2017		
		Revised completion date	30/06/2018		
Project duration (months)	11	Date required	19/12/2017		
In-house or outsourced	External	Actual completion date	30/6/2018		
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 effects upon 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.
- Qualitative models representing ecological processes on the revegetated mine site were produced with key experts and stakeholders on 15-16 August 2017.
- A full quantitative analysis of risk to the revegetation success was completed and a report submitted.
- The report has been reviewed by external experts in the field.

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.
- Further developmental work on quantifying revegetation risk is required to: (i) calibrate and validate the underlying ecological risk models incorporated into the proposed Bayesian Belief Network (BBN) ecological risk assessment framework; (ii) incorporate an overstory and understory structure in the State-Transition-Revegetation model developed in the project; (iii) quantify the strong interaction between landform and vegetation development, and erosion; (iv) incorporate decision nodes in the BBN risk assessment framework to evaluate different management strategies under different scenario settings to help minimise risks to revegetation; (v) use the current assessments to help design a cost-effective revegetation monitoring program on Pit 1 and, similarly; (vi) design field experiments and pot trials to close knowledge gaps on the potential effects of toxicants in mine-soil and shallow ground water on the growth and survival of revegetation.
- In the near future and outside of the current project, the complexity of the risk assessment needs to be synthesised and communicated appropriately for a wider audience, and the models need to be used to undertake scenario testing for assessment of the Ranger Mine Closure Plan.

Workplan for 2018-19

- Undertake scenario testing for assessment of the Ranger Mine Closure Plan but outside the current project.

Planned project outputs and associated outcomes

The primary outputs for this project are:

- Report on the most appropriate methodology for undertaking the quantitative assessment of cumulative ecological risks at Ranger uranium mine.
- 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.

The outcomes of this project include:

- 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.

Project details			
Project title	Deriving site-specific concentration factors for metals in bush foods to inform human health risk assessments for the Ranger final 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 resident Aboriginal people and other members of the regional community from potential exposures to metals.		
Key Knowledge Needs (KKN)	WS10B. What are the concentration ratios for chemical pollutants in bush foods?		
Closure criteria theme (if applicable)	Cross-themes Water and sediment	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2017-024	Project commencement date	01/03/2018
		Estimated completion date	31/12/2018
Project duration (months)	10	Date required	31/12/2018
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	McMaster, Scott	Project total estimated internal resources (person weeks)	12
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	0

Aims

- To derive concentration factors for metals in bush foods.
- To derive maximum allowable concentrations of metals in soil and water that would give rise to food safety guidelines for metals.

Background

Dietary exposure to metals can be harmful to humans. The Environmental Requirements stipulate that the rehabilitation of the Ranger uranium mine does not result in "an adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to...chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law". This project will derive concentration factors between the concentrations of metals in bush foods and those in soil and water. The concentration factors will be used to derive maximum allowable concentrations of metals in soil and water from food safety guidelines. The metals selected include arsenic, cadmium and lead, which are generally the higher toxicity metals for human health.

Progress against plan

- Concentration factors for metals in bush foods have been derived from existing tissue concentration data.

Key findings

- There are no key findings to report.

Workplan for 2018-19

July-December 2018:

- Finalise data analysis and write up of research paper or internal report.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Metal concentration factors for bush foods.
- Maximum allowable concentrations of metals in soil and water.

The outcomes of this project include:

- Enhanced knowledge of metal uptake in bush foods.
- Public and regulator assurance that dietary exposures to metals from the final landform conform with relevant Australian law.

Planned communication activities

- Internal report on metal concentration factors.
- Key findings published in Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Cumulative risk assessment for Ranger mine site rehabilitation and closure - Phase 2 (aquatic pathways)		
SSB function	Research	Site	Ranger
Project category	Rehabilitation – overarching	Project status	Active
What business need does this project inform?	This project determines the potential cumulative ecological impacts of risks identified through the risk screening component of the ecological risk assessment. The focus in this phase of the project is aquatic ecosystems.		
Key Knowledge Needs (KKN)	CT1A. What are the cumulative risks to the success of rehabilitation and to the offsite environment?		
Closure criteria theme (if applicable)	Cross-themes	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2017-032	Project commencement date	01/03/2018
		Estimated completion date	28/12/2019
Project duration (months)	10	Date required	31/12/2018
In-house or outsourced	External	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	N/A
Supporting team(s)	CSIRO; ERA; R&L		
Project manager	Harford, Andrew	Project total estimated internal resources (person weeks)	8
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	40

Aims

- To develop qualitative and quantitative risk models that assess the cumulative risks to on-site and off-site aquatic ecosystems during the decommissioning and post-decommissioning phases of the Ranger uranium mine.

Background

At the completion of mining, Energy Resources of Australia Ltd is required to close Ranger Uranium Mine (RUM) and meet the Environmental Requirements (ERs) stated in the mine's Authorisation. A robust screening-level ecological risk assessment process has identified a number of environmental risks and knowledge gaps for the rehabilitation of the mine-site. However, these risks were assessed in isolation of one another, and the interaction and cumulative impact of the risks was outside the scope of the risk-screening process. Hence, there is a need to conduct a cumulative ecological risk assessment (CERA) process. Phase 1 of the CERA project focused on the risks to the on-site terrestrial environment, in particular, risks that might result in failed revegetation of the mine-site.

For the next phase (2) of the CERA project, the Supervising Scientist Branch requires risk model(s) that are capable of assessing the cumulative effects of multiple-stressors on the aquatic ecosystems surrounding Ranger uranium mine at multiple-scales (spatial and temporal). The modelling needs to be spatially-explicit and assess the risks arising during the decommissioning and post-decommissioning phases. The model will be used to assess if adverse environmental impacts will result from exposure scenarios derived from ERA's groundwater and surface water modelling, which is scheduled for completion at the end of 2018. The spatial and temporal resolution of the model(s) should align with the assessment tasks that are required to determine if ERA can meet the ERs. The modelling will need to include the riparian zones of the creeks as these were omitted from CERA Phase 1. Depending on further scope discussions, the model may also need to quantify risks to the health of Aboriginal communities downstream of the mine.

At this stage, stressors that will need to be included in the model include: magnesium, uranium, manganese, ammonia, turbidity/suspended sediment, bedload, sulfate (in the context of acid sulfate soils) and numerous other trace metals (e.g. copper, zinc, cadmium, etc.). Where applicable, the model needs to be able to predict risks to surface water and sediment biotic communities.

A mixtures toxicity project is currently underway to assess the extent and nature of interactions amongst the major contaminants of potential concern in surface and ground waters around the mine site (which would be reflective of contaminated waters entering the creeks during decommissioning and post-decommissioning). The results of the mixtures toxicity project will inform the necessary level of model complexity.

This phase of the CERA project will build on the methods and lessons learnt from the phase 1 CERA (see Bayliss 2017). There are also a number of data sources that it can draw-on including toxicity and field-effects data for some contaminants of potential concern, and whole-effluent toxicity test results.

This phase of the CERA will be run jointly with ERA.

Progress against plan

- CSIRO has been engaged and a cost-sharing arrangement has been agreed between SSB and ERA.
- Key aquatic ecology experts and stakeholders participated in a workshop held at SSB on 28 May 2018, in order to construct a qualitative model of the Magela catchment aquatic ecosystem processes. The model was used to test the important links in the ecosystems and the effect of perturbations. A draft report has been circulated to participants for review.
- The process of conducting a quantitative cumulative risk assessment has progressed and datasets have been collated and catalogued.

Key findings

- There are no key findings to report.

Workplan for 2018-19

- Identify, collate and catalogue existing datasets for use in the risk assessment.
- Based on initial results of mixtures toxicity project, determine the required level of model complexity and, hence, the model structure.
- Complete and report on the full Quantitative Ecological Risk Assessment - provision of final risk assessment report for phase 2.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A preliminary report from aquatic qualitative modelling workshops.
- A journal paper on the qualitative models and scenario testing.
- Journal papers on the quantitative cumulative risk model for the aquatic ecosystems.
- Electronic copies of the model including catalogued datasets used in the modelling.
- A catalogue of datasets for aquatic ecosystems identified for use in the risk assessment.

The outcomes of this project include:

- Assessment of the surface water concentrations of stressors during post-decommissioning and if they are likely to result in ecological impacts.
- Identification of interactions amongst risks and how these can affect risks as a whole. Interactions amongst risks have the potential to change the profile of risks, e.g., moving a low or moderate risk to a high risk.
- As a result of such findings, identification of knowledge gaps and prioritise further research.

Planned communication activities

- Presentation to ARRTC.
- A journal article about the qualitative modelling.
- 1-2 journal articles about the quantitative modelling.
- Relevant communication products for the different stakeholder groups, developed with the Public Assurance and Advice team.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Cataloguing World Heritage values on the Ranger Project Area		
SSB function	Research	Site	Ranger
Project category	Rehabilitation – overarching	Project status	Active
What business need does this project inform?	This provides information that can be provided to Ministers and stakeholders that may assist in decisions in the future for the incorporation of the site into Kakadu National Park.		
Key Knowledge Needs (KKN)	CT2A. What World Heritage Values are found on the Ranger Project Area, and how might these influence the incorporation of the site into Kakadu National Park and World Heritage Area?		
Closure criteria theme (if applicable)	Cross-themes	Relevance	3
		Time-frame	1
Project Priority		Importance	3
		Time buffer	A
Project number (if allocated)	RES-2017-004	Project commencement date	01/07/2017
		Revised completion date	24/08/2018
Project duration (months)	6	Date required	30/06/2018
In-house or outsourced	Internal	Actual completion date	N/A
Lead team	R&L	Reason for project delay (where applicable)	Internal priorities have delayed SSB staff in finalising draft report.
Supporting team(s)	Department Graduate (Rachel Everitt), Environmental Resources Information Network, Wildlife, Heritage and Marine Division, Environmental Standards Division, and Parks Australia		
Project manager	Bartolo, Renee	Project total estimated internal resources (person weeks)	21
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	0

Aims

- To collate spatial data and undertake analysis to quantify the locations and spatial extent of natural values on the Ranger Project Area (RPA) that map to the World Heritage values for which Kakadu National Park is listed.
- To identify threatened and significant species that may utilise the habitat, as determined through cataloguing the natural values.

Background

The Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger uranium mine outline the Commonwealth's environmental protection conditions for Ranger mine. The Ranger Project Area must be rehabilitated to establish an environment that could be incorporated into the Kakadu National Park.

Kakadu National Park is inscribed on the World Heritage List for five criteria: three physical and two cultural. Some of the features for which Kakadu is listed are also present on the Ranger Project Area. Elements of most of the natural World Heritage Values present in Kakadu are also present on the Ranger Project Area. This project will outline the elements of natural World Heritage values for which Kakadu is listed that are also present within the Ranger Project Area.

Progress against plan

- Draft report under final review

Key findings

- There are no key findings to report.

Workplan for 2018-19

- Finalise draft report and publish.

Planned project outputs and associated outcomes

- The primary outputs for the project are:
- Internal Report.
- Spatial database containing data on location and extent of natural values on the RPA.
- Communication products for a range of stakeholders (e.g. infographics).

The main project outcome is a summary of the locations and spatial extent of natural values (for which Kakadu National Park is World Heritage listed for) occurring on the Ranger Project Area, that can be used to provide advice in SSB's assessment processes.

Planned communication activities

- Internal report.
- Spatial database of core datasets used in the project.
- Supervising Scientist Branch Coffee Break seminar.

Project publications to date (if applicable)

N/A

Ranger – Rehabilitation

CC theme: Water and sediment (12 projects)

Project details						
Project title	Macroinvertebrates responses to magnesium in lentic waterbodies associated with the Ranger mine site					
SSB function	Research		Site	Ranger		
Project category	Developing closure criteria		Project status	Completed		
What business need does this project inform?	A line of evidence informing closure criteria for magnesium (Mg) in surface waters.					
Key Knowledge Needs (KKN)	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures and modifying factors?					
Closure criteria theme (if applicable)	Water and Sediment	Project Priority	Relevance	1	Time-frame	1
			Importance	1	Time buffer	A
Project number (if allocated)	RES-2005-002	Project commencement date		01/05/2006		
		Revised completion date		30/04/2018		
Project duration (months)	2	Date required		30/06/2017		
In-house or outsourced	Internal	Actual completion date		30/11/2017		
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)		0		
Project sponsor	Humphrey, Chris	Project total estimated collaborator resources (person weeks)		0		

Aims

- To quantify macroinvertebrate community structure across a gradient of mine-related water quality disturbance in lentic waterbodies of the Alligator Rivers Region.
- To 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 waste-waters. 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 on-site, mine water-exposed and off-site reference waterbodies. Initially, the work focused on Georgetown Billabong, a Ranger on-site waterbody that had until recent years (~2009) received only mildly contaminated mine waste-waters. Closure criteria were to be based upon that water quality supporting 'no effects'. From 2013, the study was expanded to include the full mine water-contaminated gradient available in Djalkmara Billabong (1995 and 1996), Coonjimba and Georgetown billabongs (1979 to 2013) and Retention Pond 1 (1995 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 was externally reviewed, and authors have attended 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 2018-19

N/A

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

- 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 2018. Use of field-effects information to inform surface water closure criteria for magnesium sulfate in Magela Creek. Supervising Scientist Report 212, Darwin, NT.

Project details			
Project title	The toxicity of U to sediment biota of Gulungul Billabong		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Informing SSB's rehabilitation standard and, potentially, ERA's final closure criterion through the provision of an environmental protection threshold for uranium in sediments.		
Key Knowledge Needs (KKN)	WS5A. To what extent will contaminants accumulate in sediments over time, including the development of acid sulfate sediments?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2009-002	Project commencement date	01/07/2008
		Revised completion date	30/12/2018
Project duration (months)	108	Date required	30/12/2018
In-house or outsourced	Internal	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	Competing priorities, mostly the ecological risk assessment and KKNs
Supporting team(s)	CSIRO		
Project manager	Harford, Andrew	Project total estimated internal resources (person weeks)	80
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	20

Aims

- To derive a site-specific sediment quality guideline value for uranium (U).

Background

A project that aims to derive a sediment Guideline Value (GV) for uranium (U) has been on-going since 2009. Following an initial site characterisation during the 2008–09 wet season, two pilot studies were conducted during the 2009–10 and 2010–11 wet

seasons, respectively. The methods and results of the pilot studies have been previously reported in Annual Research Summaries (van Dam et al 2010, Harford et al 2011, Harford et al 2012). Briefly, sediments spiked with U were deployed in an un-impacted billabong (Gulungul) for the duration of the wet season. They were retrieved and sub-sampled for the analysis of bacteria (prokaryotes), and micro- and macro-invertebrates (eukaryotes) using a combination of ecogenomic and traditional taxonomic methods.

The analyses showed that benthic macroinvertebrate taxa typically colonising fine silt-clay sediments of backflow billabongs are only likely to be directly impacted by high U contamination. However, all multivariate analyses indicated a compositional change of microinvertebrates (as measured by ecogenomics) across the U concentration range, as well as effects at lower concentrations. Numerous analyses found statistically significant changes across the concentration gradient, with thresholds of change determined between 40–420 mg kg⁻¹ U.

It was identified recently (2017) that the original molecular sequencing of the 18S gene was too limiting to be making strong inferences about threshold change detection and to that end, the original sequencing data were bolstered by sequencing a different region of the 18S gene plus the CO1 gene. Further work over 2018 will analyse these new data to corroborate or refine the original conclusions, publishing the results in peer-reviewed journals. The results will be used to derive a sediment quality Guideline Value (GV) for U for current operations and closure of the mine. The GV will inform SSB's rehabilitation standard and, potentially, ERA's final closure criterion.

Progress against plan

- All field experiments have been completed. Write-up of the results was delayed due to competing priorities and the recognition that the original DNA sequencing was too limited.
- Additional sequencing of the 18S and CO1 gene is being finalised with data analysis and journal publication to be finalised.

Key findings

- A sediment quality guideline for U of 94 mg/kg (AEM) or 115 mg/kg (TRM) was derived and this interim GV has been communicated to ERA.

Workplan for 2018-19

- Two papers to be completed and submitted for peer-review.

Planned project outputs and associated outcomes

The primary outputs for the project are a site-specific GV for U in sediments, and four journal papers detailing the study, published in peer-reviewed journals.

The outcome that this project will achieve is an understanding of the effects of sediment-bound U on benthic communities and increased confidence in assurances that the environment of the ARR is protected from U mining activities.

Planned communication activities

- Four papers published in peer-reviewed journals.
- Reports/presentations to key stakeholders as appropriate.

Project publications to date (if applicable)

Sutcliffe B, Chariton AA, Harford AJ, Hose GC, Greenfield P, Stephenson S, Midgley DJ & Paulsen IT 2017. Insights from the genomes of microbes thriving in uranium-enriched sediments. *Microbial Ecology* (in press)

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*. 19(11), 4799

Harford, AJ, van Dam RA, Humphrey CL, Jones DR, Simpson SL, Stauber JL, Gibb KS & Streten-Joyce C (2011). The toxicity of uranium to sediment biota of Magela Creek backflow billabong environments. In eriss research summary 2009–2010. Jones DR & Webb A (eds) Supervising Scientist Report 202, Supervising Scientist, Darwin NT.

Harford AJ, van Dam RA, Humphrey CL, Jones DR, Simpson SL, Chariton AA, Gibb & Stauber JL (2012). The toxicity of uranium to sediment biota of Magela Creek backflow billabong environments. In eriss research summary 2010–2011 Jones DR & Webb A (eds). Supervising Scientist Report 203, Supervising Scientist, Darwin NT.

Harford AJ, Simpson SL, Chariton AA, van Dam RA & Humphrey CL (2013). The toxicity of uranium (U) to sediment biota of Magela Creek backflow billabong environments. In eriss research summary 2012–2013. Supervising Scientist Report 205, Supervising Scientist, Darwin NT, 2 – 7.

Project details			
Project title	Assess the effects of turbidity on aquatic ecosystems using field effects information		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Informing SSB's rehabilitation standard and, potentially, ERA's final closure criteria for turbidity in billabongs and creek channels through the provision of environmental protection thresholds based on multiple lines of evidence.		
Key Knowledge Needs (KKN)	WS8A. What are the physical effects of suspended sediment on aquatic biodiversity, including impacts from sedimentation and variation in sediment characteristics (e.g. particle size and shape)?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2009-003	Project commencement date	01/07/2009
		Estimated completion date	31/08/2018
Project duration (months)	100	Date required	30/12/2018
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	Humphrey, Chris	Project total estimated internal resources (person weeks)	120
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	0

Aims

- To develop a turbidity rehabilitation standard for Ranger billabongs and off-site stream channels.
- To publish supporting evidence for the standard.

