Australian Government

Department of the Environment and Energy

Supervising Scientist

SUPERVISING SCIENTIST

Annual Technical Report

2018–19

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

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

Photos (clockwise spiral from top left): Workers survey Ranger Trial Landform, *Delias argenthona* (Scarlet Jezebel butterfly), Storm clouds over Kakadu National Park, Snail shell, Collecting water samples from Magela Creek, *Thysanotus banksii* (Fringe Lily), Preserving specimens collected from pit traps, *Litoria caerula* (Green Tree frog), SSB staff flying a drone

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Plate 1 Kakadu National Park floodplain with smoke haze

SUPERVISING SCIENTIST'S OVERVIEW

2018-19 was another significant year for the Supervising Scientist Branch (SSB). Rehabilitation work at the Ranger mine is gathering pace, as are the research and supervision programs which support it. Our comprehensive monitoring programs were completed successfully and continue to show that the people and environment surrounding Ranger mine remain protected from the effects of uranium mining.

Our focus on the development and implementation of new monitoring technologies continued throughout the year, improving both the safety and efficiency of our activities. Increasing numbers of crocodiles mean that many of our previous monitoring activities now present an unacceptable risk to staff. New techniques are required which allow us to continue this important work, but also ensure the safety of our people.

- Fish videography is now well established in channel billabongs, and is being adapted to shallow seasonal billabongs to replace our previous pop-netting program in combination with Unmanned Aerial Vehicle (UAV)-based vegetation surveys.
- The Branch now has both airborne and ground-based 3D laser scanning (LiDAR) capability allowing vegetation surveys to be conducted over large areas in a fraction of the time it would previously have taken.
- Our macro-invertebrate genomics database continues to expand, and should allow for genomic based surveys to commence in about 12 months' time. This will eventually eliminate the requirement for the very time intensive manual sorting and identification of macro-invertebrate

samples. Additionally, this information will be made available to inform other monitoring programs across northern Australia.

We have completed a significant amount of planning and re-alignment of the Branch over recent years to better coordinate our oversight of the Ranger mine rehabilitation project and manage our scientific research. Our revised research Key Knowledge Needs (KKNs), which represent the additional information required to successfully rehabilitate the Ranger mine, have been finalised, agreed and adopted by Energy Resources of Australia Ltd (ERA) and endorsed by the independent Alligator Rivers Region Technical Committee. A detailed project schedule to address the KKNs has been established, aligned with the Ranger rehabilitation schedule and is being managed through a purpose-built project management system. The SSB and ERA teams are working closely on this collaborative research program to ensure that high quality, fit-for-purpose scientific information is available at the required time to allow its incorporation into rehabilitation planning and activities.

The public release of the Ranger Mine Closure Plan (RMCP) on 5 June 2018 was a key step in the rehabilitation process and the trigger for a detailed review by the SSB. We published a detailed assessment of the RMCP on 11 September 2018 which utilised the KKNs as the basis for capturing the information still required to inform rehabilitation. ERA will publish an updated version of the RMCP addressing this feedback later in 2019. In addition to the RMCP, ERA continues to seek specific approval for key rehabilitation activities. During the year SSB reviewed and endorsed applications from ERA for the continuation of backfill of Pit 1 and a revised method of tailings deposition in Pit 3.

In addition to our work on Ranger, SSB continues to provide technical advice to the Department in support of assessments under the *Environment Protection and Biodiversity Conservation Act*, and undertakes a range of scientific and technical engagements both within Australia and internationally. Internally, we have commenced planning the future beyond the major rehabilitation works at Ranger mine and I am excited that the Branch is ideally place to assist the Department with a range of existing and emerging issues, both within the Alligator Rivers Region and nationally.

Once again I must thank the staff of the SSB for their dedication and hard work over 2018-19. It is a privilege to work with such an amazing group of people, and of particular note is the award of Fulbright scholarship to Dr Renee Bartolo, head of our Ecosystem Restoration and Landform Team. This award provides international recognition, at the highest level, of the innovative and world-leading work being undertaken at SSB, and in particular by Dr Bartolo's team. It is due to the efforts and unwavering enthusiasm of all SSB staff that we are now in such a strong position to fulfil our role in ensuring the long-term protection of the environment through the successful rehabilitation of the Ranger uranium mine.