Background

As Ranger moves into the decommissioning and rehabilitation phases, the risk to aquatic ecosystems from suspended sediment in runoff increases significantly, through the erodibility of newly-formed and initially unvegetated landforms. Excessive and sustained turbidity in aquatic ecosystems can disrupt ecological function in aquatic ecosystems, including changes to other water quality variables (temperature, dissolved oxygen), changes to light conditions and hence to primary (plant) production, and disruption of feeding and respiration activities of aquatic organisms. Turbidity is one of a number of water quality measures being developed to represent surface water quality closure criteria for receiving waters, including billabongs and stream channels, adjacent to the Ranger uranium mine.

Biological-effects information for turbidity for the Alligator Rivers Region is available for two different ecosystem types, billabongs and sandy stream channels. The information for each ecosystem type has been reported in previous ARRTC summaries and SS Annual Reports. The current phase of the study represents the review of the previous work, which will culminate in specification of a rehabilitation standard for turbidity and publication of the supporting evidence.

Progress against plan

No work ensued over the 2016-17 nor 2017-18 periods due to competing priorities. Prior to 2017-18, progress included:

- The algal biomass (chlorophyll a) and turbidity relationships were established for billabongs, 1980–81 and also investigated in the 2009–2013 studies.
- Macroinvertebrate and turbidity relationship established for sandy streams, were conducted in a 1996 study (Stowar et al. 1997) with additional data analysis in 2014.

Key findings

- No external publications to date for this project.

Workplan for 2018-19

- Review work conducted to date on biological effects of turbidity on billabongs and sandy stream channels.
- Specify rehabilitation standards for turbidity for billabongs and sandy stream channels downstream of Ranger.
- Publish the evidence supporting the rehabilitation standard for turbidity.

Planned project outputs and associated outcomes

The primary outputs for the project are site-specific GVs for turbidity in streams and billabongs, and a journal paper detailing the study published in a peer-reviewed journals.

The outcome that this project will achieve is an understanding of the effects of turbidity on aquatic biota and an associated increased confidence in the ability to ensure the environment of the ARR is protected from U mining activities.

Planned communication activities

- SSB Annual Research Summary paper (cited below).
- A paper published in a peer-reviewed journal.
- Reports/presentations to key stakeholders as appropriate.

Project publications to date (if applicable)

George A & Humphrey C 2014. Development of turbidity closure criteria for receiving surface waters following Ranger minesite rehabilitation. In eriss research summary 2012–2013. Supervising Scientist Report 205, Supervising Scientist, Darwin NT, 154–163.

No external publications to date for this project

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.		
Key Knowledge Needs (KKN)	WS6A. What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2012-003	Project commencement date	01/12/2012
		Revised completion date	30/09/2017
Project duration (months)	24	Date required	02/01/2017
In-house or outsourced	Internal	Actual completion date	29/06/2018
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)	0

Aims

- To assess the toxicity of ammonia to six local species.
- To 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 (ie: Magela and Gulungul creeks) to a range of local freshwater species, and to use this information to derive site-specific guideline 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.
- A manuscript has been prepared and submitted to an appropriate journal.

Key findings

- Toxicity of ammonia varied greatly among the eight species tested with the concentration of ammonia to cause 50% effect (EC50) 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.
- Organisms resident in waters with low ionic strength were more sensitive to ammonia when compared to ammonia sensitivities in the international literature.

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary output for this project is an assessment of the toxicity of ammonia to six local species.

The outcomes of this project include the derivation of a site-specific ammonia guideline value for Magela and Gulungul creeks.

Planned communication activities

- Key findings for this project will be published in a scientific journal and communicated to key stakeholders through the Ranger Minesite Technical Committee, ARRTC and ARRAC.

Project publications to date (if applicable)

Manuscript submitted to Environmental Toxicology and Chemistry and is currently under review.

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	Completed
What business need does this project inform?	Protection of aquatic ecosystems, specifically lentic water bodies, from the effects of ammonia, particularly post-rehabilitation.		
Key Knowledge Needs (KKN)	WS6A. What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2016-006	Project commencement date	05/09/2016
		Estimated completion date	31/08/2017
Project duration (months)	12	Date required	30/06/2017
In-house or outsourced	Internal	Actual completion date	31/12/2017
Lead team	WASQ	Reason for project delay (where applicable)	Unexpected laboratory results, requiring investigation. Prioritisation of routine bio-monitoring over the present study.
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 (GV)s are appropriate for local species and conditions.

Background

Water quality GVs for ammonia were 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 GVs based on local conditions (pH and temperature). It is important to provide evidence that the algorithms applied to local species and conditions are appropriate. This project aimed to validate the algorithms used to adjust ammonia water quality GVs (dependant on pH) derived for the creeks for use on local species (inferred from one species *H. viridissima*) and conditions.

Progress against plan

- Manuscript published in the journal: Environmental Toxicology and Chemistry.

Key findings

- *Hydra viridissima* was among the most sensitive species to ammonia reported in the international literature. Its sensitivity to ammonia increased with increasing pH.
- The speciation equations derived by Emerson et al. (1975) were determined to be the most accurate method of adjusting ammonia toxicity values derived in the low ionic strength waters of Magela Creek.

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary output for the project is to examine the ammonia toxicity of a local species with increasing pH and compare it to the modelled response.

The outcome of this project include providing confidence in the site-specific algorithm derived GV for ammonia.

Planned communication activities

- Journal paper.

Project publications to date (if applicable)

Mooney Thomas J, et al. "Modeling the pH–ammonia toxicity relationship for *Hydra viridissima* in soft waters with low ionic concentrations." Environmental toxicology and chemistry 37.4 (2018): 1189-1196

Project details			
Project title	Formalisation and publication of the weight of evidence assessment to derive a water quality standard for magnesium in surface waters		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Informing SSB's rehabilitation standard and, potentially, ERA's final closure criteria for magnesium in billabongs and creek channels through the provision of environmental protection thresholds based on multiple lines of evidence.		
Key Knowledge Needs (KKN)	WS7. Determining the impact of chemical contaminants on aquatic biodiversity and ecosystem health		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2016-011	Project commencement date	28/02/2018
		Revised completion date	14/12/2018
Project duration (months)	4	Date required	30/12/2018
In-house or outsourced	Internal	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	New acting duties and priorities for the project manager
Supporting team(s)	N/A		
Project manager	Humphrey, Chris	Project total estimated internal resources (person weeks)	7
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	0

Aims

- To assess the quality, quantity and relevance of the various lines of laboratory and field evidence used to derive independent, guideline and closure criteria candidate values for Mg in surface waters (potentially) contaminated by Ranger mine waste waters.
- To evaluate the congruence of the data contained in these different lines of evidence, and describe the basis for the decisions made in deriving, as well as assigning measures of confidence in, the final guideline value for Mg.

Background

Biological effects data provide the basis for deriving water quality guideline and closure criteria values for protection of aquatic ecosystems from Ranger mine waste waters. For magnesium, various laboratory and field studies have derived independent guideline and closure criteria candidate values. Key national (ANZECC/ARMCANZ 2000) and international jurisdictions acknowledge that some combination of laboratory and field-effects data, using weight of evidence (WOE) methodology, provides the most robust approach to guideline value derivations. This is particularly important for Mg in the Ranger context, as this contaminant is the most restrictive in the long-term achievement of meeting the Environmental Requirements for rehabilitation. Therefore, high confidence is required in the closure criterion set for this solute. Such confidence is garnered when formal and other precepts associated with WOE methodology are met, including:

- Consistency of and timing of result amongst different lines of evidence (LOEs). Included here is (i) evidence of both biological gradients in the field and laboratory/field dose-response relationships observed for the same stressor; and (ii) for field studies, biological responses in exposed and reference sites were similar prior to contamination.
- Precedence elsewhere for similar effects, and plausibility and ready interpretation of the effects observed.
- Within a line of evidence, (i) different independent analytical methods provide similar outcomes and interpretation, and (ii) for field effects, confounding stressors are effectively disentangled to isolate the effect of the contaminant of interest.

Progress against plan

- Analysis of the results for all studies contributing independent lines of evidence is either completed, in review or well advanced.
- Relevant literature pertaining to use of different lines of evidence for GV derivations has been compiled.

Key findings

- A rehabilitation standard for Mg has been determined as the mean of the lowest available candidate guideline values for which there was deemed to be sufficient confidence, for each of the laboratory (2.5 mg/L), mesocosm (2.3 mg/L) and field (3.9 mg/L) studies. This value is 2.9 mg/L. The WOE evaluation underlying these decisions is currently being drafted.

Workplan for 2018-19

December 2018:

- Submit the WOE evaluation for journal peer review.

Planned project outputs and associated outcomes

The primary outputs for the project are a journal article: a WOE evaluation of laboratory and field lines of evidence used to derive or support a guideline value for magnesium in Magela and Gulungul creeks, NT.

The outcome that this project will achieve is a high level of confidence in the Mg standard set by SSB for Ranger closure.

Planned communication activities

- Mg rehabilitation standard.
- Presentation to SETAC AU, September 2017.
- ARRAC and ARRTC meetings for 2017-18.
- Website updates.

Project publications to date (if applicable)

Published articles or reports in preparation or in review that are associated with each of the lines of evidence are not cited here at this stage.

Project details			
Project title	Assess 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 during operations and post-decommissioning.		
Key Knowledge Needs (KKN)	WS4. Characterising baseline aquatic biodiversity and ecosystem health WS7. Determining the impact of chemical contaminants on aquatic biodiversity and ecosystem health		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2016-012	Project commencement date	31/03/2017
		Estimated completion date	31/03/2020
Project duration (months)	36	Date required	30/12/2018
In-house or outsourced	Collaboration	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	N/A
Supporting team(s)	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 groundwater communities and associated habitat and water quality in Magela Creek, by:

- describing the community structure and function of groundwater fauna and environmental conditions (water quality, habitat) in Magela Creek sand channel, and
- assessing the uniqueness or otherwise of Magela Creek sand channel communities in relation to another creek (Nourlangie) in Kakadu National Park.
- To assess the sensitivity of these communities to contaminants of potential concern arising from Ranger minesite.
- To investigate the implications for ecological functions provided in Magela subsurface sands 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 will be magnesium sulfate (MgSO_4) derived from the waste rock landform and pit capping. Solute egress modelling predicts that within 10 years of closure, groundwater with MgSO_4 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 investigate fauna and water quality in subsurface sands of Magela Creek during the dry season. The results are reported in Chandler et al (2017). 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 cited below (Chandler et al, 2017).

- Piezometer sites were installed in late July 2017 for water chemistry and biota (whole organism and genomic) sampling and collections.
- 2017 dry season sampling completed - initial water chemistry analysis and sorting of biota samples underway.
- DNA extraction of metagenomic samples completed May 2018.

Key findings

- Examination of water chemistry data indicates contamination gradient around Coonjimba Billabong reported in 2016 pilot still present.
- Elevated EC, magnesium and sulfate concentrations were recorded at sites adjacent to Coonjimba Billabong, with maximum values recorded in October 2017 (416 $\mu\text{S}/\text{cm}$, 24 mg/L and 160 mg/L, respectively).
- Site near ERA MG001 monitoring and release point showed elevated concentrations of manganese and strontium but uncertain as to whether this is natural variation or mine derived contamination.
- Continuous data recorded maximum EC values of 605 $\mu\text{S}/\text{cm}$ from a site near Coonjimba Billabong.
- Preliminary investigations of fauna samples indicate groundwater taxa more prevalent during later months of the dry season. However and to date, specimens of Syncarida (Parabathynellidae) collected in the 2016 pilot study, have not been recorded from 2017 samples.

Workplan for 2018-19

June-December 2018:

- Monthly collection of biota and water chemistry samples with strategic spatial analysis using grid of piezometers at two sites in Magela, to examine small-scale spatial variability.
- Collection of biota and water chemistry samples at three sites along Nourlangie Creek, to assess endemism and conservation values of Magela catchment fauna.

July 2018-March 2019:

- Lab investigation - sediment rewetting with MgSO_4 spiking.

September-October 2018:

- DNA sequencing of 2017 metagenomic samples using 16s, 18s and CO1.

December 2018-June 2019:

- Analysis of 2018 biota and metagenomics samples.

Planned project outputs and associated outcomes

The primary outputs for the project are a PhD thesis, including four journal papers detailing the study published in peer-reviewed journals.

Outcomes of the project include:

- A spatial understanding of the water quality characteristics and biological communities of the shallow groundwater (to 2m) in Magela Creek.
- An improved ability to assess the risk to environmental values in Magela Creek from solute contamination in groundwater discharge from Ranger uranium mine.

Planned communication activities

- 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)

Confirmation of Candidature seminar successfully presented in November 2017 as part of PhD assessment requirements.

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 NT (this report produced for RES-2016-004, the pilot project which feeds into the current project).

Project details			
Project title	Acid sulfate soils: Further knowledge needs and impact assessment		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Provision of knowledge on potential environmental impacts of emerging stressors on aquatic ecosystems, in order to inform regulation.		
Key Knowledge Needs (KKN)	WS7D. How do acidification events impact upon, or influence the toxicity of contaminants to, aquatic biota?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2017-003	Project commencement date	01/07/2017
		Estimated completion date	30/06/2019
Project duration (months)	24	Date required	31/12/2018
In-house or outsourced	Collaboration	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	N/A
Supporting team(s)	External consultant		
Project manager	Trenfield, Melanie	Project total estimated internal resources (person weeks)	3
Project sponsor	Harford, Andrew	Project total estimated collaborator resources (person weeks)	3

Aims

- To identify current and potential (future) sources of acid generating sediments and soils, and their ecosystem receptors, associated with mine-derived sulfate (i.e. on-site and offsite).
- To assess possible impacts of sulfate concentrations present in Coonjimba catchment. This includes an assessment of impacts of acid events in Coonjimba Billabong (CJB) in early 2016 upon resident macroinvertebrate communities, as well as assessment of potential impacts of the surface and groundwater quality in Coonjimba catchment to adjacent Magela Creek.

Background

There are concerns about the potential for generation of acid sulfate sediments (ASS) over time within water bodies receiving treated or untreated mine water. This is already occurring in the onsite waterbody, CJB, which receives low levels of contaminated mine waters. The pH in CJB fluctuates significantly each year, falling to levels significantly below neutral in response to early wet season rains.

SSB is currently focusing on the development of Rehabilitation Standards for the Ranger uranium mine. Given the ASS issue outlined above, there is a need to develop a Rehabilitation Standard for sulfate in the context of ongoing issues associated with ‘mine-generated’ ASS. A consultancy study has been advising SSB on a site-specific rehabilitation standard for sulfate based on the relationships between sulfate concentrations in surface waters over time in Ranger mine site waterbodies (CJB and Retention Pond 1) and the first occurrence of acid sulfate events observed in these waterbodies (in the early wet season). The consultant’s report contained recommendations for further work. The present study is designed to provide advice for sampling design of future studies required on acid sulfate soils, relevant to Ranger operations and rehabilitation, and to assess the results of these future studies. The investigations are a collaboration between SSB and ERA and their respective consultants.

A component of this new project work will identify the potential for surface and groundwater ecosystems, onsite and offsite, to either develop acid generating sediments in future and/or receive poor water quality (low pH, high concentrations of metals) associated with ASS events.

Another component of this project work will assess the impacts to aquatic biota (specifically, macroinvertebrate communities) arising from a significant acid event that occurred in CJB in January 2016. Several weeks after the event and while the billabong was still acidic (mid-late February 2016), replicate pond net samples were collected from the littoral edges of the billabong, and also from adjacent Georgetown Billabong which served as a control (unaffected by acid events). These samples have been sorted and identified, and preliminary analysis of the data has been undertaken. Further analysis and reporting will be undertaken during the 2018-19 period to assess impacts on the macroinvertebrate fauna.

Progress against plan

- A site visit with SSB, ERA and consultants (Rivers and Wetlands and ERM) was undertaken on 26 June 2018.
- A consultant to SSB, Dr Darren Baldwin (Rivers and Wetlands), provided a report containing a recommended sampling design based on a risk framework.

Key findings

- Preliminary analysis of macroinvertebrate data from the 2016 acidification event in Coojimba Billabong found that there were marked difference in the abundance of

organisms and in the community assemblages between Coonjimba Billabong (mine-impacted) and Georgetown Billabong.

- A site-specific rehabilitation standard for sulfate has been produced. It was based on the relationships between sulfate concentrations in surface waters over time in Ranger mine site waterbodies (CJB and Retention Pond 1) and the first occurrence of acid sulfate events observed in these waterbodies (in the early wet season).

Workplan for 2018-19

- Identify sampling and chemical analysis needs for locations on and off-site. Assess the results arising from the sampling program to determine potential for impacts and provide advice possible on possible remediation actions.
- Revise sulfate standard if necessary.
- Complete the analysis and reporting of the 2016 CJB acid event.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Data that will support and potentially refine SSB's sulfate rehabilitation standard.
- Knowledge on the source and distribution of ASS on the Ranger mine site.
- Knowledge on possible remediation activities for sites with significant ASS.
- Identification of offsite ecosystems at potential risk from ASS formation.
- Sampling protocols for monitoring surface water and sediment at risk from ASS formation.
- Knowledge of short-term impacts of early wet season ASS events in CJB on resident biota and on water quality and biota in adjacent Magela Creek.

The outcomes of this project include knowledge on potential development and environmental impacts of acid sulfate soils in onsite and offsite aquatic ecosystems, in order to inform regulation.

Planned communication activities

- Reports or paper.

Project publications to date (if applicable)

Sulfate Rehabilitation Standard for the Ranger uranium mine

Consultant's Phase 1 consultancy reports reviewing ERA reports and SSB's sulfate standard

Project details			
Project title	Deriving a candidate magnesium guideline value (GV) based on a mesocosm study (re-analysis of 2002 PhD data)		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Informs the Mg GV for operations and closure - an additional line of evidence.		
Key Knowledge Needs (KKN)	WS7. Determining the impact of chemical contaminants on aquatic biodiversity and ecosystem health		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2017-031	Project commencement date	01/04/2016
		Revised completion date	30/10/2018
Project duration (months)	4	Date required	30/06/2018
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	Mooney, Tom	Project total estimated internal resources (person weeks)	6
Project sponsor	Humphrey, Chris	Project total estimated collaborator resources (person weeks)	0

Aims

- To assess the toxicity of magnesium (Mg) to aquatic communities (phytoplankton, zooplankton and macroinvertebrates) in Magela Creek by re-analysing data collected from a mesocosm study conducted in 2002.
- To derive candidate GVs from Mg community effects data to incorporate as a line of evidence in the magnesium rehabilitation standard.

Background

Magnesium is a contaminant of concern for the operation and closure of Ranger Mine. A laboratory-based, site-specific guideline value (GV) has been derived. However, to ensure the adequacy of the GV for closure, a weight-of-evidence approach is being implemented. This evaluation is using additional lines of evidence from field studies of the toxicity of Mg to biota in Magela Creek. Previously, McCullough (2006) reported the results of a mesocosm experiment conducted during the 2002 dry season in the Magela Creek channel upstream of Ranger. Mesocosms were spiked with a range of Mg sulfate concentrations (0-68 mg/L) and left for 2 months. Periodically, the mesocosms were sampled for a range of community biota, including: macroinvertebrates, microinvertebrates, diatoms and phytoplankton communities. Changes to these assemblages were assessed across the range of Mg concentrations.

Given advances in statistical analysis methods and software since 2006, the results require re-analysis, together with publication in a peer reviewed scientific journal.

Progress against plan

- This project work was submitted in 2006 as part of McCullough's PhD thesis "A multi-scale assessment of the ecological risk of magnesium sulfate to aquatic biota of Magela Creek, Northern Territory, Australia".
- A re-analysis of the results of the PhD has been completed. Concentration-response relationships for zooplankton and phytoplankton have been re-analysed and re-assessed after re-processing of one of the original zooplankton samples by an interstate expert.
- Results have been used as a line of evidence for deriving the magnesium rehabilitation standard.

Key findings

- Results of this work, including recent re-analyses, have demonstrated sensitivity after four-week exposure of phytoplankton (algal biomass viz chlorophyll a and green algal abundance) and zooplankton. The 1% effect concentrations (EC1) for algal biomass and community structure response measures for zooplankton were 1.5 and 2.3 mg/L Mg respectively. These results have been incorporated with other laboratory and field evidence in a weight of evidence evaluation to derive a Mg standard for Ranger mine-site closure.

Workplan for 2018-19

- Complete journal manuscript.

Planned project outputs and associated outcomes

The primary outputs for the project are (field) community-based toxicity estimate(s) for Mg arising from an earlier (2002) mesocosm study.

The outputs will be used as additional lines of evidence for the weight of evidence assessment evaluating the closure criterion for Mg.

Planned communication activities

- Journal manuscript.
- Presentations to relevant fora (e.g. ARRTC, SETAC).

Project publications to date (if applicable)

McCullough (2006). A multi-scale assessment of the ecological risk of magnesium sulphate to aquatic biota of Magela Creek, Northern Territory, Australia. Charles Darwin University, PhD Thesis

Project details						
Project title	Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity (NESP fish migration)					
SSB function	Research	Site	Ranger			
Project category	Developing closure criteria	Project status	Active			
What business need does this project inform?	Informs SSB’s rehabilitation standard and, potentially, ERA’s final closure criterion, through the provision of a fish migration threshold for magnesium sulfate in surface waters.					
Key Knowledge Needs (KKN)	WS7F. Can a contaminant plume in creek channels form a barrier that inhibits organism migration and connectivity (e.g. fish migration, invertebrate drift, gene flow)?					
Closure criteria theme (if applicable)	Water and Sediment	Project Priority	Relevance	1	Time-frame	1
			Importance	1	Time buffer	A
Project number (if allocated)	RES-2018-002	Project commencement date		01/07/2018		
		Estimated completion date		01/07/2020		
Project duration (months)	27	Date required		31/12/2018		
In-house or outsourced	Collaboration	Actual completion date		N/A		
Lead team	WASQ	Reason for project delay (where applicable)		N/A		
Supporting team(s)	CDU/NESP					
Project manager	Mooney, Tom	Project total estimated internal resources (person weeks)		1		
Project sponsor	Humphrey, Chris	Project total estimated collaborator resources (person weeks)		4		

Aims

- To identify sources of colonization by different fish species of the Magela sand channels during the wet season.
- To characterise the seasonal movements of different fish species through the sand channels and thereby determine key periods when different species may be at risk from mine-derived solute egress to the creeks after Ranger mine rehabilitation.

- To determine where possible, the risks to migrating fish species associated with mine-derived solute egress to Magela Creek through exposure observations or experiments.

Background

The importance of ecological connectivity in maintaining critical ecosystem processes has been increasingly recognised over recent years. Egress of contaminants into Magela Creek associated with the waste rock cover of the Ranger uranium mine (RUM) final landform via surface and ground water has been identified as a potentially important threat to ecological connectivity and the processes it supports (Bishop et al. 1995; Humphrey et al 2017; Supervising Scientist 2017). Following closure of RUM, the rehabilitated landform is predicted to become a source of surface water runoff and exfiltrating groundwater with elevated electrical conductivity (EC) derived from waste rock. Detailed studies of the movements of fish in Magela Creek based on visual observations and trapping were conducted by SSB in the 1980s and 1990s. Based on this research, Bishop et al. (1995) identified that fish in Magela Creek took dry season refuge in billabongs in the escarpment country upstream of Ranger mine, and in channel and floodplain billabongs downstream of the mine. During the wet season fish migrate from these refugia to spawn and feed: downstream migration from below-escarpment billabongs to the sand channels and inundated floodplains, and lateral or upstream migrations from channel and floodplain billabongs to the sand channels and adjacent inundated floodplains. At the end of the wet season, large numbers of fish migrate back upstream from or through the sand channels. This conceptual model of fish migration suggests that future egress of saline surface and ground waters from Ranger has the potential to both affect fish resident in the sand channels during the wet season and reduce connectivity between upstream refugia and the floodplain and, thus, interrupt important ecological processes.

Building upon the early work of Bishop et al. (1995), this research will use the most up-to-date methods available (sonar, videography, electronic tagging) to develop a comprehensive understanding of fish migration dynamics in the Magela Creek region. Where possible, these results will be directly linked to surface and ground water solute modelling for the Ranger mine rehabilitation site, as well as to additional possible risk assessments, to assess the likely effects of saline mine waters on ecological connectivity and the processes it supports. This will include exposure information available from operational mine water releases to Magela Creek. Such risk assessment will include observations of fish migrating adjacent to sites of mine waste water releases in Magela Creek.

Additionally, the project will use Magela Creek as a model system to build upon previous work on food web dynamics conducted under the NERP and NESP programs by providing quantitative estimates of the biomass transported via fish migration.

Progress against plan

- Meetings between collaborators have been held to establish project design while a field trip was undertaken in May 2018 to assist in field study planning. The main body of field work has yet to commence.

Key findings

- There are no key findings to report.

Workplan for 2018-19

Dry season 2018:

- Sonar trials to test efficacy of fish detection in local ARR streams.
- Tag fish in late dry season in escarpment refuge pools.
- Deploy acoustic array for detection of electronic tags.

Wet season 2018-2019:

- Sonar and camera surveys, including imagery from equipment located adjacent to sites of mine water release.
- Download and process data.
- Tag fish in Mudginberri Billabong.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Literature and data review of seasonal utility of Magela channel for ecological connectivity purposes. The basis of this review is a draft report prepared by SSB and which was undertaken as a project (RES-2016-005) described in the last (2016-2017) Annual Technical Report.
- Reporting of dry season and wet season fish residency in Magela Creek, and use of Magela Creek channel as a migration conduit by various fish species during the period of creek flow
- Reporting of key periods when different species may be at risk from mine-derived solutes and where possible, quantification of the risks to migrating fish species associated with solute egress to Magela Creek after Ranger mine rehabilitation.
- If necessary, prescription of a monitoring program and associated design for ongoing assessment of potential impacts to fish communities associated with mine water egress to Magela Creek.

The outcomes of this project include:

- An improved understanding of the use of Magela Creek channel by resident and migrating fish species.
- An assessment of the risks of saline mine discharged from Ranger uranium mine waters on ecological connectivity (including fish migration) and the processes it supports.

Planned communication activities

- Standard corporate reporting requirements.
- Reporting and presentations to key stakeholders as necessary.
- All NESP Northern Australia Environmental Research (NAER) hub generated publications arising from the project will be made freely available on the NAER website.
- Journal publication.
- Conference and workshop presentations.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Predicting uranium accumulation in sediments		
SSB function	Research	Site	Ranger
Project category	Demonstrating achievement of closure criteria	Project status	Active
What business need does this project inform?	Informs the ability to achieve the sediment quality guideline values for uranium.		
Key Knowledge Needs (KKN)	WS3E. What are predicted contaminant (including nutrients and contaminants bound to sediment) and suspended sediment concentrations in surface waters over time? WS3F. To what extent will the mobilisation of contaminants from sediment influence surface water quality?		
Closure criteria theme (if applicable)	Water and Sediment	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2016-013	Project commencement date	01/06/2018
		Estimated completion date	31/12/2018
Project duration (months)	6	Date required	31/12/2018
In-house or outsourced	External	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	N/A
Supporting team(s)	To be determined		
Project manager	Harford, Andrew	Project total estimated internal resources (person weeks)	1
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	4

Aims

- To estimate the accumulation of uranium (U) in sediments for various water column concentrations, e.g.in particular, the proposed surface water U rehabilitation standard of 2.8 µg/L (guideline value for surface waters).

Background

Uranium Guideline Values (GVs) for water and sediment have been derived separately and have been based on biological responses that were measured in laboratory and field experiments, respectively. The water quality GV of 2.8 µg/L U was based on a Species Sensitivity Distribution of toxicity estimates from 7 local species. The interim sediment quality GV was derived from a No Effect Concentration of 94 mg/kg AEM U in a field experiment, where laboratory-spiked sediments were assessed for re-colonisation after being deployed in the field for the duration of a wet-season. Following rehabilitation, U will enter the aquatic environment from various sources in both particulate bound and dissolved forms. It will partition from the water column to the sediment and vice-versa, depending on environmental conditions. An understanding of the movement of U between the water column and sediments is needed in order to predict if water and sediment GVs will be achieved. This project will involve a desktop review using local and international data to determine the partitioning co-efficient of U, which can be used to make predictions regarding the effect of water column U concentrations on sediment concentrations. If necessary, it may be extended to further laboratory work and/or field data collection.

Progress against plan

- Water and sediment quality data provided to consultant, Dr Barry Noller, Centre for Mined Land Rehabilitation.
- Consultant has provided a preliminary report with indicative results.

Key findings

- There are no key findings to report at this stage.

Workplan for 2018-19

- Desktop review using local and international data to determine the partitioning co-efficient of U.
- Assess implications of results for the effect of water column U concentrations on sediment concentrations, and whether the current uranium in water rehabilitation standard requires review.
- If necessary, extend the study to further laboratory work and/or field data collection.

Planned project outputs and associated outcomes

The primary output will be a report from the consultant. The project will primarily inform the water and sediment rehabilitation standards for U.

The outcomes for this project include an understanding of the relationship between water and sediment guideline values.

Planned communication activities

- Report to ARRTC at end of year meeting.
- Report to OSS any findings that significantly change the rehabilitation standard.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Assess the cumulative toxicity of Ranger contaminants of potential concern (COPCs) 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 limits and rehabilitation standards for the (COPCs).		
Key Knowledge Needs (KKN)	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures and modifying factors? CT1A. What are the cumulative risks to the success of rehabilitation and to the offsite environment?		
Closure criteria theme (if applicable)	Water and Sediment Cross-themes	Relevance	2
		Time-frame	1
Project Priority		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2017-001	Project commencement date	01/05/2017
		Revised completion date	01/12/2018
Project duration (months)	18	Date required	31/12/2018
In-house or outsourced	Internal	Actual completion date	N/A
Lead team	WASQ	Reason for project delay (where applicable)	N/A
Supporting team(s)			
Project manager	Trenfield, Melanie	Project total estimated internal resources (person weeks)	60
Project sponsor	Harford, Andrew	Project total estimated collaborator resources (person weeks)	0

Aims

- To assess whether the Guideline Values (GVs) derived from single COPC toxicity testing are still protective for all species when combined together as a mixture in a synthetic water.
- To (i) test whole mine waters to establish the protectiveness of the derived GV's when in natural waters as mixtures. (ii) If testing from part (i) indicates that the derived GV's are not protective, develop the capacity to predict the toxicity of a given mine site water with particular physicochemical conditions using statistical modelling.
- To trial the use of synthetic waters in place of whole mine-site waters if necessary: If the sensitivity of local species is comparable between a whole mine water and an equivalent synthetic water of similar COPC composition, then synthetic water testing can be used to assess the toxicity of COPCs mixtures predicted to emanate from the Ranger site post closure.

Background

Much effort has been invested in deriving site-specific water quality guideline values for individual COPCs (such as uranium, manganese, magnesium and ammonia). However, this approach does not consider potential interactive (e.g. additive, synergistic, antagonistic) effects of toxicant mixtures in mine site waters or other modifying effects that may occur in the field. It is important to ensure that the GV's for the individual COPCs are protective of the aquatic environment when found in a mixture. It is also important, if toxicity is observed in mine-site waters, to be able to predict the toxicity of future waters with particular physiochemical conditions to ensure the protection of the aquatic environment within and surrounding the Ranger Project Area following rehabilitation.

Progress against plan

- Aim 1 of this project is complete. The GV's were protective for all species at the Ca:Mg ratios observed in the creek (5:1 and 9:1). When there is less Ca in the system (28:1) effects were observed at GV concentrations.
- Aim 2(i): Four whole mine waters were initially selected for testing, TDWW, PJ, RP2 and GCT2. Toxicity testing for the first three waters is mostly complete with data for two species missing from the PJ (*Mogurnda mogurnda* and *Moinodaphnia macleayi*) data set. Further testing of PJ will be undertaken during the late dry season so that the mine water is similar to the tailings/process water that the original test water resembled. TDWW water is very acidic and as such test solutions in previous testing with this water were at a much lower pH. Re-testing of the TDWW water adjusted to pH 6 is currently underway.
- Advice has been provided by modelling experts (Peter Bayliss, Angus Webb and Joe Myers) on the best approach to analysing the complex data set.

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. However, the same testing at Mg:Ca ratios of 5:1 and 9:1 resulted in no toxicity of the COPCs at their GV concentrations. Hence, the addition of calcium appears to greatly influence the toxicity of the COPCs, acting most likely and predominantly on Mg, and to varying degrees depending on the species.
- The TDWW water with a Mg:Ca ratio of 14:1 was 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). PJ water was much less toxic to all species with the snail again the most sensitive (EC10 = 0.01%) and Lemna growth stimulated at up to 1% strength. RP2 was less toxic again to all species with the most sensitive species being the snail (EC10 = 2%) and the cladoceran (EC10 of 6%). Additional toxicity testing is required for the hydra. GCT2 water was the least toxic of all the waters tested. The most sensitive species was *A. cumingi* (EC10 = 1.75%).
- Preliminary findings suggest that TDWW water adjusted to pH 6 is less toxic than the unadjusted water. However, it is still the most toxic of the waters tested (work still in progress).

Workplan for 2018-19

- Re-testing of manganese, uranium and magnesium using the updated fish chronic toxicity method (see RES-2015-028) will be undertaken as a priority.
- Complete toxicity testing for all four whole mine waters. TDWW adjusted to pH 6 will be completed by the end of August, as will PJ testing.
- Once toxicity testing has been completed the full dataset will be assessed accordingly:
 - If species responses meet equivalent species toxicity estimates for individual COPCs, this may indicate no further toxicity testing is needed. In this event, Cumulative Ecological Risk Assessment (CERA) modelling will be simpler in not needing to model COPCs interactions to identify potential water quality issues.
 - If there is exceedance of species toxicity estimates for individual COPCs (i.e. a species EC50 for whole mine waters exceeds EC50 for individual COPCs), additional data needs will be considered (e.g. possibility of an additional mine-site water DTA added to the dataset such as another groundwater seep) and more complex modelling may ensue to model COPCs interactions (e.g. contracting Melb Uni or CSIRO researchers).
- Should any assessment of modelled COPCs arising from ERA's groundwater modelling invoke a need for toxicity testing of the modelled chemical composition using a synthetic water, the accuracy of this approach would need to be verified using a toxicity assessment of a natural mine water with a mimicked synthetic water.

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 include:

- Additional knowledge regarding the toxicity of Ranger COPCs to local freshwater species when those contaminants occur as mixtures – either in mine waters or simulated mine waters.
- Information to assess the appropriateness of the guideline values for the individual contaminants.
- Verification of data using Direct Toxicity Assessments of various site waters.

Planned communication activities

- Journal manuscript.
- Conference presentation at SETAC US meeting 2017.
- Internal presentation to Chemicals & Assessment Branch 2018.
- Discussions with key stakeholders as appropriate.

Project publications to date (if applicable)

No project publications to date.

Ranger – Rehabilitation

CC theme: Landform (10 projects)

Project details					
Project title	Determining and testing representativeness of long-term rainfall patterns for use in final landform modelling				
SSB function	Research	Site	Ranger		
Project category	Demonstrating achievement of closure criteria	Project status	Active		
What business need does this project inform?	Assurance that synthetic rainfall data used in landform modelling at the 10,000 year scale sufficiently capture the magnitude, number and frequency of large historic floods inferred from slackwater deposits found in regional streams.				
Key Knowledge Needs (KKN)	LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?				
Closure criteria theme (if applicable)	Landform	Project Relevance	2	Time-frame	1
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2014-006	Project commencement date	20/05/2015		
		Revised completion date	17/12/2018		
Project duration (months)	36	Date required	30/06/2018		
In-house or outsourced	Collaboration	Actual completion date	N/A		
Lead team	R&L	Reason for project delay (where applicable)	Sediments have been been dispatched for dating; awaiting the results. Higher priorities.		
Supporting team(s)	Bob Wasson - National University of Singapore, Wayne Erskine Newcastle University.				
Project manager	Saynor, Mike	Project total estimated internal resources (person weeks)	12		
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	5		

Aims

- To use slackwater deposits in the East Alligator River, representing historic extreme floods, to determine the number, magnitude and frequency of palaeofloods that occurred before the start of hydrographic measurements on the river in 1971.
- To quantify the derived long term rainfall data set using the rainfall that would generate the extreme floods.

Background

SSB must assess the stability of the rehabilitated Ranger Mine for 10,000 years after construction and convince the stakeholders that there will be no major on- and off-site environmental effects associated with erosion. Evidence of large historic floods on the East Alligator River shows that large floods have occurred in the past and floods of this magnitude have the potential to impact on the rehabilitated landform at Ranger. Therefore, to undertake landform evolution modelling at the 10,000 year scale, it is essential that the synthetic rainfall datasets used, which include large rainfall events, sufficiently represent extreme events as have occurred historically. This study seeks information on the number, magnitude and frequency of palaeofloods that have occurred during the last 7000 years since sea level has been stable, and which are larger than the largest (modern) recorded event.