Keith Tayler

Supervising Scientist

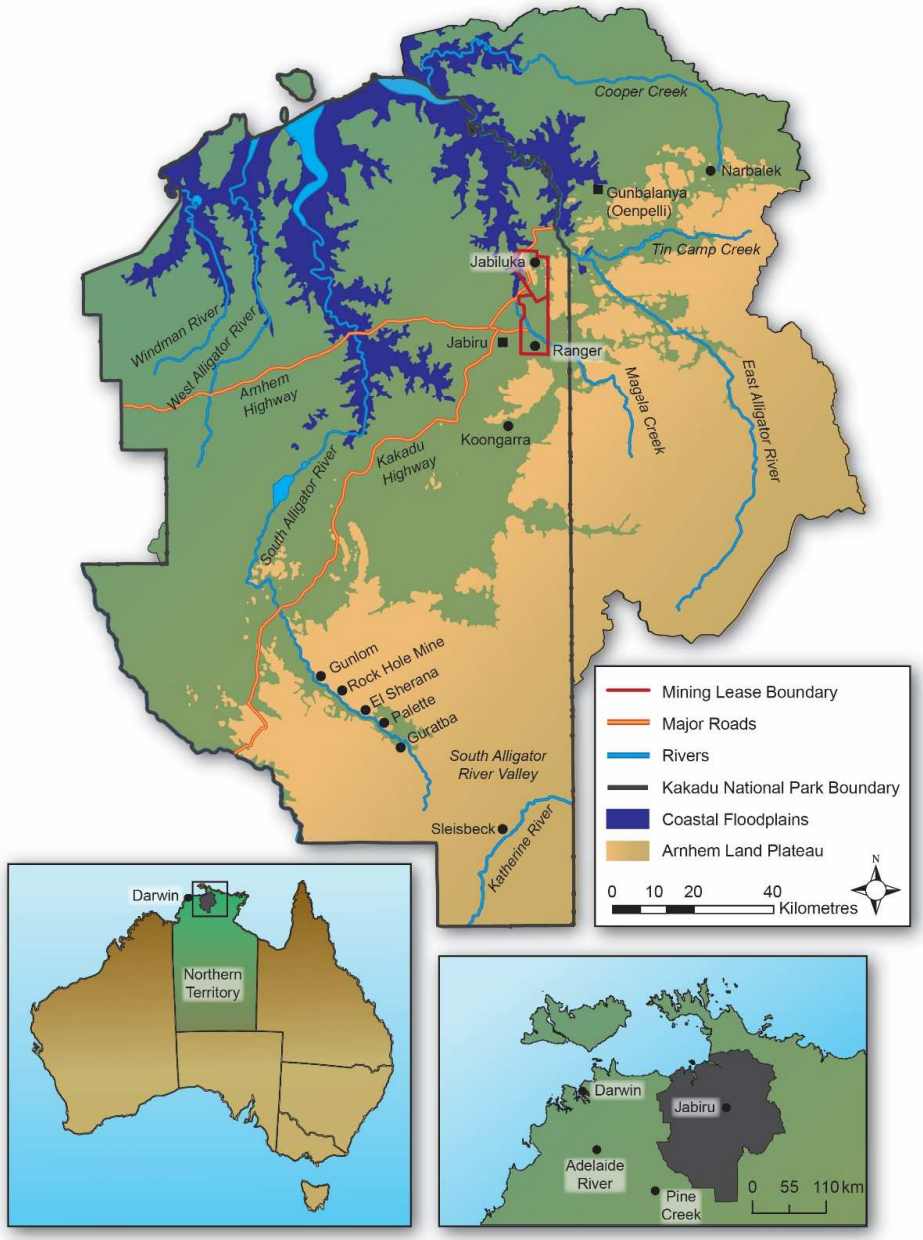


Figure 1 The Alligator Rivers Region.

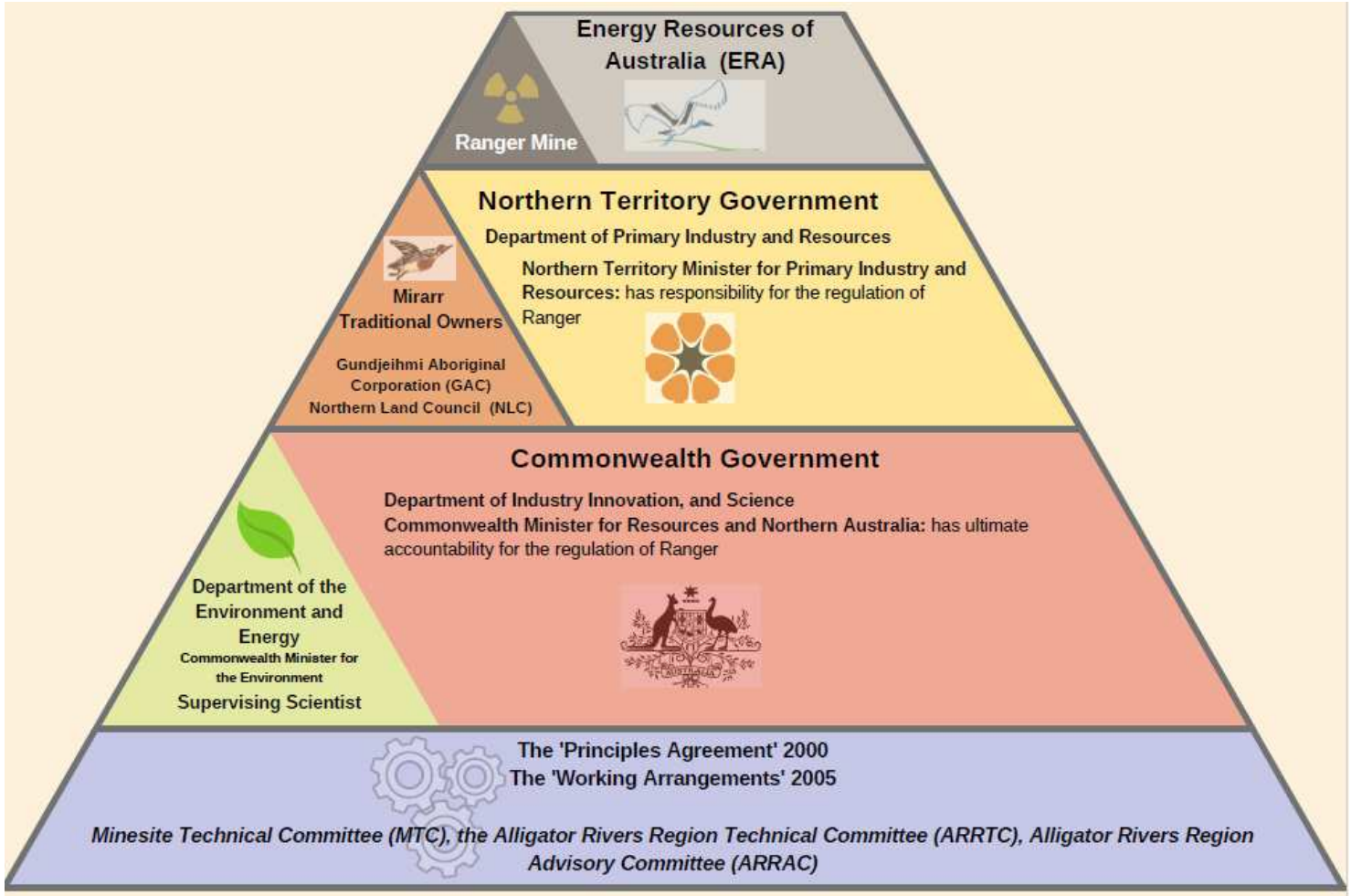
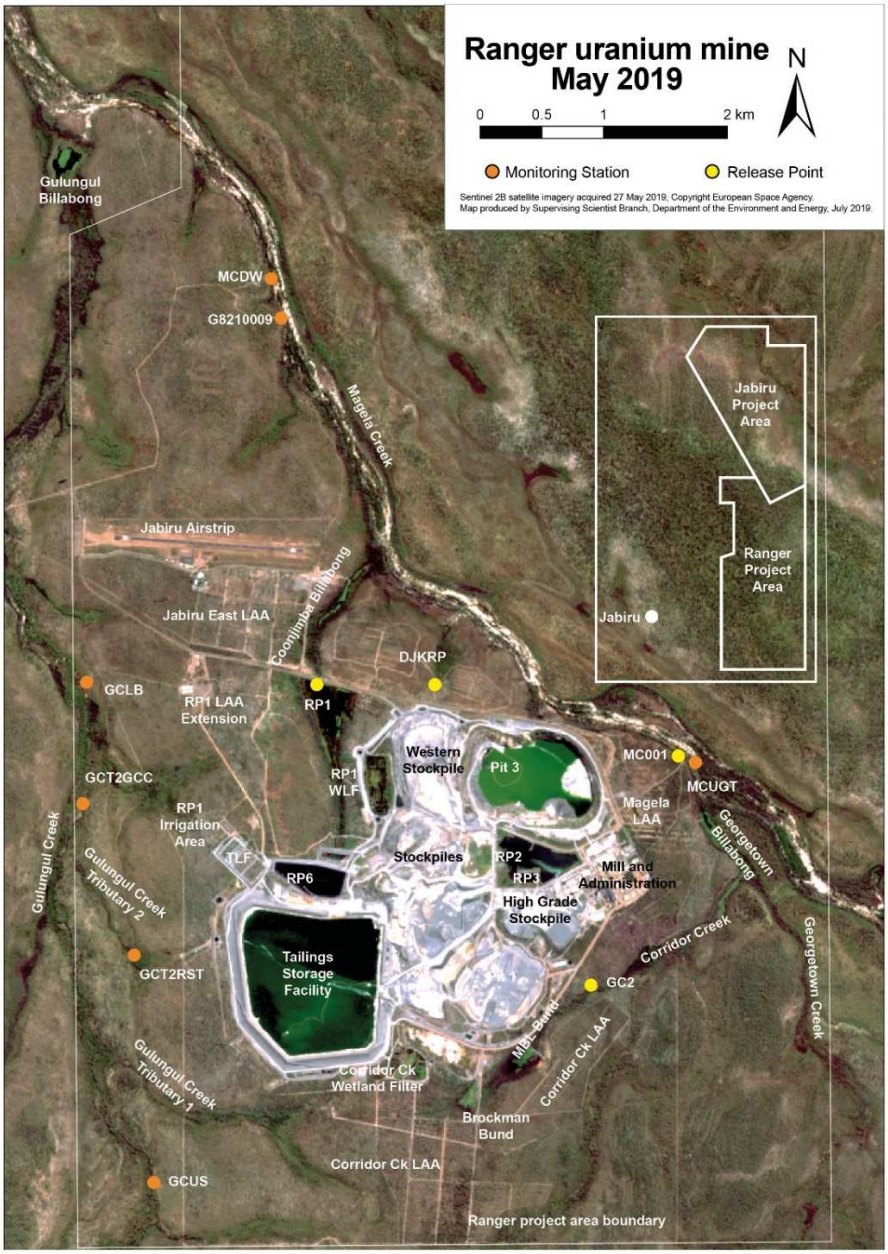


Figure 2 Regulatory framework for Ranger uranium mine.



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 3 Ranger minesite including location of water release points and SSB monitoring sites.

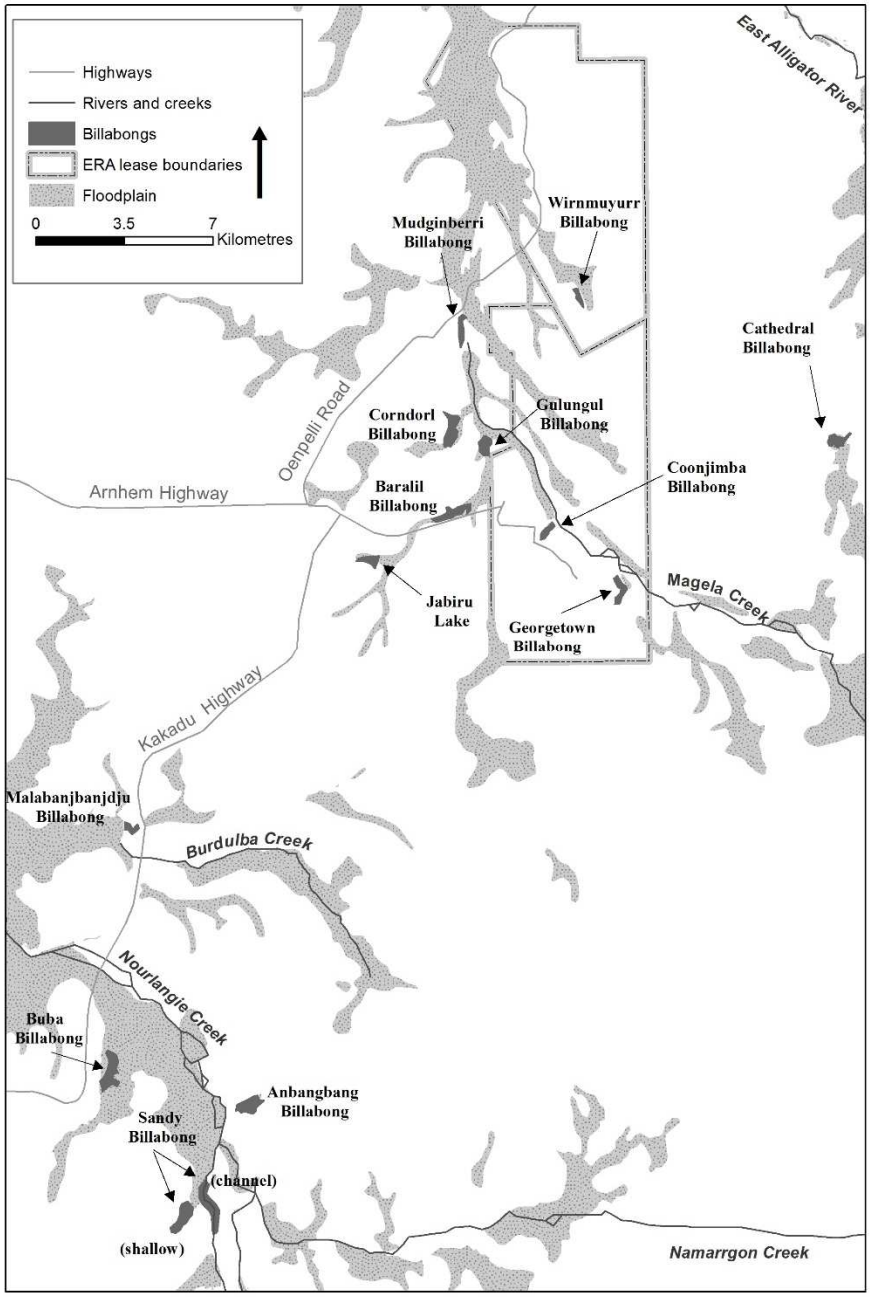


Figure 4 Location of waterbodies in the Supervising Scientist Branch's environmental research and monitoring programs.

Plate 2 *Pandanus aquaticus* Kakadu National Park

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 Second Report (also known as the Fox Report) in May 1977. The role of the Supervising Scientist is held by the Assistant Secretary of the SSB in the Government Department of the Environment and Energy, situated within the Heritage, Reef and Marine Division.

The Supervising Scientist ensures the protection of the Alligator Rivers Region (ARR) from the impacts of uranium mining by undertaking environmental research and developing standards and practices for environmental protection. SSB has four key functions with respect to mining activities in the 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 km^2 (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 2018–19 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 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 provides advice to both the Commonwealth Minister for Resources and Northern Australia, and the Northern Territory Minister for Primary Industry and Resources. See Figure 2 for a visual representation of the regulatory framework for Ranger uranium mine.