Locating and dating of the slackwater deposits either by optically stimulated luminescence (suitable for quartz sand) (OSL) and/or accelerator mass spectroscopy radiocarbon dating (suitable for coherent charcoal, wood or leaves) is essential in describing these extreme events.

Progress against plan

- Sites on the East Alligator River and Magela Creek were visited in 2015. A site on the upper East Alligator in the gorge section was identified as the most likely to contain slackwater deposits. Preliminary sediment samples were collected and have been dated.
- The site in the gorge section of the East Alligator River was visited again in August 2017. Several holes were excavated and the stratigraphy profile was described. Sediment samples from these holes were collected for particle size analysis and five samples from the profile of one hole have been sent away for dating by OSL.
- A topographic survey was undertaken of the height of the flood deposits from the creek bed.

Key findings

- Slackwater deposits have been identified in gorge areas in the East Alligator River. The height above the river bed indicates that the sediments were deposited by large floods. Determination of the rainfall required to generate these large floods will be compared with large rainfall events in the sythetic rainfall data set.

Workplan for 2018-19

- Analyse samples and determine dates of sediments.
- Run HEC-RAS to determine discharges and rainfall for the flood events.
- Prepare and submit a journal paper.

Planned project outputs and associated outcomes

- Determine magnitude, frequency and dates of large rainfall and associated flood events on the East Alligator River.
- Compare extreme rainfall that produced the large floods with that determined in the synthetic rainfall data to ensure that they are represented. If they are not represented then the sythetic data set will need to be adjusted accordingly.

Planned communication activities

- Journal publication.
- Presentations and discussions with the Landform technical working group, and ARRTC.
- Internal reports (data) and annual research summaries.

Project publications to date (if applicable)

Saynor MJ & Erskine WD 2016. Sand slugs formed by large-scale channel erosion during extreme floods on the East Alligator River, Northern Australia. *Geografiska Annaler: Series A, Physical Geography* 98 (2), 169-181.

Saynor MJ & Erskine WD 2015. Use of slackwater deposits and other forms of geologic evidence to determine the number, magnitude and frequency of palaeofloods in the Alligator Rivers Region In *eriss research summary 2013-2014*, ed Supervising Scientist, Darwin NT, 150-156.

Project details			
Project title	Impact of rip lines on runoff and erosion from the Rannger trial landform		
SSB function	Research	Site	Ranger
Project category	Demonstrating achievement of closure criteria	Project status	Completed
What business need does this project inform?	Assess impact of rip lines on a landform surface, through modelling the amounts of erosion resulting from comparable ripped and non-ripped surfaces.		
Key Knowledge Needs (KKN)	LAN3A. What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?		
Closure criteria theme (if applicable)	Landform	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2015-016	Project commencement date	01/07/2015
		Revised completion date	01/03/2018
Project duration (months)	6	Date required	30/06/2018
In-house or outsourced	Internal	Actual completion date	16/02/2018
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)	10
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	0

Aims

- To determine the effectiveness of rip lines in reducing erosion and runoff from the final landform at Ranger for time periods up to 50 years post rehabilitation.

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. In the limited literature there are differing opinions on the effectiveness that rip lines have in

mitigating erosion and runoff off rehabilitated landforms. There is also concern regarding the costs associated with the construction of rip lines. This project will 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 has been completed .
- A Journal paper has been submitted to Land Degradation and Development, titled “Assessment of rip lines using CAESAR-Lisflood on a Trial Landform at the Ranger Uranium Mine”, by Saynor MJ, Lowry, JBC & Boyden JM. The paper has been reviewed and reviewers comments are being addressed.

Key findings

- Rip lines are very effective at reducing the sediment load from a landform under conditions of low slope angle. Under the conditions modelled in this study, reflecting slopes proposed for the final landform, 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. 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 breaks down over time, with depressions infilling and peaks being eroded and reduced in height. These model results indicate that rip lines will not remain in perpetuity in the landscape.

Workplan for 2018-19

- Completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

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

The outcome of this project will be information on the effectiveness of rip lines in reducing erosion on the final landform at Ranger.

Planned communication activities

- Communication to the relevant stakeholder closure committees.
- Peer reviewed journal publication.

Project publications to date (if applicable)

Saynor MJ & Lowry JBC 2018. The impact of rip lines on erosion at the Ranger mine site. In Life-of-Mine 2018. Brisbane, Australasian Institute of Mining and Metallurgy, Carlton Victoria, 150-155.

Saynor MJ, Lowry JBC & Boyden JM. Assessment of rip lines using CAESER-Lisflood on a Trial Landform at the Ranger Uranium Mine. Submitted to Land Degradation and Development - Attending to reviewers comments.

Project details			
Project title	Analysis of data from historical unpublished erosion studies in the ARR		
SSB function	Research	Site	Ranger
Project category	Demonstrating achievement of closure criteria	Project status	Completed
What business need does this project inform?	The analysis of data arising from flume experiments will provide results to assist with the validation of CAESAR-Lisflood.		
Key Knowledge Needs (KKN)	LAN1A. What is the baseline rate of gully formation for areas surrounding the RPA?		
Closure criteria theme (if applicable)	Landform	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2015-022	Project commencement date	01/07/2015
		Estimated completion date	30/06/2018
Project duration (months)	36	Date required	30/06/2018
In-house or outsourced	External	Actual completion date	30/06/2018
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

- To analyse and report on the unpublished experimental erosion data for Ranger uranium mine collected by Steve Riley in the early 1990s.

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 simulations, and were undertaken at the Ranger site (Waste Rock dumps – cap and batter slopes), 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 will collate data relevant to landform evolution modelling. It was proposed to outsource the work as a small non-consultancy to Professor Ken Evans (Charles Darwin University), as he had been present when the fieldwork and data collection were undertaken in 1993.

Progress against plan

- The data sheets and electronic data sets for 1993 Tin Camp Creek flume studies were collated for analysis and supplied to Ken Evans.
- A report was received with results for the concentrated flume studies.

Key findings

- Hydraulic parameters (including Mannings's N, Bed shear stress, Froude Number, Units stream Power) from the 1993 fieldwork at Tin Camp Creek were derived.
- Bedload sediment loss from the flumes decreased over time, due to the depletion of sediment and exposure of a more resistant surface. Suspended sediment concentration quickly declined for constant discharge.
- Comparisons between vegetated and non vegetated flume runs showed that peak sediment concentrations occurred at higher discharges and were higher for unvegetated sites.
- It was recommended that the results of the study be used in CAESAR-Lisflood simulations to calibrate the shear stress component of the model. This further work was undertaken as part of a sensitivity analysis by Professor Tom Coulthard (University of Hull).

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary outputs for the project will be an analysis of results from previously unpublished experiments (concentrated flume), which will be used to assist 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)

Evans KG & Proudfoot M 2017. Tin Camp Creek Mica schist site concentrated flow study prepared for the Department of the Environment and Energy – Supervising Scientist by EnviroConsult, Darwin, 32 pages.

Project details			
Project title	Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to the rehabilitated Ranger mine - Gulungul Creek scale		
SSB function	Research	Site	Ranger
Project category	Demonstrating achievement of closure criteria	Project status	Completed
What business need does this project inform?	This project will provide confidence in landform model predictions of suspended sediment output - specifically, verifying that model predictions reflect actual measured / monitored observations at a catchment scale.		
Key Knowledge Needs (KKN)	LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?		
Closure criteria theme (if applicable)	Landform	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2016-002	Project commencement date	01/07/2016
		Revised completion date	30/06/2018
Project duration (months)	6	Date required	30/06/2018
In-house or outsourced	Collaboration	Actual completion date	30/06/2018
Lead team	R&L	Reason for project delay (where applicable)	Masters project unable to satisfactorily answer questions. In addition, results of Masters project identified more questions that needed to be addressed.
Supporting team(s)	Professor Ken Evans, CDU; Associate Professor Greg Hancock, University of Newcastle		
Project manager	Lowry, John	Project total estimated internal resources (person weeks)	8
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	20

Aims

- To calibrate and validate the CAESAR-Lisflood model outputs of suspended sediment load at the catchment scale.

Background

This 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. Refinement of the model will assist in improved accuracy in assessing impacts arising from the transport of suspended sediment on the on-site and off-site environment. This project was intended to be undertaken by a Masters-by-coursework student at Charles Darwin University, supervised by Professor Ken Evans. However, while two students attempted to undertake the project, neither student was able to address the objectives fully. Consequently, in 2017-18 the project was undertaken as a contract by Associate Professor Greg Hancock at the University of Newcastle.

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 thesis for a Masters of Engineering has been submitted, assessed and passed. However, the results of this study and a subsequent 4th-year Engineering project in 2016-17 were not able to address the project objectives fully.
- Consequently, calibration of the model was undertaken as a contract by University of Newcastle in May 2018.
- The project was completed by the University of Newcastle in June 2018 with the submission of a report documenting the methods used to calibrate the model, and initial simulation results.

Key findings

- The CAESAR model successfully modelled (with qualification) both discharge and sediment loads in Gulungul Creek
- The model can be reliably used to assess discharge from storm events. However, running the model at high DEM resolution (i.e. 10 m) is not practical for centennial to millennial time scale modelling.
- High quality long-term discharge and sediment data are needed for the continued calibration and validation of the model.
- It is recommended that multiple pluviographs be installed across the catchment to better quantify rainfall.

Workplan for 2018-19

- Not applicable. This project concluded on 30 June 2018.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Revised / enhanced parameter sets for measuring modelled suspended sediment loads from the CAESAR-Lisflood model.
- A completed Masters thesis.
- Report from University of Newcastle detailing methods and results of study.
- 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

- Input into relevant technical working group discussions relating to rehabilitation of Ranger mine.
- Conference proceedings or peer-reviewed journal paper.

Project publications to date (if applicable)

Ao, Xinsike 2017. Calibrating the CAESAR landform evolution model for application to rehabilitation reconstruction at Ranger Mine NT, unpublished Masters thesis, Charles Darwin University.

Submission of a report from the University of Newcastle detailing methods and results of study.

Project details					
Project title	Model the geomorphic stability of the Ranger final conceptual landform for up to 10,000 years				
SSB function	Research	Site	Ranger		
Project category	Demonstrating achievement of closure criteria	Project status	Active		
What business need does this project inform?	Provision of a rigorous scientific basis for the assessment of the geomorphic stability of the conceptual final landform, ensuring erosion characteristics similar to comparable landforms in surrounding undisturbed areas and containment of tailings for at least 10,000 years.				
Key Knowledge Needs (KKN)	LAN3D. What are erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, timeframe, groundwater expression and effectiveness of mitigations)?				
Closure criteria theme (if applicable)	Landform	Relevance	2	Time-frame	1
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2017-010	Project commencement date	31/01/2018		
		Estimated completion date	31/12/2018		
Project duration (months)	18	Date required	31/12/2018		
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)	Tom Coulthard, University of Hull; Greg Hancock, University of Newcastle				
Project manager	Lowry, John	Project total estimated internal resources (person weeks)	27		
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	35		

Aims

- To assess the geomorphic stability of the rehabilitated final landform for a simulated period of 10,000 years under a range of modelled scenarios, including extreme wet and dry climate scenarios.

Background

The project aims to assess the geomorphic and erosional stability of the final Ranger conceptual rehabilitated landform for a period of 10,000 years. A key element of the project is incorporating and modelling the range of climate / rainfall extremes that may be expected to occur over 10,000 years. Information needs relevant to the different climate / rainfall regimes includes identifying and determining the potential size and distribution of gullies on the landform; the composition (bedload, suspended sediment), volume and distribution of sediment transport; and the effects of weathering and different surface covers that may result through these scenarios. Modelling will be principally undertaken using the CAESAR-lisflood Landform Evolution Model (LEM), supported and supplemented by the SIBERIA LEM, which will be run separately to validate and assess CAESAR-Lisflood results.

A wholly desktop exercise, this project will model a series of agreed scenarios associated with long term rainfall predictions, weathering and surface cover. This project is a successor to the preceding project that modelled earlier versions of the landform. Specifically, this project focuses on modelling the 'definitive' conceptual landform and integrates different modelling components developed and implemented in earlier projects.

Progress against plan

- Modifications and enhancements to the CAESAR-Lisflood model have been undertaken. These include completion of uncertainty analysis, modelling of sub-surface layers and enhancement to the vegetation component through updating / revising the shear stress parameter.

Key findings

- Not yet applicable - final landform not yet received.

Workplan for 2018-19

July-November 2018:

- Model landform using plausible worst case rainfall and surface cover scenario for simulated period of 10,000 years in CAESAR-Lisflood.

October 2018:

- Model landform using plausible worst case rainfall and surface cover scenario for simulated period of 10,000 years in SIBERIA.

November 2018:

- Report to ARRTC assessment results for geomorphic stability of the conceptual final landform.

November-December 2018:

- Report to ERA assessment results for the geomorphic stability of the conceptual final landform.
- Journal papers and conference paper on 10,000 year assessment of final landform.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A long-term (10,000 year) assessment of the geomorphic stability of the conceptual rehabilitated landform of the Ranger mine ie whether tailings will be exposed and if erosion will return to background rate within the long-term timeframe.
- Peer-reviewed journal papers and conference presentations / proceedings describing the processes involved in the long-term modelling used to assess the final landform, including the use of the CAESAR-Lisflood and SIBERIA LEMs.

The outcomes of this project include:

- An optimum landform design with respect to erosional stability and geomorphic impact on the surrounding catchments, which is able to incorporate the potential impact of extreme climate events and the weathering / evolution of the landform surface.
- Confidence that the CAESAR-Lisflood model is a successful tool for assessing the long term stability of a rehabilitated landform.

Planned communication activities

- Research papers published in international and peer-reviewed scientific journals.
- Key findings published in Annual Technical Report.
- Formal report for ERA assessing the long-term stability of the final conceptual landform.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

No publications have been produced by this project yet. The related precursor project resulted in the following publications:

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 & Dever C 2016. Surface disturbance and erosion by pigs – a medium term assessment for the monsoonal tropics. *Land Degradation and Development*. DOI: 10.1002/ldr.2636.
- 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, Verdon-Kidd D & Lowry JBC 2017. Sediment output from a post-mining catchment – Centennial impacts using stochastically generated rainfall. *Journal of Hydrology*, 544 pp180-194.
- 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

Project details					
Project title	Weathering of Ranger waste rock to inform landform evolution model predictions				
SSB function	Research	Site	Ranger		
Project category	Demonstrating achievement of closure criteria	Project status	Active		
What business need does this project inform?	Determine the weathering rates of Ranger waste rocks and use these rates to calibrate and enhance the CAESAR-Lisflood landform evolution model.				
Key Knowledge Needs (KKN)	LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?				
Closure criteria theme (if applicable)	Landform	Relevance	2	Time-frame	1
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2017-013	Project commencement date	01/09/2017		
		Revised completion date	10/12/2018		
Project duration (months)	12	Date required	30/06/2018		
In-house or outsourced	Internal	Actual completion date	N/A		
Lead team	R&L	Reason for project delay (where applicable)	Higher priorities		
Supporting team(s)	N/A				
Project manager	Saynor, Mike	Project total estimated internal resources (person weeks)	5		
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	0		

Aims

- To determine weathering rates of chlorite schist and pegmatite characteristic of Ranger mine waste rock.

Background

Early work conducted in the 1980s at the Ranger mine suggested that some of the waste rocks break down rapidly, thus creating at a relatively early stage, a rudimentary soil. In contrast, observations over the 20 years at Ranger suggest that the rocks that break down rapidly are a small proportion of those represented in waste rock. Associated studies simulating weathering of chlorite schist and pegmatite over a long time frame show that weathering takes place over decadal time scales.

In 1998, chlorite schist and pegmatite material were sampled from waste rock dumps on-site to determine how the material weathers over the long term. These rocks have been in-situ on the roof of the Jabiru Field Station for 20 years, exposed to natural sunlight and rainfall, and have been measured for their mass annually. Control samples have also been stored in a laboratory controlled environment for the same period of time, but have not been measured to date.

This project focuses on data analysis of the measurements and photographic records obtained over the 20 year period to determine weathering rates for chlorite schist and pegmatite, albeit in the absence of biological processes (including growth of vegetation) that accelerate weathering. The control samples will also be measured. If available, XRD and XRF analyses of both the exposed and control samples will be undertaken to determine differences in mineralogy and elements due to weathering. The derived weathering rates will be incorporated into the weathering function of the CAESAR-Lisflood model thereby enhancing the predictive capacity of the model.

Progress against plan

- Rocks have been weighed nearly annually since 1998.
- Control rocks are stored in the R&L laboratory.

Key findings

- Measurements made of the exposed rocks in 2017 indicate that the rocks are still largely competent with some evidence of weathering. However, the weathering is not as rapid as indicated by Milnes et al 1986.
- Observations of rocks on the trial landform over nine wet seasons still show competent rock with minimal weathering though no in-situ measurements have been made.

Workplan for 2018-19

- Conduct XRF analysis on rocks (exposed and control).
- Submit a Journal paper detailing the weathering results.
- Incorporate weathering rates into the use of CAESAR-Lisflood model.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Provision of information on weathering rates of chlorite schist and pegmatite for the Ranger mine site.
- Understanding the changes in mineralogy and elements during the weathering process on the Ranger site.
- Incorporation of the weathering rates into the weathering function of CAESAR-Lisflood.

The outcomes of this project include a journal paper on weathering rates and changes to mineralogy and elements of Ranger waste rock.

Planned communication activities

- Journal publication.
- Presentations and discussions with the relevant technical working group for Ranger rehabilitation and ARRTC.

Project publications to date (if applicable)

Smith B, Saynor M & Evans K 2003. Weathering rates of waste rock from ERA Ranger mine – initial results. Internal Report 464, December, Supervising Scientist, Darwin, Unpublished paper.

Wells T, Binning P & Willgoose G 2005. The role of moisture cycling in the weathering of a quartz chlorite schist in a tropical environment: findings of a laboratory simulation. *Earth Surface Processes and Landforms* 30 (4), 413-428.

Project details					
Project title	Assessing the impact of groundwater discharge on landform stability				
SSB function	Research	Site	Ranger		
Project category	Demonstrating achievement of closure criteria	Project status	Completed		
What business need does this project inform?	This project informs the long-term stability of a rehabilitated landform by providing an initial assessment of the likelihood that groundwater discharge provides a mechanism for erosion of the Ranger final landform, including where and under what conditions this may occur.				
Key Knowledge Needs (KKN)	LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?				
Closure criteria theme (if applicable)	Landform	Relevance	2	Time-frame	1
		Project Priority	Importance	2	Time buffer
Project number (if allocated)	RES-2017-027	Project commencement date	01/03/2018		
		Estimated completion date	30/06/2018		
Project duration (months)	3 months	Date required	30/06/2018		
In-house or outsourced	Collaboration	Actual completion date	02/08/2018		
Lead team	R&L	Reason for project delay (where applicable)	N/A		
Supporting team(s)	Centre for Mined Land Rehabilitation, The University of Queensland				
Project manager	Lowry, John	Project total estimated internal resources (person weeks)	2		
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	6		

Aims

- To assess if there is potential for ground water discharge to cause erosion or instability in the final rehabilitated landform in areas where break of slope occurs.

Background

Landform stability has the potential to be compromised by both surface and groundwater discharge. Groundwater infiltrating into and flowing through the final landform may express at various points: (i) where there is a change (or ‘break’) in the slope of the surface of the landform; (ii) at the interface between highly permeable layers and compacted layers within the landform; and (iii) at the interface between the constructed landform and the natural Koolpinyah Surface. Depending on a number of factors (e.g. flow rate, slope, waste rock particle size distribution and extent of consolidation, etc.), erosion and gully formation may occur at and downstream of these points of expression.

Two concerns therefore arise:

1. Where there are changes in topographic gradient on the landform surface, will the volume and velocity of the water moving through the landform result in “break of slope” erosion?
2. Due to the relatively impermeable nature of the Koolpinyah Surface and potentially other compacted layers within the landform, will the volume and velocity of the water moving through and out of the landform at this surface result in ‘cavitation’ along the margins of the landform, i.e. within the landform or outside or both, resulting in instability and heightened erosion?

The objective of this work is to provide an initial assessment of the likelihood of these mechanisms of erosion occurring on the Ranger final landform.

Progress against plan

- This project is complete.
- A contract was awarded to CMLR to investigate the potential effect of groundwater discharge on landform stability in April.
- A draft report was submitted by CMLR in June 2018.
- A final report was received from CMLR on 2 August 2018.

Key findings

- The report prepared by CMLR concludes that there is a risk of seepage erosion occurring on the final landform at the Ranger mine site at the toe of the landform where it meets the Koolpinyah surface.

Workplan for 2018-19

- Not applicable as this project concluded on 30 June 2018. The final report was received on the 2nd August.

Planned project outputs and associated outcomes

The primary outputs for the project will be the summary consultants report identifying if break of slope may occur on the landform, and potential effects of groundwater expression on landform stability – in particular erosion, gully formation and sediment transport.

The outcomes of this project include enhanced understanding of effects of how groundwater may impact on surface erosion, sediment transport and stability of the final rehabilitated landform.

Planned communication activities

- The completed consultants report will be used to inform future project workplans and proposals.

Project publications to date (if applicable)

Pagliero L, Baumgartl T & McIntyre N (2018). Potential of the risk of erosion due to groundwater expression on a rehabilitated mine landform, Report prepared for the Department of the Environment and Energy – Supervising Scientist, by the Sustainable Minerals Institute - Centre for Mined Land Rehabilitation at the University of Queensland, 38 pages.

Project details					
Project title	Calibrating sediment outputs for the CAESAR model using sediment load data from the trial landform				
SSB function	Research	Site	Ranger		
Project category	Developing closure criteria	Project status	Active		
What business need does this project inform?	Provision of a rigorous scientific basis for the assessment of the geomorphic stability of the conceptual final landform, ensuring erosion characteristics similar to comparable landforms in surrounding undisturbed areas and containment of tailings for at least 10,000 years.				
Key Knowledge Needs (KKN)	LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?				
Closure criteria theme (if applicable)	Landform	Relevance	1	Time-frame	1
		Project Priority Importance	1	Time buffer	A
Project number (if allocated)	RES-2010-007	Project commencement date	01/07/2017		
		Estimated completion date	30/12/2018		
Project duration (months)	24	Date required	30/06/2019		
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)	13		
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	0		

Aims

- To assess the accuracy and reliability of CAESAR-Lisflood model simulations by comparing model outputs - specifically predictions of suspended sediment load and bedload - with field measurements for the same variables over comparable time periods.

Background

The landform modelling techniques will focus on the use of the CAESAR-Lisflood model which has been specifically modified to work at the erosion plot scale. Suspended sediment data collected on the landform over a period of five years will be used to calibrate the model results by comparing simulated results with observed field measurements of erosion on the trial landform. While field data on suspended sediment were collected between 2009 and 2014, only recently has it been possible to compile the data in a manner suitable to be used to calibrate model outputs.

Progress against plan

- Calibration of the CAESAR-Lisflood was completed in June 2018, with testing showing a good correspondence between model prediction and measured outputs.
- Suspended sediment samples have been collected and analysed in the laboratory. The turbidity data have been cleaned and, where possible, a suspended sediment turbidity relationship developed. In other cases, regression and averages have been used to estimate suspended sediment data for occasions when water was flowing over the flumes. Suspended sediment has been determined only for erosion plot 1, which is the most representative plot for Ranger rehabilitation (ie waste rock, tube-stock treatment).
- Reporting of the suspended sediment analyses will be undertaken in 2018-19. The bed load component of the project has been completed with a conference presentation and publication.

Key findings

- This project found good agreement between field and modelled outputs from the trial landform for periods up to five years.

Workplan for 2018-19

- A draft report is being prepared for external publication.

Planned project outputs and associated outcomes

The primary outputs for the project are a QA/QC'd suspended sediment data set that can be used to calibrate the erosion modelling.

The outcomes of this project include calibration of the landform evolution modelling used to assess the final landform.

Planned communication activities

- A research paper published in an international and peer reviewed scientific journal on the suspended sediment data arising from erosion plot 1 on the Trial landform.
- Key findings published in Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

- Lowry J, Saynor M & Erskine W 2015. A multi-year assessment of landform evolution model predictions for the Ranger trial landform. Internal Report 633, February, Supervising Scientist, Darwin.
- Lowry J, Saynor M, Erskine W, Coulthard T and Hancock G 2014. A multi-year assessment of landform evolution predictions for a trial rehabilitated landform, in Proceedings of the Life-of-Mine 2014 Conference, 16–18 July 2014, Brisbane Australia. Australasian Institute of Mining and Metallurgy, pp. 67–80.
- 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.
- Saynor MJ & Erskine WD 2016. Bed Load losses from Experimental Plots on a Rehabilitated Uranium Mine in Northern Australia. Life-of-Mine 2016, Brisbane, Australasian Institute of Mining and Metallurgy.

Project details			
Project title	Model the geomorphic stability of the pre-mine landform for up to 10,000 years		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Completed
What business need does this project inform?	Calibration of the CAESAR-Lisflood landform evolution model for different surfaces, i.e. pre- and post-mine.		
Key Knowledge Needs (KKN)	LAN3D. What are erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, timeframe, groundwater expression and effectiveness of mitigations)?		
Closure criteria theme (if applicable)	Landform	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2015-017	Project commencement date	01/07/2015
		Revised completion date	30/06/2018
Project duration (months)	6	Date required	30/06/2018
In-house or outsourced	Collaboration	Actual completion date	30/06/2018
Lead team	R&L	Reason for project delay (where applicable)	Unable to find appropriate external student collaborator with whom to commence project.
Supporting team(s)	CDU - Professor Ken Evans and Dr Monishka Narayan, University of Newcastle - Dr Greg Hancock		
Project manager	Lowry, John	Project total estimated internal resources (person weeks)	3
Project sponsor	Bartolo, Renee	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

This desktop 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 assess how the landscape may evolve without the presence of the mine. Specifically, they will provide information on the topographic and erosion characteristics of the pre-mine landform that could be used to inform the design of the post-mine landform. In addition, understanding how the undisturbed, pre-mine landform may evolve under a range of extreme scenarios will improve confidence in the ability of landform evolution models to predict the evolution of the final rehabilitated landform for extended time periods of up to 10,000 years.

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.

This project was originally conceived as a potential collaborative honours project that could be undertaken by a student at Charles Darwin University using the CAESAR-Lisflood landform evolution model. However, no students were available. Subsequently a post-doctoral research fellow undertook this work as part of their research program.

The Supervising Scientist involvement was limited to providing advice and support in applying the landform evolution models and collaborating on updating parameter input values.

Progress against plan

The project concluded on 30 June 2018 with the completion of the following tasks:

- 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 representing the surface characteristics have been revised and enhanced for modelling conditions representing both disturbed (post-mine) and undisturbed (pre-mine) landforms.
- Simulations for a period of 1,000 years have been modelled 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 (IR647) has been completed.
- A presentation was made at the 2018 Life of Mine Conference in Brisbane.
- A paper has been submitted to the journal *Geomorphology* summarising the findings of the project.

Key findings

- Landform modelling simulations of a pre-mining landscape using the same 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. Thus, as expected, the post-mining rehabilitated landform produces more erosion.
- These results are attributed to differences in the topographical (including consolidation) 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 2018-19

- Not applicable. The project was completed in 2017-18.

Planned project outputs and associated outcomes

The primary output for the project is a conference or journal paper on comparing evolution of pre-and post-mining landforms.

The outcomes of this project include:

- 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

- Conference presentation or journal submission.
- Contribution to relevant stakeholder groups.

Project publications to date (if applicable)

Lowry J, Narayan M, Evans K & Hancock G 2017. Utilising landform evolution models to assess the long-term stability of pre- and post-mining landforms. Internal Report 647, Darwin, NT.

Lowry JBC, Narayan M, Evans KG, Saynor MJ & Hancock GR 2018. Using an undisturbed landform to calibrate long-term predictions of the evolution of a rehabilitated landform. In Proceedings of the Life of Mine 2018 Conference, Brisbane 25-27 July 2018, Australian Institute of Mining and Metallurgy, pp 133-137

Project details			
Project title	Development of a method for monitoring gully formation on the rehabilitated landform using stereopsis and LiDAR		
SSB function	Research	Site	Ranger
Project category	Monitoring of closure criteria	Project status	Active
What business need does this project inform?	Provision of a rigorous scientific basis for the assessment of rehabilitation planning, specifically assessment of the stability of the final landform.		
Key Knowledge Needs (KKN)	LAN4A. How do we optimise methods to measure gully formation on the rehabilitated landform?		
Closure criteria theme (if applicable)	Landform	Relevance	1
		Time-frame	2
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2017-005	Project commencement date	01/12/2017
		Estimated completion date	01/11/2019
Project duration (months)	20	Date required	30/03/2020
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)	30
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	0

Aims

- To develop a RPAS (remotely piloted aircraft system) based method to identify and monitor gully formation on the final landform.
- To test and compare methods for assessing gully formation through the capture of Digital Elevation Models (DEMs) from both LiDAR and optical sensors.
- To determine the accuracy of the RPAS derived DEMs in assessing gully formation.

Background

There will be a requirement to monitor and assess erosion and gully formation for landform closure criteria. It is critical that gully formation does not occur over tailings in mine pits and the tailings are not exposed. Given the size of the final rehabilitated landform, RPAS (remotely piloted aircraft systems), commonly referred to as drones, are a useful tool to monitor and assess gully formation at such a scale.

The Supervising Scientist Branch has various RPAS that produce digital elevation data at spatial accuracies suitable for measuring gully formation. Most recently, we acquired a LiDAR, and we have been able to generate DEMs derived from SfM (structure from motion) techniques using optical sensors for gullies located near the South Alligator River Valley containment facility. The increasing accuracies with these technologies and the ease of obtaining data, make this a valuable monitoring tool.

This project will focus on the area located adjacent to the South Alligator River Valley containment facility, where there is known gully formation. The site enables us to develop methodologies that can be applied to monitoring the final landform at Ranger and elsewhere in the region.

Progress against plan

- LiDAR flights were completed in December 2017 and June 2018 of the area around the South Alligator Valley Containment. Data have been processed from both flights. Data comparisons have not yet commenced.

Key findings

- There are no key findings to report.

Workplan for 2018-19

- Undertake UAV flights over the gullies adjacent to the South Alligator containment facility before and after the 2018-2019 wet season.
- Process RPAS data to detect and measure gullies; determine changes to the gully dimensions as a result of the 2018-2019 wet season; and compare 2018-2019 data with 2017-18 wet season results.

Planned project outputs and associated outcomes

The primary output for the project is a RPAS-based method for monitoring gully formation on the rehabilitated landform.

The outcomes for this project include the development of a robust and cost effective method suitable for detecting and assessing gully development on the rehabilitated landform.

Planned communication activities

- A research paper published in an international and peer reviewed scientific journal on gully determination using RPAS LiDAR.

- Key findings published in Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

No project publications to date.

Ranger – Rehabilitation

CC theme: Radiation (4 projects)

Project details					
Project title	Dose rates to non-human biota				
SSB function	Research	Site	Ranger		
Project category	Demonstrating achievement of closure criteria	Project status	Completed		
What business need does this project inform?	Protecting the environment of the Alligator Rivers Region from the effects of radiation associated with uranium mining.				
Key Knowledge Needs (KKN)	RAD6B. What are the whole-organism concentration ratios of uranium and actinium series radionuclides in wildlife represented by the representative organism groups?				
Closure criteria theme (if applicable)	Radiation	Relevance	2	Time-frame	1
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2012-002	Project commencement date	01/07/2012		
		Revised completion date	30/06/2018		
Project duration (months)	24	Date required	30/12/2018		
In-house or outsourced	Collaboration	Actual completion date	30/06/2018		
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)	40		
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	8		

Aims

- To derive factors to convert radionuclide activity concentrations in specific tissues to whole organism values.
- To derive concentration ratios between radionuclide activity concentrations in wildlife (whole organism) and those in soil and water.
- To derive soil and water radiological quality guideline values for wildlife.

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 purpose of this 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 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

- Factors to convert radionuclide activity concentrations in specific tissues to whole organism values have been derived and published.
- Concentration ratios between radionuclide activity concentrations in wildlife (whole organism) and those in soil and water have been derived and submitted for publication.
- A soil radiological quality guideline value for terrestrial wildlife protection has been derived and published.
- A water radiological quality guideline value for freshwater wildlife protection has been derived and submitted for publication.

Key findings

- A guideline value of 1000 Bq/kg of radium-226 in surface waste rock would ensure radiation protection of terrestrial wildlife.
- A guideline value of 14 mBq/l of radium-226 in water would ensure radiation protection on freshwater wildlife.

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Factors to convert radionuclide activity concentrations in specific tissues to whole organism values.

- Concentration ratios between radionuclide activity concentrations in wildlife (whole organism) and those in soil and water.
- Soil and water radiological quality guideline values for radiation protection of wildlife.

The outcomes of this project include public and regulator assurance that the final landform will meet the rehabilitation standard for radiation protection of the environment.

Planned communication activities

- Research papers published in international and peer reviewed scientific journals.
- Key findings published in Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

Doering C, Carpenter J, Orr B & Urban D. Whole organism concentration ratios in freshwater wildlife from an Australian tropical U mining environment and the derivation of a water radiological quality guideline value. *Journal of Environmental Radioactivity*, submitted.

Doering C, Medley P, Orr B & Urban D 2018. Whole organism to tissue concentration ratios derived from an Australian tropical dataset. *Journal of Environmental Radioactivity* 189, 31-39.

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.

Project details			
Project title	Atmospheric dispersion of radon and radon daughters from the Ranger rehabilitated landform		
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 resident Aboriginal people and other members of the regional community from potential exposures to radiation.		
Key Knowledge Needs (KKN)	RAD6A. What are the representative organism groups that should be used in wildlife dose assessments for the rehabilitated site?		
Closure criteria theme (if applicable)	Radiation	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2014-004	Project commencement date	01/01/2016
		Revised completion date	31/03/2018
Project duration (months)	24	Date required	31/12/2018
In-house or outsourced	Collaboration	Actual completion date	30/06/2018
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)	20
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	8

Aims

- To model the atmospheric dispersion of radon-222 from the Ranger final landform.
- To develop maps of radon progeny dose potential for people located in the vicinity of the final landform.

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 includes 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 activity concentration 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

- Maps of radon-222 dispersion out to 10 km from the final landform have been developed.
- Estimates of radon-222 pathway dose have been made for potential exposure scenarios.
- A research paper describing the modelling methods and results has been published in *Journal of Environmental Radioactivity*.

Key findings

- There is a higher radon dose potential within 10 km of the final landform during the dry season due to higher exhalation flux densities from waste rock.
- The radon dose potential is highest along the prevailing wind direction, which, in the dry season, is towards west-northwest.

Workplan for 2018-19

N/A

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Contour maps of radon-222 dispersion from the Ranger final landform.
- Estimates of potential radon progeny dose to the public from the final landform.

The outcomes of this project include public and regulator assurance that the final landform will meet the rehabilitation standard for radiation protection of the public.

Planned communication activities

- A research paper published in an 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 at conferences and/or workshops.

Project publications to date (if applicable)

Doering C, McMaster SA & Johansen MP. Modelling the dispersion of radon-222 from a landform covered by low uranium grade waste rock. Journal of Environmental Radioactivity 192, 498–504.

Project details					
Project title	Modelling the atmospheric dispersion of radionuclides in dust from the Ranger final 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 resident Aboriginal people and other members of the regional community from potential exposures to radiation.				
Key Knowledge Needs (KKN)	RAD4B. What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?				
Closure criteria theme (if applicable)	Radiation	Relevance	2	Time-frame	1
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2017-025	Project commencement date	01/03/2018		
		Estimated completion date	31/12/2018		
Project duration (months)	10	Date required	30/06/2018		
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	McMaster, Scott	Project total estimated internal resources (person weeks)	12		
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	0		

Aims

- To model the wet and dry season dispersion of radionuclides in dust from the Ranger final landform.
- To develop wet and dry season dose rate contour maps for radionuclides in dust.
- To conduct sensitivity analysis on dispersion modelling inputs to identify which parameters most strongly influence radiation dose rates from dust inhalation.

Background

The inhalation of radionuclides in dust represents one of the potential radiation exposure pathways to the public from the Ranger final landform. The above-background dose to the public from radionuclides in dust needs to be estimated to determine whether the sum of the dose from all exposure pathways is above or below the statutory dose limit of 1 mSv in a year.

Progress against plan

- Mass loadings of airborne dust derived from high volume air sampling data.
- Modelling the dispersion of radionuclides in dust from the final landform completed.
- Research paper in draft.

Key findings

- Dust dispersion is primarily governed by wind direction and speed.
- Dust inhalation does not represent a significant radiation exposure pathway to the public from the Ranger final landform.

Workplan for 2018-19

July 2018:

- Develop wet and dry season dose rate contour maps for radionuclides in dust based on dispersion modelling results.