Plate 3 Georgetown Billabong, Kakadu National Park

2 PUBLIC ASSURANCE AND ADVICE

The outcomes of the Branch's research and monitoring activities are reported to key stakeholders, interested parties and the general public throughout the year using a range of consultative and communication activities. Regular engagement provides ongoing assurance that the environment of the ARR remains protected from the impacts of uranium mining, while also providing opportunities for the Branch to better understand and address expectations, concerns and sensitivities relating to uranium mining in the Region.

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 ARR. The committee comprises of representatives of government and regulatory bodies, stakeholder organisations, and companies involved in uranium mining activities in the region.

The 50th ARRAC meeting was held in Jabiru in September 2018 and 51st meeting took place in Darwin in May 2019. At these meetings the committee was advised of SSB's current activities, including updates on SSB's supervision, assessment and monitoring at Ranger uranium mine and other sites in the ARR. The meetings also provided opportunities for the Branch to present on the progress of Key Knowledge Needs (KKNs) for mine site rehabilitation and provide an update on the completion of rehabilitation standards.

ERA presented on their Ranger Closure Feasibility Study for rehabilitation and provided a broad overview of their environmental, operational and safety performance at Ranger mine. The NT Department of Primary Industries and Resources (DPIR) provided a summary of mining and exploration activities, environmental incidents, assessments and submissions as well as inspections and audits.

A the 51st meeting, Parks Australia provided an update to the committee on the Governments funding package for the transition of the township of Jabiru, and revitalisation of Kakadu National Park. The NT EPA were also present at this meeting, and expressed their interest to engage more broadly with the SSB on environmental protection and compliance assessment, with a particular interest in approaches to adaptive management.

Further updates and reports were provided by committee members including the Northern Land Council, the Environment Centre NT and the Australian Radiation Protection and Nuclear Safety Agency.

The minutes of ARRAC meetings are available on the Department's website at: http://www.environment.gov.au/science/supervisingscientist/communication/committees/arrac/meetings

2.2 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) reviews the annual research programs undertaken by the SSB and ERA and provides the Minister for the Environment independent advice on their adequacy.

The Minister for the Environment appointed Prof Craig Simmons to the position of Chairperson of ARRTC on 1 November 2018.

The 41st ARRTC meeting was held in Darwin in November 2018. The meeting focussed on the review of the research program required to inform ecological restoration of the Ranger uranium mine. ERA presented updates on the backfilling and restoration of Pit 1 and the Ranger Closure Feasibility Study. SSB provided the Committee with an update on its Ranger Mine Closure Plan Assessment Report and rehabilitation standards, and the joint SSB-ERA KKNs.

The 42nd ARRTC meeting was held in Darwin in May 2019. The meeting had a continued focus on ecosystem restoration research, as well as updates from ERA and their consultant INTERA on the progress of their groundwater modelling work. There were a number of relevant presentations from the Australia Government's National Environmental Science Program (NESP) which is undertaking key rehabilitation-related research at the Ranger mine on behalf of the SSB. SSB provided updates to the Committee on the status of its 2018-19 research program and the KKNs consolidation process. This meeting also included updates on other legacy uranium mine sites in the ARR to ensure the Committee is maintaining sufficient visibility, and that any lessons from these sites can be used for the restoration of Ranger.

The minutes of ARRTC meetings are available on the Department's website at: http://www.environment.gov.au/science/supervisingscientist/communication/committees/arrtc/meetings

2.3 Communication with other stakeholders

Over the reporting period SSB staff members have participated in a number of meetings, conferences and technical working groups, both within Australia and internationally, as detailed in Table 1. Presentations at these fora allow our staff to share the outcomes of SSB's research and monitoring programs with the broader scientific community and serve to benchmark our programs against national and 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 2018 TO 30 JUNE 2019

Conference	Place/date (no. Papers)
Life of Mine 2018	Brisbane, Queensland, 25-27 July 2018 (2 presentations)
SETAC-Asia Pacific, Weight of Evidence Symposium	Daegu, South Korea, 16 September 2018 (1 presentation and panel discussion)
Society of Ecological Restoration Australasia 2018	Brisbane, Australia, 25-27 September 2018 (4 presentations)
ForestSAT Association for Forest Spatial Analysis Technologies.	Maryland, USA 1-5 October 2018 (1 presentation)
International Atomic Energy Agency (IAEA) Modelling and Data for Radiological Impact Assessments (MODARIA II)	Vienna, Austria, 22–25 October 2018 (1 presentation; working group discussions)
South Pacific Environmental Radioactivity Association (SPERA) Conference 2018	Perth, Australia, 6-9 November 2018 (2 presentations)
Planning for Closure 2018	Santiago, Chile 7-9 November 2018 (1 presentation)
Australian & New Zealand Geomorphology Group Conference	Inverloch, Victoria, 4-8 February 2019 (1 presentation, participation in a workshop)

A key focus for the Branch is our engagement with the local Aboriginal community, including the Mirarr people, Traditional Owners of the land on which Ranger mine is located. This engagement facilitates the transfer of both cultural and environmental knowledge and information between local Indigenous people and SSB staff. The Branch employs an Indigenous Communications Officer, based at the Jabiru Field Station, whose role focusses on face to face engagement within local indigenous communities, providing a trusted source of information where other methods of communication are not as effective. SSB participated in a number of community activities in the reporting period, including the Mahbilil Wind Festival in Jabiru in September 2018 (Figure 5) and a Gunbalanya Community School careers day in November 2018. Our marquee at both these events was equipped with educative posters and videos and 'hands-on' activities including live samples of aquatic macroinvertebrates for people to look at under

microscopes. The branch has developed a new virtual reality experience to allow viewers to have an immersive view of some of SSB's research and monitoring activities (Figure 6).

Figure 5 Supervising Scientist Branch hosted an interactive display at Mahbilil Wind Festival in Jabiru in September 2018.

In October 2018 our scientists held a community BBQ at Mudginberri Billabong at which they demonstrated mussel collecting techniques as part of a long-term SSB monitoring project. Sharing information is of critical importance to local Aboriginal people and allows SSB staff to receive feedback and local knowledge to use in our research and monitoring programs.

Figure 6 Mirarr Traditional Owner Simon Mudjandi having a virtual reality experience of Supervising Scientist monitoring work in local streams, with explanation provided by one of our water monitoring scientists.

SSB also co-hosted a series of National Reconciliation Week themed events in Jabiru including a community AFL football game for young, mainly indigenous players from the Kakadu region. These events help to promote SSB's profile in the region, and provide avenues to familiarise local residents with the important work undertaken by the Branch.