August 2018:

- Investigate the influence of model inputs on dispersion modelling results through sensitivity analysis.

September-December 2018:

- Draft research paper on modelling methods and results.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Contour maps of dust dispersion from the Ranger final landform.
- Estimates of potential dose to the public from radionuclides in dust arising from the final landform.

The outcomes of this project include public and regulator assurance that the final landform will meet the rehabilitation standard for radiation protection of the public.

Planned communication activities

- A research paper published in an 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 at conferences and/or workshops.

Project publications to date (if applicable)

No project publications to date.

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 resident Aboriginal people and other members of the regional community and protecting the environment of the Alligator Rivers Region from the effects of radiation associated with uranium mining.				
Key Knowledge Needs (KKN)	RAD5A. What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?				
Closure criteria theme (if applicable)	Radiation	Relevance	2	Time-frame	1
		Project Priority Importance	2	Time buffer	A
Project number (if allocated)	RES-2015-014	Project commencement date	1/2/2015		
		Estimated completion date	1/2/2021		
Project duration (months)	72	Date required	30/6/2018		
In-house or outsourced	Collaboration	Actual completion date	N/A		
Lead team	ENRAD	Reason for project delay (where applicable)	N/A		
Supporting team(s)	ANU				
Project manager	Doering, Che	Project total estimated internal resources (person weeks)	40		
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	100		

Aims

- To develop methods to prepare and measure environmental samples for actinium-227 (Ac-227) and protactinium-231 (Pa-231).
- To measure Ac-227 and Pa-231 in environmental samples and determine concentration ratios between the activity concentration in biota and that in soil or water.

- To estimate radiation dose contributions to people and wildlife from Ac-227 and Pa-231.

Background

Although a significant body of research has been undertaken on the behaviour of radionuclides of the uranium decay series in the environment, there is very little information for actinium decay series radionuclides, partly because techniques for measurement of two key isotopes in the actinium decay series – Pa-231 and Ac-227 – are limited and prone to technical difficulties (particularly in the chemical separation steps). It is also argued that the activity concentration of U-235, at the head of the actinium decay series, is ~20 times below that of U-238 for natural uranium and therefore presents fewer radiological risks. However, Ac-227 dose coefficients are typically higher than those for the uranium decay series radionuclides, with ingestion dose coefficients similar to those of Po-210, 1.6 times higher than Pb-210 and 4 times higher than Ra-226. Inhalation dose coefficients for both Ac-227 and Pa-231 are higher than those for Po-210, Pb-210 and Ra-226 even after taking into account the relative abundances of the parents of the different decay series. Uranium mining and milling may significantly increase the mobility of radionuclides in both the uranium and actinium decay 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 wildlife.

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 PhD project involves research into techniques for measurement of environmental concentrations of Pa-231 and Ac-227, and the potential mobility of these isotopes in aquatic and terrestrial environments in the vicinity of the Ranger mine.

Progress against plan

- Method developed for preparation of a Pa-233 tracer for determining the recovery efficiency of Pa-231 in environmental samples undergoing radiochemistry processing.
- Calibration of Ac-227 tracer solution completed and the solution used to validate an extraction chromatography method for Ac-227 separation.
- Preliminary testing of a liquid scintillation counting method for Ac-227 measurement undertaken.
- Preliminary testing of a lanthanide hydroxide precipitation technique for alpha spectrometric measurement of Ac-227 started. Initial results presented at RACI National Congress, July 2017.
- Testing of Pa-231 separation method started. Only limited success in preliminary testing. However, there was sufficient separation from the gross sample matrix to enable a single measurement of a mussel from Mudginberri billabong.

- Paper presented at the 14th International Conference on Accelerator Mass Spectrometry. Manuscript accepted for publication in the conference proceedings reporting development of Pa-233 tracer, injection of PaO₂ and activity concentration result for a mussel from Mudginberri Billabong.

Key findings

- The use of liquid scintillation 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 Alligator Rivers Region to enable the use of current sample preparation methods for analysis of Pa-231.
- Newly published research provides evidence that a recently developed chromatography resin, TK400 from Triskem International, is suitable for separation of Pa without the use of HF that may provide a suitable alternative to the Pa separation method being tested for the project.

Workplan for 2018-19

July -October 2018:

- Calibration of alpha spectrometer and/or liquid scintillation counters for measurement of Ac-227, including assessment of potential for chamber contamination and the use of Mylar thin film to prevent contamination.

July 2018-December 2019:

- Development of sample preparation protocols for samples requiring measurement of Ac-227 and Pa-231.

July 2018-June 2019:

- Continuing Calibration of the Accelerator Mass Spectrometer for measurement of Pa-231.

September 2018-June 2019:

- Measurement of Ac-227 in selected samples using alpha spectrometry.

October 2018 – February 2019:

- Testing of UTEVA and Triskem AK400 resins for radiochemical separation of Pa without the use of HF.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- New radiochemistry and measurement techniques for Ac-227 and Pa-231 in environmental samples.
- Data on Ac-227 and Pa-231 activity concentrations in animals, plants, soil and water.
- Concentration ratios for Ac-227 and Pa-231 in bush foods and wildlife.
- Estimates of radiation doses to people and wildlife from Ac-227 and Pa-231.

The outcomes of this project include:

- An evidence-based understanding of the radiological importance of actinium-series radionuclides in the Ranger rehabilitation context.
- Public and regulator assurance that the final landform will meet the rehabilitation standards for radiation protection of the public and the environment.

Planned communication activities

- Research papers published in international and peer reviewed scientific journals.
- Key findings published in Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

Medley P, Tims S, Froehlich MB, Fifield LK, Bollhöfer A, Wallner A & Pavetich S (2018). Development of ²³¹Pa AMS measurements to improve radiological dose assessment from uranium mining and milling. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms. (In Press).

Ranger – Rehabilitation

CC theme: Ecosystem restoration (12 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.		
Key Knowledge Needs (KKN)	EE5B. How can we develop vegetation community trajectories to predict when the rehabilitated site will move to a sustainable vegetation community without further management intervention (including different fire and weed scenarios)?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	3
		Project Priority	
		Importance	3
		Time buffer	D
Project number (if allocated)	RES-2013-002	Project commencement date	01/09/2013
		Estimated completion date	30/06/2018
Project duration (months)	24	Date required	01/01/2023
In-house or outsourced	Collaboration	Actual completion date	N/A
Lead team	R&L	Reason for project delay (where applicable)	Other priorities have delayed 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

- To develop a timeline of landscape disturbances and change for Kakadu National Park, and in particular, the Ranger lease area (1950–2016).
- To characterise vegetation change for a ‘stable’ temporal envelope (1996–2016) using the aerial photography record.
- To characterise vegetation recovery using the aerial photography record, (a) immediately post the Brucellosis and Tuberculosis Eradication Campaign (BTEC) (from 1996), and (b) post Cyclone Monica (from 2006).
- To 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 reference sites informing closure criteria for 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 that enable closure criteria and assessment of their achievement to be undertaken. 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 more complete ecosystem dynamics. A landscape approach, such as deriving measures from time series remote sensing, provides a full 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.

This project will provide an envelope of variability, or trajectory, in setting closure criteria and will 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 region, both temporally and spatially. This variability is likely attributed to the presence of disturbance agents including fire, feral water buffalo (both presence and eradication) and extreme weather events. Closure criteria relevant to revegetation, together with monitoring and assessing their achievement, will need to factor in the variability of woody cover in savanna and the impact of disturbance agents.

Workplan for 2018-19

- Finalise external publications.

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

Planned communication activities

- Timeline of landscape change.
- Report to the relevant Closure Criteria Working Groups 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	Ecohydrology and sensitivity of riparian flora (NESP)		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Assessment of the implications to riparian vegetation of groundwater solute expression to Magela and Gulungul Creeks post-decommissioning.		
Key Knowledge Needs (KKN)	EE6A. What concentrations of contaminants from the rehabilitated site will plants be exposed to, including riparian vegetation?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2017-022	Project commencement date	01/03/2018
		Estimated completion date	01/09/2020
Project duration (months)	30	Date required	30/06/2018
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)	Lindsay Hutley (NESP)		
Project manager	Bartolo, Renee	Project total estimated internal resources (person weeks)	16
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	162

Aims

- To use stable isotopes and tritium to age and quantify water sources (soil water, creek water and/or surface and deep groundwaters) used by riparian vegetation within the Magela Creek catchment in the vicinity of Ranger uranium mine.
- To undertake a pot trial to examine the sensitivity of dominant riparian woody species to MgSO_4 .
- To assess the implications to riparian vegetation of groundwater solute expressing to Magela and Gulungul Creeks, and determine the salt tolerances of key riparian species.

Background

Current understanding of ecohydrological properties of Top End vegetation suggests spring-fed monsoon vine forests and riparian vegetation have a high groundwater dependence. Contamination of surface and/or groundwater post-rehabilitation of Ranger mine site could have a potential impact on riparian vegetation and thus stream health.

Pit closure at Ranger mine site is predicted to result in exfiltrating groundwater with high levels of MgSO_4 derived from waste rock. Solute modelling predicts that within 10 years of closure, groundwater may have a MgSO_4 concentration $>3 \text{ mg L}^{-1}$, in excess of desired exposure limits for surface waters. This presents a potential threat to the ecology of Magela Creek for any organisms utilising groundwater sources. This project will focus on risks posed to groundwater dependant ecosystems (GDEs), in particular, riparian vegetation of Magela and Gulungul Creeks.

Environmental isotopes and tritium analysis will be used to quantify groundwater dependence of riparian vegetation in the Ranger Project Area. This knowledge will be coupled with sensitivity testing of common riparian woody species to MgSO_4 to inform a risk assessment of impact from surface and/or groundwater egress of mine-related contaminants.

This project is linked to RES-2018-002 'Effects of groundwater egress to ecological connectivity'.

Progress against plan

- NESP collaborators have held consultation and planning meetings with SSB.
- Identification of species to conduct pot trials (seedling exposures to magnesium sulfate).
- Preliminary pot trials have commenced at the University of Western Australia.

Key findings

- There are no key findings to report.

Workplan for 2018-19

August 2018:

- Vegetation, soil pore water, and surface and groundwater sampling.

July 2018:

- Commence woody species pot trials to examine sensitivity of riparian vegetation to MgSO_4 .

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Comprehensive assessment of riparian vegetation and its groundwater dependence through the aging of groundwater using isotope analysis, and sensitivity to MgSO_4 .

- Data (soil and groundwater) collected from surveys. These data will be stored on the publicly accessible Terrestrial Ecosystem Research Network (TERN) Data Portal.
- Journal publications (tba).
- Conference and workshop presentations (tba).

The key outcome of this project is a catchment specific assessment of risks to environmental values in Magela and Gulungul Creeks associated with solute contamination in groundwater discharge from Ranger uranium mine. Zones identified with a high likelihood of contamination may be selected for long-term monitoring.

Planned communication activities

- Key findings published in the Annual Technical Report and reported to ARRTC and ARRAC.
- Presentations to key stakeholders on request.
- All NESP Northern Australia Environmental Research (NAER) hub generated publications arising from the project will be made freely available on the NAER website.
- Research papers published in peer reviewed scientific journals.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Assessment of available vegetation reference site information for use in ecological restoration at Ranger mine site		
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.		
Key Knowledge Needs (KKN)	EE1A. What are the key characteristics of the terrestrial ecosystems (including riparian) surrounding the RPA, and how do they vary spatio-temporally?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	3
		Project Priority	
		Importance	3
Project number (if allocated)	RES-2014-002	Time buffer	D
Project number (if allocated)	RES-2014-002	Project commencement date	01/02/2014
		Revised completion date	17/08/2018
Project duration (months)	6	Date required	01/10/2018
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, University of Queensland		
Project manager	Bartolo, Renee	Project total estimated internal resources (person weeks)	3
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	25

Aims

- To review available vegetation reference site research undertaken in relation to Ranger mine site.
- To determine appropriate use of the available reference site information for the ecological restoration of Ranger mine site.

Background

In order to meet the Ranger Environmental Requirements (ERs), it is important that ecological restoration of the Ranger mine site is based on an understanding of reference sites in the surrounding area. Research on vegetation reference sites has been undertaken in the past by SSB and ERA using traditional ecological methods, predominantly at the plot scale (i.e. ground-based surveys). Much of this research and data collection has occurred in an area referred to as the ‘Georgetown analogue’ (reference sites), an area of relatively undisturbed land to the south-east of the disturbed mine footprint and assumed in the early 2000s to be representative of the proposed final landform in terms of terrain characteristics, as opposed to the relatively flat lowlands in the surrounding Kakadu National Park.

Datasets compiled from 5 survey efforts conducted since 1979 form the basis for the review of the available reference site information for Ranger mine site. The majority of survey effort has taken place in the last 16 years and is largely focused on the overstorey vegetation (shrubs and trees >1.5m in height) of the ‘Georgetown analogue’ area. To date, the Georgetown reference site data have been used to provide information on overstorey species for planting, relative stem densities and the number of overstorey species expected to be found at the larger (final landform) spatial scale.

This project reviews the use of these reference data for ecological restoration at Ranger mine site, assessing issues of spatial scale, species composition, community structure and relevance of the Georgetown reference sites in relation to the ERs. Ultimately the project will document ‘fitness for purpose’ of the Georgetown reference site data.

Progress against plan

- Available research pertaining to vegetation reference sites that is relevant to Ranger rehabilitation has been collated and catalogued.
- The applicability of the datasets for use in ecological restoration at Ranger mine site was assessed against the following criteria: whether it was collected adjacent to the mine; what type of substrate it occurred on; variability of the landscape topography; fire frequency; distance to water; and, whether there was appropriate imagery available to determine representativeness of the sites to the savanna lowlands on the Koolpinyah surface in the surrounding Kakadu National Park..
- Rarefaction curves for available species data were calculated to inform species numbers that should be present beyond the plots sampled. This information can be used to extrapolate species numbers per vegetation community to the final landform scale.
- Initial attempts have been made to contextualise the high-resolution remote sensing data across the Ranger lease area with the Georgetown reference vegetation community classes. However, due to some of the wetter environments (rainforest and paperbark communities) not occurring in the reference area, the classification accuracy across the broader area was low.

Key findings

- The comprehensive dataset of shrubs and trees (>1.5 m in height) from a 2010 survey of the Georgetown reference sites, which coincided with WorldView-2 imagery, was determined to be the most appropriate for use in ecological restoration at Ranger mine site.
- Provision to ERA of an over-storey species list for revegetation at Ranger mine site.
- The Georgetown reference site vegetation grouped into three vegetation classes on the basis of (Bray-Curtis) similarity and cluster analyses. These three vegetation communities were clearly separated by average distance to waterways, suggesting that underlying water gradients have a strong effect on observed vegetation patterns.
- For selection of overstorey species for revegetation and for meeting the Environmental Requirement relating to ‘similarity to adjacent areas in Kakadu National Park’, the Georgetown data can be used to provide relevant reference measures. These data can also inform rank order of species stem density but this measure and associated ranges per species are better informed by larger landscape-scale measurements.
- The variability in fire regimes in the surrounding Kakadu National Park should be captured through reference sites to provide further guidance for restoration of understorey species. Additionally, the spatial scale of reference sites should be taken into account to enable appropriate scaling to the final landform.

Workplan for 2018-19

- Publication of journal manuscript.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Review of existing reference ecosystem information to determine appropriate use in ecosystem restoration at Ranger.
- Journal publication on the findings of the review described above.
- Scoping and planning for studies on understorey to derive relevant information for closure criteria.

The outcomes of this project include clear guidance on the use of reference site data for informing ecosystem restoration at Ranger mine site, including the identification of key areas where further research is required.

Planned communication activities

- Journal publication on the reference site research review and analysis of existing data using remotely sensed imagery.
- Presentation to ARRTC.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Review of revegetation outcomes arising from historic mine sites in the Alligator Rivers Region		
SSB function	Research	Site	All
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	This project provides information to inform revegetation trajectories on the rehabilitated Ranger mine site.		
Key Knowledge Needs (KKN)	EE5B. How can we develop vegetation community trajectories to predict when the rehabilitated site will move to a sustainable vegetation community without further management intervention (including different fire and weed scenarios)?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
Project number (if allocated)	RES-2016-015	Time buffer	A
Project number (if allocated)	RES-2016-015	Project commencement date	28/11/2016
		Revised completion date	24/08/2018
Project duration (months)	3	Date required	30/06/2018
In-house or outsourced	External	Actual completion date	N/A
Lead team	R&L	Reason for project delay (where applicable)	Internal priorities delayed SSB staff providing references and review of draft manuscript.
Supporting team(s)	Centre for Mined Land Rehabilitation		
Project manager	Bartolo, Renee	Project total estimated internal resources (person weeks)	3
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	11

Aims

- To review research and revegetation trials to date at Ranger mine site in the context of a waste rock substrate.
- To review revegetation methods and outcomes to date (where information is available) for the South Alligator River containment, small sites in the South Alligator River Valley and Pine Creek.
- To review research and revegetation outcomes at Nabarlek.
- To develop a preliminary State and Transition model for Ranger mine site.

Background

Ecosystem restoration closure criteria may take decades to be achieved and the use of a trajectory approach based on a reference ecosystem may be used to determine whether the rehabilitated site is on a secure trajectory to being highly similar to the surrounding environment. Trajectories are applicable to any measurement endpoint that is expected to be reached after a (typically modelled) period of time from initial establishment.

Where short-term achievement is likely, the trajectory provides a management tool to demonstrate to stakeholders that the rehabilitated area is behaving as predicted and is moving through the stabilisation and monitoring phase towards the post-closure phase. Milestones along the path may be selected, with deviations from the milestone triggering mitigating actions. Where a measurement endpoint will not be achieved in the short term, there is a need to model the trajectory carefully, then select points on the modelled pathway that would culminate in the interim agreed criteria. The Alligator Rivers Region (ARR) and near surrounds contains a number of examples of mine site rehabilitation and trajectories with some sites older than 20 years post rehabilitation. These sites can provide valuable lessons on mine site revegetation that may be used in developing a preliminary trajectory for a Eucalypt-dominated ecosystem, such as that which is the target for Ranger mine site.

A state and transition model is a systematic compilation of knowledge about a particular ecosystem, how it responds to natural and anthropogenic factors, and how the system should be managed to achieve the desired targets. In this project, a state and transition model will be developed to derive and communicate a preferred trajectory with identified deviated (and undesired) alternate states. The model will be developed from undertaking a review of grey literature, government documents, workshop materials and journal articles, with the overall goal of understanding the failures and successes of previous and current revegetation, rehabilitation and restoration efforts in the ARR and adjacent areas. More specifically, with a flora-centric vision, characteristics of targets and failures (desired compared with undesired states) will be identified to develop a preliminary Eucalypt-dominated ecosystem state and transition model for Ranger mine site.