In late 2018 SSB commenced using the Department of Environment and Energy's social media platforms to communicate the leading practice science and innovation undertaken by the Branch. Posts on Facebook, Twitter and LinkedIn have attracted a large number of unique views and shares, and have provided significantly greater reach of SSB content over traditional communication channels. Using social media allows us to generate detailed analytics to evaluate success, and enables the Branch to strategically target certain content for particular platforms and audiences. Table 2 details some of the analysis available for our social media communication activities in the reporting period, and shows that Facebook and LinkedIn perform most strongly in disseminating SSB information to a wide audience.

TABLE 2 ANALYSIS OF SOCIAL MEDIA REACH AT 19 FEBRUARY 2019

Social media platform	Total unique views	Average views per post	Highest unique views for one post
Facebook	**43568**	**4357**	**12445**
Twitter	**10901**	**1817**	**2819**
LinkedIn	**24834**	**4139**	**9335**
Total reach for all platforms	**79203**		

Plate 4 Kakadu National Park floodplain

3 SUPERVISION

SSB provides regulatory oversight of all uranium mining and exploration activities undertaken in the ARR. Throughout 2018-19 this oversight remained focussed on Ranger mine, 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 help ensure that the environmental management activities undertaken by ERA will achieve the Environmental Requirements and that the company remains in compliance with its Authorisation.

SSB also carries out a program of routine periodic minesite inspections (RPIs) and annual environmental audits for Ranger mine. These processes allow stakeholders to review ERA's environmental performance and include assessment of all reported environmental incidents and 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 km^2 Ranger Project Area (RPA) and is adjacent to Magela Creek, a tributary of the East Alligator River.

Ranger is an open cut mine and has been producing uranium oxide (U_3O_8) 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 3.

TABLE 3 WATER CLASSES AT THE RANGER MINE

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

The total rainfall recorded at Jabiru Airport for the 2018–19 wet season was 1237 mm. This was below the average annual rainfall of 1550 mm (Figure 7).

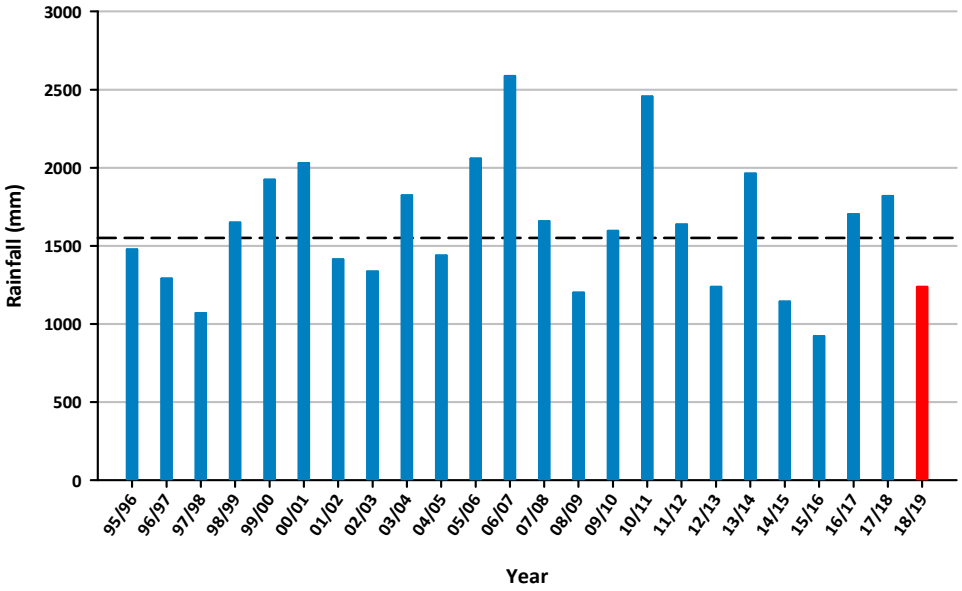


Figure 7 Annual (July - June) rainfall measured at Jabiru Airport from 1995 to 2019. Black dotted line indicates the average annual rainfall of 1550 mm.

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 3). 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 4.

TABLE 4 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
2018-19	338	2118

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

spinclear cyclones and made other minor adjustments to the operation of the brine concentrators which contributed to distillate production exceeding 115% of nominal capacity in 2018-19. ERA is exploring other options to further optimise the performance of the brine concentrator, including fan upgrades to provide additional capacity for process water treatment.

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' have been completed with refurbishment activities well advanced. Commissioning of the HDS plant is expected to be completed during the third quarter of 2019.

Treatment of pond water through the existing water treatment plants (WTP) generates brines that are added to the process water inventory. ERA are constructing a brine squeezer which is designed to further treat brines from pond water treatment plants to reduce the volume added to the process water system. Commissioning of the brine squeezer is planned to be completed towards the end of 2019. ERA is also investigating opportunities for the brine squeezer to be used to treat better quality process water from sources such as the Pit 1 decant system.

A number of other initiatives were implemented during 2018-19 to further reduce the volume of process water on-site, including improved catchment management and the development of interception systems to divert better quality water from the process water system.

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 3). 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 5 shows the annual total volumes of pond water treated and resulting permeate produced. The volume of pond water treated over the reporting period was lower than previous years due to the below average 2018-19 wet season and increased pond water requirements for commissioning the brine squeezer.

TABLE 5 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
2018-19	1661	1146

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 December 2018, ERA submitted an application to vary the permeate release conditions to include direct release of permeate to MG001 (Figure 3). The SSB assessment concluded that through existing and additional controls proposed in the application, the discharge of permeate presents a low risk to the receiving aquatic environment and to the achievement of the Environmental Requirements - Primary Environmental Objectives.

In May 2018 ERA commenced operation of two turbomisters on the eastern side of RP1 and are installing an additional 12 turbomisters in 2019. These turbomisters are used as a contingency 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 mitigate 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 stakeholders with some concerns raised by SBB regarding water quality monitoring and potential impacts communicated to ERA by DPIR in March 2018. ERA is currently reviewing options and intends to provide an updated application later in 2019.

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 3).

The volume of water released actively during the wet season generally depends on the amount of rainfall in a particular season, and the water management strategies in place

at the time. Table 6 shows the total volume of water actively released from the site since 2013–14 (noting that water released passively is not quantified). There was a significant reduction in the annual release volumes for 2018-19 compared to previous years. As discussed above this is in part attributed to the below average rainfall over the 2018-19 wet season and operational requirements for pond water that would usually be treated and released.

TABLE 6 ANNUAL WATER RELEASE VOLUMES

Year	Volume (ML)
2013-14	1674
2014-15	772
2015-16	117
2016-17	1573
2017-18	1521
2018-19	504

3.1.1.2 Tailings and waste management

TABLE 7 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	2015
Tailings transfer from TSF to Pit 3	2016

Table 7 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).

The primary mechanisms for disposal of controlled wastes include disposal in Pit 3, incineration via turbo burning and off-site recycling. Non-hazardous wastes are disposed of either through disposal to landfill or off-site recycling.