Progress against plan

- Literature review completed.
- Preliminary state and transition model completed.
- Journal paper drafted.

Key findings

- Although there is an extensive history of mining in the area, revegetation data across more than 20 mine sites were generally unavailable or unable to be located.
- Deviations from the desired trajectory in the preliminary state and transition model for a Eucalypt dominated ecosystem have been common, with communities in revegetated areas dominated by Acacias in the overstorey and exotic grasses in the ground cover of Rum Jungle, Nabarlek, and the small mines of the South Alligator Rivers Valley. These undesired states lead to a biotic-abiotic positive feedback (high fuel loads–fire cycles).
- The preliminary state and transition model considers only the successional trajectory and management of vegetation. True restoration can only be achieved when fauna has recolonised the rehabilitated area, and is able to use this ‘new’ habitat as it would the surrounding environment

Workplan for 2018-19

- Submit journal paper.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Journal publication.
- Preliminary State and Transition Model for revegetation at Ranger mine site.
- Identification of further research to be undertaken to inform understanding site trajectories.

The outcomes of this project include clear expectations of the pathway to successful revegetation of the Ranger final landform.

Planned communication activities

- Submit journal paper.

Project publications to date (if applicable)

N/A

Project details			
Project title	Deriving species composition and community structure measures for vegetation at an ecologically appropriate scale		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Provision of a rigorous scientific basis for environmental standards and closure criteria for vegetation related to Environmental Requirement 2.2a, i.e. the need to revegetate 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”.		
Key Knowledge Needs (KKN)	EE1A. What are the key characteristics of the terrestrial ecosystems (including riparian) surrounding the RPA, and how do they vary spatio-temporally?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2017-007	Project commencement date	01/10/2017
		Estimated completion date	30/06/2020
Project duration (months)	18	Date required	30/06/2018
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)	Centre for Mined Land Rehabilitation, The University of Queensland, CSIRO		
Project manager	Bartolo, Renee	Project total estimated internal resources (person weeks)	30
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)	130

Aims

- To select and establish vegetation reference plots at an appropriate scale in the natural environment surrounding the mine.
- To use standardised ground survey methods to measure species composition and community structure at reference plots.
- To develop methods to identify terrestrial plant species using Remotely Piloted Air Systems (RPAS).
- To compare RPAS imagery with the ground survey results to validate the use of RPAS.
- To use RPAS where possible to measure species composition and community structure at reference plots.
- To use RPAS where possible to measure species composition and community structure at the landscape scale (up to 1000 hectares).

Background

Over the last few decades, a considerable amount of work has been conducted throughout the Alligator Rivers Region to explore and assess reference communities to serve as targets for the Ranger mine site rehabilitation (see RES-2014-002 ‘Assessment of available vegetation reference site information for use in ecological restoration at Ranger mine site’). Surveys have generally focused on areas close, or adjacent, to the mine lease areas, and have been conducted by a number of different groups. Not surprisingly, there has also been a range of approaches to the design, replication, plot size and strata selected for the survey of vegetation. Common elements amongst studies have generally included: a stratified random design; a plot size of 20 x 20 m; and, assessments of trees/shrubs above 2 m. However, one study had a stratified systematic design and collected triplicate plot data (1200 m² total), another used 30 x 30 m sampling plots, whilst one conducted seasonal sampling, counted trees/shrubs >1.5 m and collected data up to 100 km from the Ranger mine. Understorey components were collected in two studies. These inherent differences make these datasets difficult to use together for the goal of setting clear closure criteria.

Some of the most applicable datasets are more than 20 years old, and, representing point surveys in time, do not capture the necessary inherent seasonal and interannual changes and variability required for specifying a number of the relevant closure criteria for ecosystem restoration. Further, for the development of some closure criteria, the spatial scale of measurement used in the earlier surveys may not be appropriate. For these reasons and for key ecosystem attributes, it is timely to collect new data at appropriate sampling scales (i.e. how to scale from 400 m² to 1000 ha), that can be used to derive and assess revegetation closure criteria for Ranger mine site. Using information and sites investigated in the vegetation trajectory project (RES-2013-002), one-hectare sites will be selected for measurement and assessment using the Ausplots method of field sampling. These field data will be used to calibrate measurements of species composition and community structure using RPAS wherever the latter method can be applied. Importantly, this project will include measures of understorey and seasonal changes in vegetation (phenology).

Progress against plan

- Eight one hectare plots have been established on suitable land units surrounding the mine.
- The plots have been surveyed using the AusPlots methods.
- Preliminary RPAS flights (>60 flights over 10 field trips) have been undertaken (LiDAR, hyperspectral, multispectral).
- Investigations into scaling have commenced using suitable statistical analysis.
- Comparison of Terrestrial Laser Scanning with RPAS-derived LIDAR data for measuring Diameter at Breast Height (DBH) of trees in plots has commenced.

Key findings

- There are no key findings to report.

Workplan for 2018-19

- Project review resulting in three project plans to maximise efficiencies in project management and reporting.

September 2018, October 2018 & March 2019:

RPAS flights over the plots at appropriate times to track phenology and aid in identification of species using hyperspectral and optical data (3 field trips, 8 missions each field trip).

October 2018:

- Commence developing relationships between LiDAR data and vegetation structure (e.g. size class information).

May 2019:

- Assessment of vertical take-off and landing (VTOL) RPAS to capture data at larger scales.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Journal publications (at least 3) on the following: methods for selecting and sampling plots for mine site rehabilitation; scaling reference sites for ecological restoration; and measuring plant community structure from RPAS.
- Conference presentation (Establishment of reference sites for mine site restoration- Society for Ecological Restoration Conference -September 2018).

The outcomes of this project include:

- Closure criteria for species composition and community structure that are appropriate for the scale of the rehabilitation being undertaken at Ranger. This will inform revegetation planning and contribute to assessing whether the rehabilitated site will be similar to surrounds in relation to ecosystem restoration.
- Development of methods and metrics for monitoring revegetation closure criteria and the site scale.

- Conceptualisation of reference ecosystems for communication with stakeholders.

Planned communication activities

- Key findings published in the Annual Technical Report and reported to ARRTC and ARRAC.
- Presentations to key stakeholders on request.
- Research papers published in peer reviewed scientific journals.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

No project publications to date.

Project details			
Project title	Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria - Stage 2. Inferential component		
SSB function	Research	Site	Ranger
Project category	Developing closure criteria	Project status	Active
What business need does this project inform?	Provision of information to inform the agreed trajectory for revegetation closure criteria. This relates to Environmental Requirement 2.2a which ensures revegetation provides an ongoing sustainable ecosystem that is similar to surrounds in species abundance and density.		
Key Knowledge Needs (KKN)	EE1A. What are the key characteristics of the terrestrial ecosystems (including riparian) surrounding the RPA, and how do they vary spatio-temporally?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	1
Project number (if allocated)	RES-2017-026	Time buffer	A
Project number (if allocated)	RES-2017-026	Project commencement date	30/03/2018
		Estimated completion date	29/09/2018
Project duration (months)	4	Date required	30/06/2018
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)	David Bowman, University of Tasmania		
Project manager	Whiteside, Tim	Project total estimated internal resources (person weeks)	4
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	8

Aims

- To link landscape disturbances (fire, feral animals, cyclones and rainfall) to measured landscape changes in the surrounding environment through statistical inference techniques.

- To identify the key drivers of temporal vegetation cover change.
- To provide data to inform the envelope of trajectories for Ranger rehabilitation.

Background

It is important that vegetation closure criteria for the Ranger mine site are developed in the context of temporal change in the area surrounding the Ranger mine lease. The Environmental Requirements refer specifically to revegetation and ecosystem restoration endpoints as similar to the surrounding environment under the primary environmental objectives for rehabilitation.

The current state of vegetation surrounding Ranger mine has been influenced by disturbances such as fire, rainfall variability, cyclones, buffalo and previous land tenures. This project provides a statistical analysis of the relative importance of these disturbances on vegetation trajectories. For this, the analysis uses landscape metrics derived from a time series of remote sensing imagery (RES-2013-002). The data set compiled under this linked project (the descriptive component) is time-series woody cover, extracted from historical aerial photo archive and satellite imagery. The woody cover is restricted to particular land units described as upland savanna. Years for the dry season imagery are: 1950, 1964, 1976, 1978, 1981, 1984, 2004, 2010 and 2016. The woody cover is available at three scales: the woody cover itself (e.g. canopy level), percentage per 1 ha cells within the land unit polygons, and percentage per land unit polygon.

The University of Tasmania will undertake inferential analysis to determine the drivers (natural and anthropogenic) of woody cover change for the savanna landscape surrounding Ranger uranium mine over the 1950-2016 time series of woody cover data sets. The findings will inform an envelope of outcomes/trajectories for the Ranger uranium mine revegetation.

Progress against plan

- The contract for analysis services from University of Tasmania has commenced. An interim report has been received as per contract.

Key findings

- Preliminary results indicate tree cover is strongly affected by land class. Effects of fire on woody cover in the 4 years prior to image acquisition were also detected, and in the year of image acquisition, but these have been weaker than expected. The lack of certainty in whether fires occurred before or after image acquisition has contributed to the weaknesses in inference.

Workplan for 2018-19

July 2018:

- Completion of inferential statistical analysis.

September 2018:

- Completion and submission of manuscript to peer-reviewed publication.
- Linking of results to the current State and Transition Model for revegetation at Ranger.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Identification of the drivers of change based upon the correlative analysis. This will include contextualising the changes (i.e. predominant drivers compared with secondary drivers) observed over the past and present with the landscape change timeline for Kakadu, and discussion on projected future changes (if possible).
- Refinement of the State and Transition Model for Ranger revegetation.
- Confirmation of the major natural drivers of landscape change in the surrounding environment.
- Conceptualisation of the influence of disturbances on vegetation trajectory (recovery periods).

The outcomes of this project include the statistical inference of the key drivers of historical change which can be used to indicate potential future change and recovery after natural disturbance in savanna surrounding the rehabilitated mine site.

Planned communication activities

- Research paper published in an international peer-reviewed journal.
- Key findings published in Annual Technical Report.
- Presentations to key stakeholders as required.
- Presentations to the broader scientific community at conference and/or workshop.

Project publications to date (if applicable)

No project publications to date.

Project details					
Project title	Determining closure criteria for recolonisation of fauna on the rehabilitated Ranger mine site (NESP)				
SSB function	Research	Site	Ranger		
Project category	Developing closure criteria	Project status	Active		
What business need does this project inform?	Provision of a rigorous scientific basis for environmental standards and closure criteria for fauna related to Environmental Requirement 2.2a, specifically the formation of “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”.				
Key Knowledge Needs (KKN)	EE2A. What faunal community structure (composition and relative abundance) is present in the areas surrounding the RPA?				
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1	Time-frame	1
		Project Priority	Importance	1	Time buffer
Project number (if allocated)	RES-2018-001	Project commencement date		08/01/2018	
		Estimated completion date		21/12/2018	
Project duration (months)	12	Date required		31/12/2020	
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)	Alan Andersen (National Environmental Science Program)				
Project manager	Bartolo, Renee	Project total estimated internal resources (person weeks)		3	
Project sponsor	Van Dam, Rick	Project total estimated collaborator resources (person weeks)		40	

Aims

- To develop faunal closure criteria for successful ecosystem restoration of Ranger uranium mine through identification of invertebrate animals (ants, beetles, spiders and wasps) in reference sites in the surrounding Kakadu National Park.
- To determine suitable vertebrate animal measures to inform mine site closure criteria, through analysing existing data.
- To design a robust sampling method for ongoing vertebrate animal monitoring and assessment.

Background

Fauna are a component of ecosystem restoration that needs to be accounted for in the ecological restoration of Ranger mine site, as the site is surrounded by the World Heritage listed Kakadu National Park. Mine site rehabilitation has been traditionally dominated by backfilling of pits, establishing site stability and revegetation. However the Ranger ERs refer to the formation of a sustainable ecosystem which will require not only plants, but fauna and ecosystem processes. Important for revegetation and ecosystem restoration at Ranger, are the habitat requirements of faunal communities and whether specific elements of that habitat can be introduced in shorter time frames to aid in faunal recolonization. The national standards for the practice of ecological restoration in Australia note the need to include measures of faunal composition. The scope of this project includes data on both invertebrate and vertebrate terrestrial fauna linked to the reference ecosystem. This is part of a larger project that will also assess faunal colonisation of the trial landform at Ranger with the overall aim of providing information on the performance of different revegetation practices.

The outputs and outcomes of this project will have broader applicability to ecological restoration of mine sites across northern Australia, whereby rehabilitation efforts have been historically focussed on site stabilisation through the back-fill of pits, construction of suitable landforms and revegetation.

Progress against plan

- Scope and project design has been finalised.
- Initial invertebrate surveys conducted on a selection of the vegetation reference sites established by R&L under the project RES-2017-007 (Deriving species composition and community structure measures at an ecologically appropriate scale).

Key findings

- There are no key findings to report.

Workplan for 2018-19

May-September 2018:

- Vertebrate faunal data assessed from previous surveys in the surrounds of Ranger and further surveys undertaken if required.

September 2018:

- Invertebrate faunal surveys conducted in a selection of the vegetation reference sites established by R&L.

December 2018:

- Final report.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Survey data on invertebrate assemblages occurring at reference sites. Final data and metadata will be stored on CDU's eSpace Institutional Repository, which is linked to Australian National Data Services (ANDS) data discovery portal Research Data Australia.
- Recommendations for ongoing vertebrate monitoring and assessment.
- Proposed faunal closure criteria for the rehabilitation of the Ranger mine site.
- Scientific publication on developing fauna closure criteria for mine site rehabilitation in northern Australia, report and summary factsheet.

The outcomes of this project include the development of SSB's rehabilitation standard for ecological restoration and specifically fauna and habitat requirements for faunal recolonization based on quantitative faunal survey data.

Planned communication activities

- Key findings published in the Annual Technical Report and reported to ARRTC and ARRAC.
- Presentations to key stakeholders on request.
- All NESP Northern Australia Environmental Research (NAER) hub generated publications arising from the project will be made freely available on the NAER website.
- Research paper published in peer reviewed scientific journal.

Project publications to date (if applicable)

N/A

Project details			
Project title	A review of compaction layers in mining landforms and possible implications for Ranger uranium mine		
SSB function	Research	Site	Ranger
Project category	Demonstrating achievement of closure criteria	Project status	Active
What business need does this project inform?	The placement, extent, thickness and composition of compaction layers in the final landform may affect the movement of water through the landform and influence the amount of water available for ecosystem function.		
Key Knowledge Needs (KKN)	EE7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2017-018	Project commencement date	31/10/2017
		Revised completion date	31/10/2018
Project duration (months)	12	Date required	31/10/2018
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)	N/A		
Project manager	Pfitzner, Kirrilly	Project total estimated internal resources (person weeks)	8
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	1

Aims

- To undertake a literature review on compaction layers in mining landforms with particular reference to implications at RUM.
- To determine the advantages and/or disadvantages of compaction layers for ecosystem restoration and function.

Background

The Ranger Mine Closure Plan indicates that a compaction strategy will be adopted for the Ranger final landform to provide plant available water (PAW) for ecosystem restoration. This is based on the assumption that: i) compaction layers will benefit ecosystem restoration; and ii) there will be no net detrimental internal changes to waste rock through compaction. However, there is no empirical evidence to substantiate the assumption that introducing compaction layers in the final landform will enhance ecosystem restoration. This knowledge gap has led to a review of the advantages and disadvantages of compaction layers in mining landforms.

Progress against plan

- A literature search combining words or expressions “soil, compaction, mine, rehabilitation, waste rock, store and release, evapotranspiration, cover, water balance, plant available water, infiltration flux, ecological engineering, ecosystem support”, as examples, was undertaken. Over 150 references were sourced from peer-reviewed journals, conference proceedings (e.g. “Life of Mine” (AusIMM)) and ERA-commissioned work. Some grey literature, including commercial-in-confidence company reports, could not readily be accessed.
- The objective of the present review is to provide evidence, if available, of whether compaction in the mining landscape has been used to compensate for a potential lack of PAW in a tropical savanna environment. The specific aims of this review are to: define the types of mine commodities that deliberately have compacted surfaces; outline the reasons for use of compaction in mining landforms; outline the variations in cover types used to alter water availability for ecosystem sustainability; list both the negative effects and positive effects of compaction; highlight the issues of compaction as related to studies at Ranger uranium mine; and, provide a summary as to whether there is evidence of success of compaction layers that would support its adoption in the engineering of the final landform at Ranger.

Key findings

- From the literature review it was found that soil compaction may occur with a constructed landform as: deliberate compaction of internal layers; surface compaction of the outer layer; auto-compaction as a result of construction machinery including trucks and vehicles during mining operations or during the construction of the final landscape; but also auto-compaction at the base of the waste rock piles due to the overlying pressure exerted at the surface. Compaction has been used in mining landforms in Australia and internationally to reduce radon emanation or control reactive wastes by limiting water and oxygen infiltration and ingress. Cover systems to retain water during rainfall events and release pore water to the atmosphere during extended dry periods generally serve one role, i.e. reduce the net infiltration across the cover system and into the waste material so as to prevent acid drainage from reactive wastes. So far, no reference for compaction to support ecosystem restoration, particularly in a wet-dry savanna, has been found.

Workplan for 2018-19

- Complete literature review and publish externally as a journal article. This includes compilation of an endnote database and a tabulated reference list of compaction examples to be incorporated as supplementary material.

Planned project outputs and associated outcomes

The primary output for the project is a Journal paper.

The outcomes of this project include improved understanding of effects of incorporating compaction layers in the Ranger final landform.

Planned communication activities

- Journal paper.
- Presentations and discussions with the relevant technical working group for Ranger rehabilitation and ARRTC.

Project publications to date (if applicable)

N/A

Project details			
Project title	Monitoring hydrology on the trial landform to inform water balance		
SSB function	Monitoring	Site	Ranger
Project category	Demonstrating achievement of closure criteria	Project status	Active
What business need does this project inform?	Provision of a rigorous scientific basis for the assessment of rehabilitation planning for ecosystem restoration and sustainability by providing data to be used in assessment of plant available water.		
Key Knowledge Needs (KKN)	EE7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	1
		Project Priority	
		Importance	2
		Time buffer	A
Project number (if allocated)	RES-2010-024	Project commencement date	01/12/2009
		Estimated completion date	01/01/2028
Project duration (months)	30	Date required	30/06/2018
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)	70
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	0

Aims

- To collect rainfall and runoff on the erosion plots of the Ranger trial landform to inform water balance and infiltration rates, which can also inform long-term plant available water and ecosystem sustainability.