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, may enable 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 (refer Section 1.3). In parallel with the development of the closure criteria, SSB has developed a suite of Rehabilitation Standards (http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards). These non-binding environmental Standards are 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 are based upon the highest level of ecosystem protection and will provide benchmarks against which the achievement of the rehabilitation objectives can be assessed. To ensure the relevance of the Standards routine updates will occur as additional knowledge becomes available. Throughout 2018-19 additional ecotoxicological testing was undertaken to improve the accuracy of the water quality Standards, and the SSB continues to refine the ecosystem restoration Standard as more information is gained through monitoring the vegetation surrounding the Ranger mine site, which provides the reference condition upon which site restoration will be based. Further information on the current status of the Standards is provided in Chapter 5.1.

3.1.2.2 Ranger Mine Closure Plan

ERA is required to submit a Mine Closure Plan annually for approval, under both the Commonwealth and Northern Territory legislation. The 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.

The Ranger Mine Closure Plan (RMCP) was released publicly by ERA on 5 June 2018, which included updates on the status of rehabilitation activities and addressed some of the feedback provided on an earlier draft of the plan by SSB and other stakeholders. SSB undertook a detailed technical review of the plan and published an Assessment Report on 11 September 2018 (http://www.environment.gov.au/science/supervising-scientist/publications/ranger-mine-closure-plan-assessment-report). SSB's assessment of the RMCP found that the broad rehabilitation strategy is acceptable; however, a significant amount of additional evidence is required to demonstrate that all the Environmental Requirements can be achieved. The Supervising Scientist's recommendations included the need for:

- more detail and transparency around contingency planning for key rehabilitation activities
- a focus on full ecosystem restoration, including establishment of ecological processes and faunal recolonisation
- improved modelling to provide greater certainty around predictions of future contaminant concentrations in surface waters surrounding the minesite.

The Minister for Resources and Northern Australia approved the RMCP on 20 December 2018, noting several areas of improvement (giving effect to key recommendations in SSB's Assessment Report) that would be required for approval of future iterations of the plan.

In accordance with regulatory requirements, the RMCP will be updated annually 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, 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. Examples of major activities that will be assessed via a stand-alone approval process include the decommissioning of the TSF; backfill of Pit 3; and construction and revegetation of the final landform.

3.1.2.3 Current status of rehabilitation

Approved progressive rehabilitation works are being undertaken on-site, including tailings deposition into the mined-out pits, and the final backfill of Pit 1 and subsequent construction of the final landform. Table 8 shows the performance metrics as at the end of June 2019 for major rehabilitation activities currently occurring on-site. These are discussed in the following sections. Table 9 summarises the approvals related to rehabilitation and Table 10 summarises the rehabilitation works that have been carried out to date.

TABLE 8 KEY REHABILITATION METRICS

Activity	Completed	Remaining
Dredging of TSF tailings[1]	11.8 Mm^3	11.8 Mm^3
Pit 1 Backfill	5.9 Mt	5.1 Mt
Brine injection	82 ML	1839 ML

3.1.2.4 Pit 1

Mining in Pit 1 ceased in 1995, 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 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 μS/cm.

TABLE 9 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
Pit 3 sub-aqueous deposition trial	2018
Application Pit 3 Tailings Deposition	2019
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 and monitoring	2019
TSF	
TSF east wall notching and reduction in TSF MOL	2018
TSF north wall notching Stage 1 and TSF MOL adjustment approach	2018
TSF north wall notching Stage 2 and reduction in TSF MOL	2019
Ranger 3 Deeps	
Ranger 3 Deeps exploration decline decommissioning	2018
Water treatment and release	
Application to change permeate discharge conditions	2019
Brine squeezer operation	2019
Site-wide activities	
Ranger Mine Closure Plan	2018
Surface water modelling	Still under assessment
Groundwater modelling	Still under assessment

TABLE 10 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
Commencement of sub-aqueous deposition	2019
TSF	
Tailings dredging commenced	2016
Commissioning of a second tailings dredge	2019

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 (http://www.environment.gov.au/resource/assessment-report-ranger-pit-1-final-tailings-deposition-level-7-mrl) 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. Assessment of this application by SSB identified that further information would be required to demonstrate that the proposed Pit 1 final landform will be able to support a sustainable

ecosystem in the future, and will effectively isolate tailings from the environment. SSB also recommended that a monitoring program be developed to ensure critical data is collected during and after the construction of the Pit 1 landform to inform tailings consolidation model verification, relevant KKNs and refine future rehabilitation activities as required. To assist ERA in identifying key monitoring requirements during progressive rehabilitation (including Pit 1), SSB hosted a workshop on 4 September 2018 which involved ERA and both internal and external stakeholders.

On 1 March 2019, ERA submitted an updated application to proceed with placement of the final 6 million tonnes of backfill material. The updated application included a proposed monitoring framework describing the Pit 1 rehabilitation monitoring activities and is intended to provide the basis for progressive rehabilitation of the wider Ranger site. This updated application addressed comments provided by the Supervising Scientist on the original 2018 application, particularly in relation to predicting future plant available water in the waste rock substrate. The Supervising Scientist endorsed regulatory approval of the Application, subject to the implementation of the Pit 1 Progress Rehabilitation Monitoring Framework. Regular meetings are held between SSB and ERA to help develop and review detailed monitoring and research programs.

This working group has since been established with meetings scheduled on a fortnightly basis. The initial focus has been on developing monitoring plans for construction phase activities. Draft plans have been developed for material movement, tailings settlement and particle size distribution within the landform. A timeline of progressive rehabilitation activities has been developed to prioritise the development of future monitoring plans and to ensure that research and monitoring data collected from the TLF is also included.

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 (waste produced from treatment of process water) 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.

Several projects are underway to transfer all tailings into Pit 3 for permanent disposal. This includes the deposition of mill tailings directly into to Pit 3 and the transfer of tailings from the TSF to Pit 3 using two custom-built dredges. Brine injection into the waste rock under fill commenced intermittently 2016 but 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 or treated through the processing plant to recover additional uranium product. 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 maintained at an optimal depth for operation of the tailings dredges. 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).

In October 2017 SSB completed a detailed technical review of tailings deposition in Pit 3 which concluded that continuing the current deposition method may extend the rehabilitation timeframe and potentially impact on environmental outcomes. In January 2018 a technical workshop was facilitated by ERA with information presented by ERA demonstrating that proposed changes to the tailings deposition strategy did not increase the risk to the environment.

In November 2018 ERA commenced trials of a new tailings deposition method into Pit 3 involving placement of tailings sub-aqueously directly into the Pit 3 water column. This trial was used to demonstrate 'proof of concept' and assist in reducing tailings segregation that had occurred through sub-aerial deposition from the Pit 3 walls.

In April 2019 ERA submitted an updated application to deposit tailings into Pit 3 informed by the current deposition trials and to address outstanding SSB concerns on tailings management. This application proposed that dredged tailings from the TSF (including those from a second dredge) would be deposited sub-aqueously into the Pit 3 water column. Mill tailings would continue to be deposited sub-aerially, with the installation of additional discharge locations along the pit wall. The application also proposed that a maximum operating level for water in Pit 3 would be established at +3.5 mRL and the final consolidated tailings level would increase to -15 mRL from the previously-approved level of -20 mRL. The SSB undertook a detailed technical review of the application and concluded that the changes in the deposition strategy did not substantively increase the risk to people or the environment. The SSB also noted in this assessment that:

- further work was required to reduce the uncertainty in potential future impacts from mine contaminants including tailings to the off-site environment.
- ongoing refinement of tailings consolidation modelling and post closure solute egress modelling should be undertaken by ERA.
- that the maximum post consolidation tailings level be better defined to reflect the potential variability in the final tailings surface.

On 18 July 2019, the revised deposition strategy was approved by DPIR, noting that further consideration was required to support the application request to change the final maximum tailings level to -15 mRL.

3.1.2.6 Tailings Storage Facility

Tailings stored in the TSF are currently being transferred to Pit 3, the final disposal location. Advice provided by ERA indicates that tailings transfer is behind schedule due to sub-

optimal dredge performance. ERA installed a second dredge in the TSF in June 2019, which is expected to increase the tailings dredging rate and ensure the transfer of tailings from the TSF to Pit 3 is completed on schedule in Q1 2021.

In February 2018 ERA submitted an application to notch the eastern embankment of the TSF. This notching to reduce the TSF crest height from 60.5 mRL to 51.0 mRL 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.

In August 2018 ERA submitted an application to construct a second notch and access ramps in the northern embankment of the TSF. The purpose of this notch was to provide ongoing dredge maintenance access and would be constructed in multiple stages as the water level in the TSF reduced through dredging activities. Supporting this application, ERA put forward a method to establish the MOL to support future staged notching of the northern embankment based upon the new certified crest height and ensuring there was sufficient freeboard to contain process water during extreme rainfall events. Stage 1 of this application and the method to establish future MOLs was assessed and supported by SSB. ERA completed construction of Stage 1 in December 2018 which reduced the TSF certified crest height from 51.0 mRL to 48.5 mRL. Stage 2 of this northern embankment notch to facilitate the successful launch of the second dredge in the TSF was completed in June 2019 which reduced the certified crest height to 45.1 mRL.

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 has met five times during the 2018–19 reporting period. Significant agenda items discussed at the meetings included the following:

- ERA resourcing and workforce planning
- assessment and approval streamlining and potential variations to the Ranger Authorisation
- Pit 3 brine injection, tailings deposition and tailings consolidation modelling
- site water management processes, pond water treatment initiatives and water inventory forecasting
- Pit 1 water balance, contaminated groundwater management, tailings settlement monitoring and bulk backfill strategy
- 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.

3.1.3.2 Audits and inspections

The 2018 annual environmental audit on behalf of external stakeholders of Ranger mine was undertaken from 17 September to 21 September 2018, comprising three days on-site and two days in the ERA Darwin Offices.

In 2018, variation of the Ranger Authorisation granted under the Northern Territory *Mining Management Act*, resulted in amendments to a number of statutory requirements. In particular, changes were made to clarify expectations around environmental monitoring, management and reporting. The subject of the 2018 audit was to assess ERA's capacity to comply with the amended Ranger Authorisation, with a strong focus on the newly embedded expectations relating to the Ranger Mine Closure Plan, groundwater and rehabilitation reporting requirements.

The audit comprised 26 questions and the grading for each question was assigned based upon the status of management strategies being developed and in place, in consideration of potential consequences to the environment and/or rehabilitation and closure timeframes.

The audit found that generally ERA had commenced developing strategies to address the newly embedded planning and reporting requirements within the Authorisation with no statutory breaches to the requirements of the Authorisation determined during the audit.

Three Category 2 Non-Compliances were identified that related to ERA not complying with their own management systems which may create the potential for future non-compliance to the Authorisations environmental protection intent. These non-compliances related to:

- The site Compliance and Obligations Register has not been updated with the amended Authorisation requirements and ERA could not demonstrate a systematic roll out of these amended Authorisation requirements.
- The lack of a formal process to monitor, prioritise and track recommended actions from the Annual Groundwater Report.
- The failure to undertake validation and archiving of continuous water monitoring data in accordance with documented procedures.

Five conditional findings were also identified, where the audit team felt improvement was needed or specific components of the audited activity had yet to be fully implemented. These conditional findings related to:

- ERA commitments and stakeholder recommendations tracking for routine reports and plans.
- Potential variation of the submission date for components of the Annual Groundwater Report.
- Assessment of cumulative surface water release loads throughout the wet season.
- Development of a procedure for calculating the annual surface water loads.
- Assuring that input of laboratory data into LIMS is undertaken in a timely fashion.

Ten observations were provided by the audit team for consideration by ERA aimed at improving the ERA systems or activities relevant to the questions posed.

Follow-up on the 2017 Annual Environmental Audit significant findings concluded that all matters identified had been satisfactorily addressed by ERA at the time of the 2018 Annual Environmental Audit. The 2019 Annual Environmental Audit is scheduled for September as shown in in Table 11.

The 2019 Ranger RPI and audit program was agreed by stakeholders in December 2018. Each RPI in the program has a specific theme, aligned with relevant activities on-site (Table 11). RPIs were carried out as scheduled during 2018–19 and Table 12 shows the focus areas for each of the RPIs.

TABLE 11 2019 RANGER ROUTINE PERIODIC INSPECTION PROGRAM

Month	Primary Focus
January	Surface water monitoring and release management (completed)
February	Radiation management (completed)
March	TSF 6 monthly inspection, dredging & tailings/water transfer (completed)
April	Land use management: Weed and Fire management (completed)
May	Water treatment and management (completed)
June	Groundwater monitoring and management (completed)
July	Rehabilitation activities status and planning (complete)
August	TSF Annual Inspection
September	Annual Stakeholder Audit
October	Revegetation
November	Hydrocarbons, Non-mineral contaminated sites and waste management
December	Crushing, milling and processing circuits

3.1.3.3 Environmental incidents

During 2018-19, 18 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 hydrocarbon leaks from mobile plant and equipment. The number of reported incidents has decreased from the 23 incidents reported in 2017–18.

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 six years is shown in Figure 8. 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 9 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. To date, the number of process water, tailings and hydrocarbon related incidents have all decreased in 2018–19 from the number reported in 2017–18.