Background

Rainfall and runoff have been collected from four plots on the Ranger trial landform since 2009, primarily as part of the trial landform erosion studies (RES-2009-011). Rainfall data are collected by a pluviometer and runoff data are calculated from calibrated flumes at the outlet of each erosion plot.

After discussion with experts in plant physiology in 2018, it was strongly suggested that monitoring of hydrology be continued on the trial landform to inform plant available water (PAW) studies. Rainfall, runoff and infiltration on the trial landform occurs during the wet season and it is important to know these parameters to assess the availability of PAW for the vegetation. A below average wet season followed by a long dry season could mean that the PAW has declined well before the end of the wet season, impacting on the health of vegetation for the ensuing dry season.

Progress against plan

- Rainfall and runoff data have been cleaned, quality assessed and checked, and archived in Hydstra database for all for plots for the wet seasons 2009–2010 to 2016–2017.

Key findings

- Annual Runoff coefficients determined for the four erosion plots on the trial landform (TLF) provide average runoff coefficients ranging from 6.1 to 28.2, suggesting that more than 70% of rainfall is lost/removed by processes other than runoff, including infiltration. Water that infiltrates into the trial landform could add to the PAW.

Workplan for 2018-19

- Process data collected during the 2017-18.
- Maintain the gauging stations on the trial landform to collect rainfall and runoff during the 2018-2019 wet season.
- Data cleaned and assessed during the wet season.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Rainfall and runoff data from the four erosion plots on the trial landform.
- Summary data sets.

The outcomes of this project include an understanding of rainfall, runoff, and infiltration relationships to inform long term sustainability of the revegetated landform specifically related to PAW.

Planned communication activities

- A research paper published in an international and peer reviewed scientific journal on the hydrology of the erosion plots on the Trial landform.
- Key findings published in Annual Technical Report.
- Presentations to key stakeholders on request.
- Presentations to the broader scientific community at conferences and/or workshops.

Project publications to date (if applicable)

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.

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.

Project details			
Project title	Characterising and mapping salt efflorescences using remotely sensed data		
SSB function	Research	Site	Ranger
Project category	Rehabilitation - overarching	Project status	Completed
What business need does this project inform?	This project demonstrates the ability to detect magnesium sulfate on the ground from airborne hyperspectral data over large areas.		
Key Knowledge Needs (KKN)	EE6. Understanding the impact of contaminants on vegetation establishment and sustainability EE7. Understanding the effect of physical and geochemical properties of waste rock on vegetation establishment and sustainability EE9. Developing monitoring methods for revegetation		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	3
		Project Priority	
		Importance	3
		Time buffer	D
Project number (if allocated)	RES-2015-015	Project commencement date	14/4/2015
		Estimated completion date	31/12/2016
Project duration (months)	6	Date required	N/A
In-house or outsourced	Internal	Actual completion date	29/6/2018
Lead team	R&L	Reason for project delay (where applicable)	Low priority
Supporting team(s)	WASQ		
Project manager	Pfitzner, Kirrilly	Project total estimated internal resources (person weeks)	8
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	

Aims

- To map surface efflorescence salts from airborne hyperspectral HyMap data using ground based reflectance spectrometry, X-ray diffraction and X-ray fluorescence data.

Background

Measuring the location and extent of surface efflorescence can indicate solute movement before changes in electrical conductivity are detected in waterways. We hypothesised through the use of a case study based on salts associated with the Ranger uranium mine that ground-based reflectance spectrometry and airborne hyperspectral HyMap (450–2500 nm) analysis of surface efflorescence could be a rapid method for monitoring of salts over large areas of the surrounding environment, including remote locations downstream of the source mine sites. The method deployed X-ray diffraction and X-ray fluorescence to determine mineralogy and elemental composition of surface salts, then using other techniques, the field reflectance spectra were matched to the airborne data for remote sensing purposes.

Data were collated and processed with results being presented in a Coffee Break Seminar in 2015/2016. The project was suspended in 2016/2017 due to higher priorities. The project was activated in 2017/2018 to complete the journal paper write up.

Progress against plan

2015–2016:

- Commission hyperspectral airborne survey. Collection of ground based X-ray diffraction and X-ray fluorescence data.
- Determine mineralogy and elemental composition of surface salts, analysis of results, preparation and presentation of Coffee Break Seminar.

2017–2018:

- Preparation and submission of paper for external publication.

Key findings

- Field collected salt samples were found to be mixtures of magnesium sulfate compounds, as determined through XRD. The reflectance of field spectra varied depending on the hydration of the mineral, namely hexahydrite and starkeyite. A constrained energy minimisation technique was used to match the field reflectance spectra to the airborne data. Airborne matches were confirmed at the field sampling sites and surrounds. Salts were also detected at lower matches at mine water irrigation areas where excess mine water had previously been applied. Hyperspectral remote sensing is a potentially rapid and sensitive method for mapping magnesium sulfates over large areas in operating and rehabilitated mine sites. It was successfully demonstrated as a tool for monitoring and assessment of efflorescence arising from salt-generating processes.

Workplan for 2018–19

N/A

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Coffee Break Seminar
- Journal Paper in *Science of the Total Environment*

The main outcome that this project will achieve is demonstration that magnesium sulfates can be identified from airborne hyperspectral data and can be used as a tool for monitoring and assessment of efflorescence.

Planned communication activities

- Coffee break seminar (2015/16).
- Journal paper (2017/2018).

Project publications to date (if applicable)

Pfitzner K, Harford A, Whiteside T, and Bartolo R. Mapping magnesium sulfate salts from saline mine discharge with airborne hyperspectral data, *Science of The Total Environment*, Volumes 640–641, 2018, Pages 1259-1271, ISSN 0048-9697, <https://doi.org/10.1016/j.scitotenv.2018.05.396>.

Project details			
Project title	Hydrology 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 hydrology and infiltration of a rehabilitated mine-site in order to validate predictions from the landform evolution model, CAESAR-Lisflood.		
Key Knowledge Needs (KKN)	EE7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	2
		Time-frame	1
		Project Priority	
		Importance	1
		Time buffer	A
Project number (if allocated)	RES-2009-011	Project commencement date	01/03/2018
		Revised completion date	30/12/2018
Project duration (months)	146	Date required	30/06/2018
In-house or outsourced	Internal	Actual completion date	N/A
Lead team	R&L	Reason for project delay (where applicable)	Higher priorities
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 assess whether different surface treatments and vegetation establishment strategies on the Ranger trial landform result in different erosion rates through measurements of hydrology and infiltration.
- To measure and determine infiltration rates on the trial landform that will inform various knowledge needs including plant available water and terms for groundwater modelling.

Background

Construction of the trial landform was completed in early March 2009, with instrumentation of erosion plots and planting of tube stock and direct seeding completed by November 2009. Four plots were established: two on waste rock and two on laterite mix surfaces. Each surface was initially divided into areas of direct seeding and tubestock, thus each plot, initially collected information for a unique surface cover and treatment condition. Quantitative data on runoff, water quality, bed load, suspended load and solute load have been collected from the trial landform since the 2009-2010 wet season.

The collected data are being used for a number of purposes including validation of surface water discharge from the CAESAR-Lisflood model, discharge predictions from groundwater modelling and input for plant available water calculations.

Progress against plan

- Rainfall, runoff and bedload data have been collected for seven wet seasons 2009–2010 to 2015–16 and data are 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.
- Rainfall and runoff data have been cleaned, quality assessed and checked, and archived in Hydstra for all for plots for the wet seasons 2009–2010 to 2015–2016.
- Bedload yields have been calculated for all four plots for eight wet seasons (2009–2010 through to 2016–2017).
- Continuous monitoring of EC, turbidity and stage height has been undertaken at each of the four plots over the five wet seasons (2009–2010 to 2013–2014), and associated 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 measured 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 2014, and the earlier data have been reported in an internal report.

Key findings

- Rainfall and runoff data have been used to inform infiltration rates which have also been measured directly by disk permeometer. Infiltration appeared to be high. Rates from direct measurement need to be further analysed and compared with those reported in previous infiltration studies at the Ranger site.
- As reported in the 2016-17 Annual Technical Report, bedload has been found to be declining in the eight years since the trial landform was constructed.

- Suspended sediment appears to comprise less than 20% of the total sediment load. This work is continuing under project RES-2010-007.
- High initial sediment loads with a subsequent rapid decline predicted by modelling of the trial landform are matched by the field result, providing confidence in the model predictions of CAESAR-Lisflood.

Workplan for 2018-19

- Complete analysis of the infiltration measurements undertaken on the trial landform in June 2018.
- Prepare and submit a journal paper discussing infiltration rates on the Ranger mine site.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Rainfall, runoff, solute, suspended sediment and bedload data 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 the suspended sediment – turbidity relationships to derive event-based and annual loads of suspended sediment.

The outcomes of this project include rainfall, runoff, sediment and solute load data from the trial landform that will assist with the validation of the CAESAR-Lisflood LEM modelling. The data and modelling validation will assist with the development of the rehabilitated landform.

Planned communication activities

- Presentations and discussions with the relevant technical working group for mine rehabilitation 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	Developing monitoring methods for revegetation using Remotely Piloted Aircraft Systems (RPAS): Jabiluka revegetation		
SSB function	Research	Site	Ranger
Project category	Monitoring of closure criteria	Project status	Active
What business need does this project inform?	Provision of cost effective and rigorous methods for the monitoring of relevant revegetation closure criteria. Informs Environmental Requirement 2.2a which states that revegetation of the disturbed sites of the Ranger Project Area is undertaken using local native plant species and is similar in density and abundance to those existing in adjacent areas of Kakadu National Park.		
Key Knowledge Needs (KKN)	EE9A. How do we optimise methods to measure revegetation structure and sustainability on the rehabilitated site, at a range of spatio-temporal scales and relative to the areas surrounding the RPA?		
Closure criteria theme (if applicable)	Ecosystem Restoration	Relevance	1
		Time-frame	2
		Project Priority	
		Importance	2
		Time buffer	D
Project number (if allocated)	RES-2014-003	Project commencement date	01/07/2014
		Estimated completion date	01/10/2018
Project duration (months)	24	Date required	01/04/2020
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	Whiteside, Tim	Project total estimated internal resources (person weeks)	32
Project sponsor	Bartolo, Renee	Project total estimated collaborator resources (person weeks)	0

Aims

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

Background

Monitoring of mine site rehabilitation requires the assessment of indicators, including those relevant to vegetation establishment and erosion. For the rehabilitated Ranger mine site, the impact of disturbances such as fire, weeds and cyclones also need to be measured and modelled. To help make assessment of rehabilitation success, data and information on these indicators are required at a suitable frequency and scale.

RPAS technologies allow the acquisition of data that meet different 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 mine site provide a suitable area for testing RPAS techniques for data collection and analysis. The methods developed here will then be applied to the Ranger mine site as rehabilitation work progresses.

Progress against plan

- To date, ten missions have been conducted over Jabiluka mine site. Data have been processed and analysed for all flights.
- A manuscript detailing the method of data capture, processing and analysis has been accepted for publication to International Journal for Applied Earth Observation and Geo-information.

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 initially decreased, the size of the surviving plants increased. Also of note was the significant number of volunteer plants (mostly *Acacia* spp.) so far detected.

Workplan for 2018-19

September 2018:

- Complete and submit the time series analysis paper as a peer-reviewed publication.
- Publish details of data capture procedures and the data captured, as supplementary material.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Analysis of a time-series of RPAS imagery over the Jabiluka mine site showing revegetation progress.
- An established set of methods for monitoring with RPAS technologies relevant to the assessment of particular vegetation closure criteria (to be detailed in the supplementary material to one of the following journal articles).

The outcomes of this project include:

- 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

- Conference presentations.
- Research papers published in peer-reviewed journals detailing the data collection and analysis method, and highlighting the time-series analysis.
- Reporting and presentations to key stakeholders as required.

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 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.

Whiteside T & Bartolo R (2018). A robust object-based woody cover extraction technique for monitoring mine site revegetation at scale in the monsoonal tropics using multispectral RPAS imagery from different sensors, *International Journal of Applied Earth Observation and Geo-information*, 73, 300-312.

OTHER SITES

1 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 resident Aboriginal people and other members of the regional community from potential exposures to radiation.				
Key Knowledge Needs (KKN)	N/A				
Closure criteria theme (if applicable)	N/A	Relevance	2	Time-frame	2
		Project Priority Importance	2	Time buffer	C
Project number (if allocated)	MON-2013-006	Project commencement date		01/07/2012	
		Estimated completion date		30/06/2026	
Project duration (months)	168	Date required		01/07/2026	
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)		90	
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.

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. The 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 2018-19

May-June 2019:

- Radon exhalation and gamma dose rate survey.

June 2019:

- Gamma counting of radon cups.

June 2019:

- Data analysis and write up of internal report.

Planned project outputs and associated outcomes

The primary outputs for the project is a dataset of radon exhalation and gamma dose rate measurements for the El Sherana containment facility.

The outcomes of this project include:

- Public and regulator assurance that there have been no changes in radiological conditions at the facility.
- Public and regulator 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)

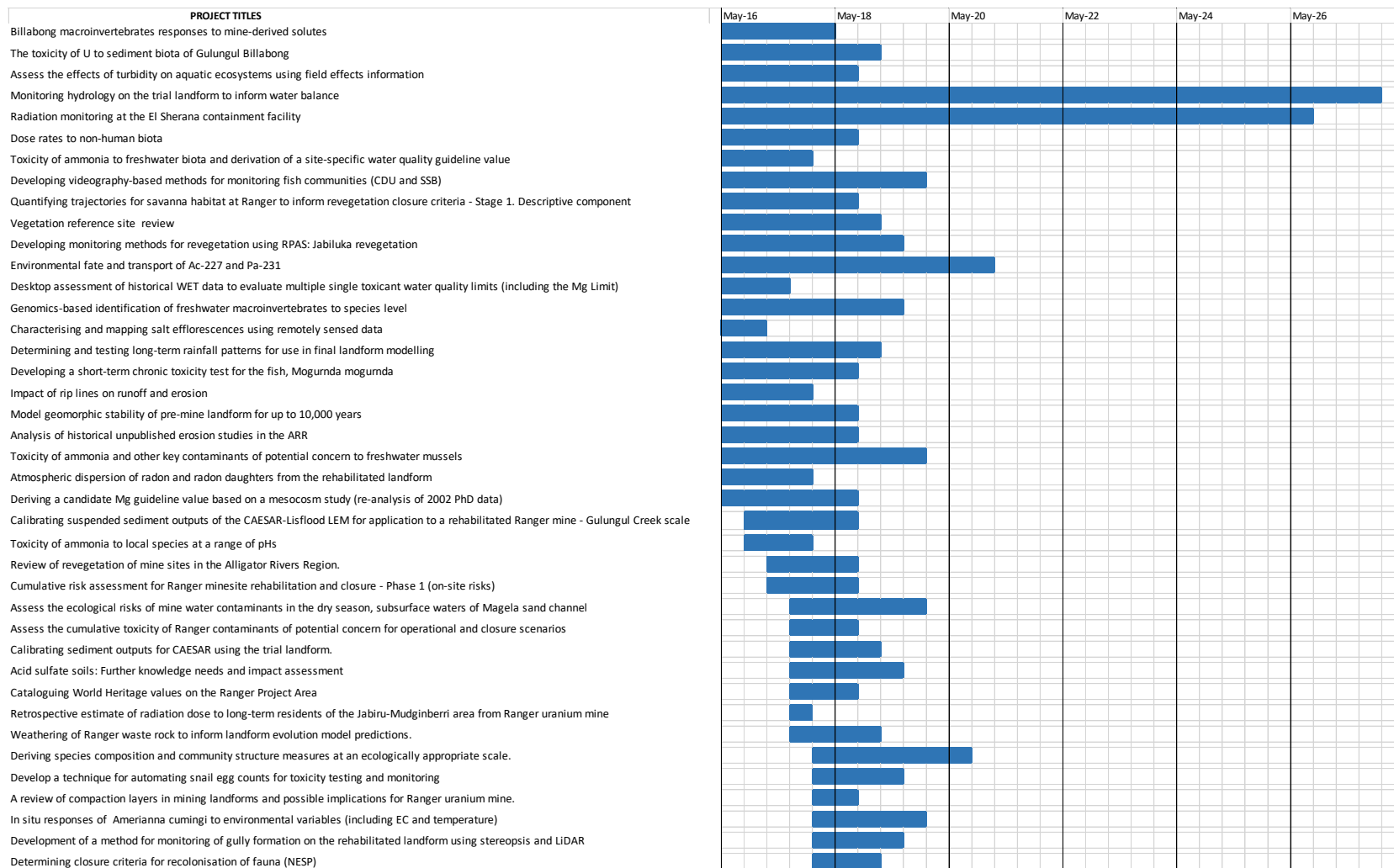
Doering C, Bollhöfer A, Ryan B, Sellwood J, Fox T & Pfitzner J 2011. Baseline and post-construction radiological conditions at El Sherana airstrip containment, South Alligator River valley, Australia. Internal Report 592, June, Supervising Scientist, Darwin.

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.

Doering C, Medley P & Chen J 2017. Gamma dose rates and radon-222 exhalation flux densities at El Sherana containment in 2017. Internal Report 635, Supervising Scientist, Darwin.

**APPENDIX 3 SUPERVISING SCIENTIST
BRANCH DRAFT RESEARCH PROJECT
SCHEDULE, 2017-2026**



PROJECT TITLES	May-16	May-18	May-20	May-22	May-24	May-26
Model the geomorphic stability of the final conceptual landform for up to 10,000 years						
Formalisation and publication of the weight of evidence assessment to derive a water quality standard for magnesium in surface waters						
Hydrology and infiltration studies on the Ranger trial landform						
Ecohydrology and sensitivity of riparian flora (NESP)						
Deriving site-specific concentration factors for metals in bush foods to inform human health risk assessments for the Ranger final landform						
Modelling the atmospheric dispersion of radionuclides in dust from the Ranger final landform						
Assessing the impact of groundwater discharge on landform stability						
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 2 (aquatic pathways)						
Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria - Stage 2. Inferential component						
Predicting uranium accumulation in sediments						
Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity (NESP fish migration)						

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 <i>Mining Management Act 2008</i> (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.
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
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 ' <i>a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation</i> ' 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'
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
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
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
UAV	Unmanned Aerial Vehicle
UEL	Uranium Equities Ltd
U	Uranium. The product mined from the Ranger uranium mine.