TABLE 12 RANGER ROUTINE PERIODIC INSPECTIONS 2018-19

Month	Primary Focus
July 2018	Rehabilitation activities and planning, Pit 3 CPT testing, TSF East Wall notching, Pit 1 backfill, revegetation activities
August	TSF annual inspection, reported incidents for July/August 2018, fire ring main upgrades, site rehabilitation and closure update
September	Annual environmental audit by stakeholders
October	ERA transformations initiatives, vehicle clearance incident 25/09/2018 and TSF North Wall notching
November	Bulk acid storage, HDS plant refurbishment, brine squeezer construction, ERA management reporting, southern boundary erosion repairs and reported incidents for October/November 2018
December	Processing area inspection, process safety activities and initiatives, Pit 3 sub aqueous deposition trials, GCT2 water diversion systems, production improvements initiatives, and reported incidents for November/December 2018
January 2019	Surface water monitoring and release, ERA release plan calculator, Pit 3 sub aqueous deposition trials, process water enhanced evaporation and reported incidents for January 2019.
February	Radiation management, 2018 radiation and atmospheric monitoring results, contamination monitoring and reported incidents for February 2019.
March	TSF post-wet season inspection, TSF dredging activities, 2018 Annual environmental audit follow-up and initiatives and reported incidents for March 2019.
April	Weed and fire management planning and status, revegetation nursery construction, Pit 3 sub-aqueous deposition trials and reported incidents for April 2019.
May	HDS plant refurbishment, brine squeezer, TSF north wall notch (Stage 2), TSF-Pit3 tailings and process water line upgrades, GCT2 water diversion systems and reported incidents May 2019.
June	Groundwater monitoring bore reconciliation program, Pit 1 backfill progression, bulk acid bund refurbishment, stockpile bore program, West Indian Pinkroot management update and reported incidents June 2019.

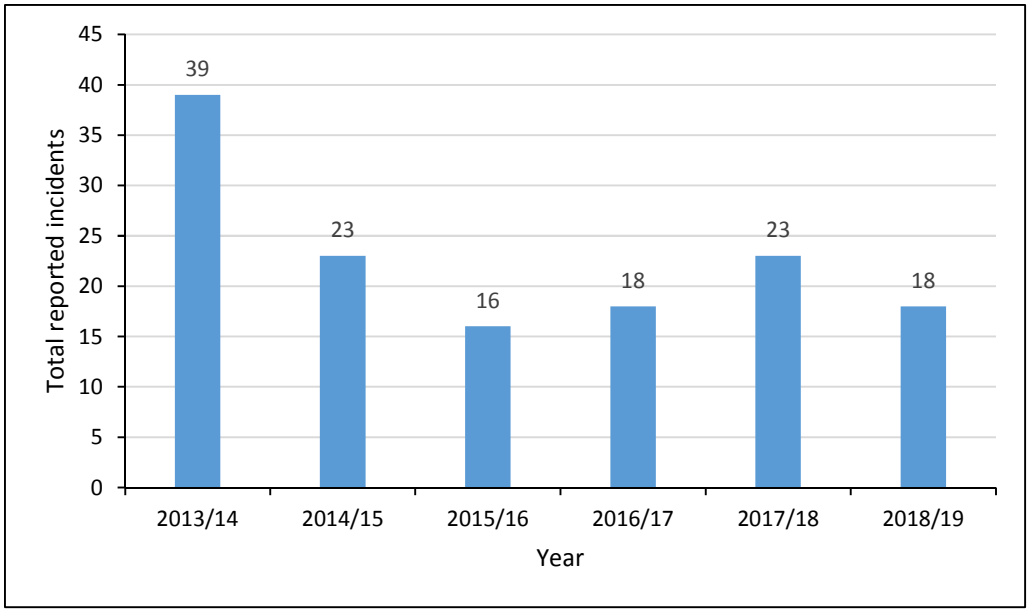


Figure 8 Ranger mine reported environmental incidents by year

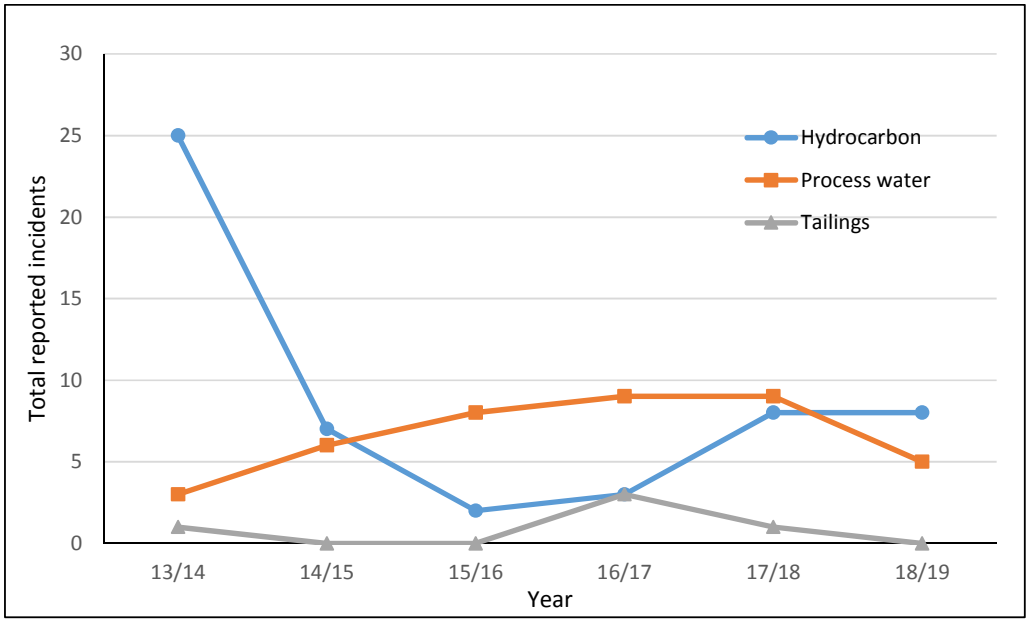


Figure 9 Hydrocarbon, process water and tailings incidents by year

3.1.3.4 Significant incidents

No incidents requiring formal investigation by SSB have been reported during 2018–19, however two notable incidents were reported:

On 21 September 2018 a hire franna (crane) was returned to the supplier without adequate cleaning prior to leaving the site. No radioactivity was detected from the uncleaned area of the crane and it was returned to Ranger for additional cleaning. Following investigation of the incident by ERA a number of improvements in the vehicle clearance procedures and temporary controlled vehicle management have been implemented on-site. Stakeholders followed up on this incident through the RPI process and were satisfied with the remediation activities undertaken and improved control strategies implemented to minimise the risk of re-occurrence.

On 17 April 2019, ERA notified stakeholders that an unfamiliar weed, identified by the Northern Territory Herbarium as West Indian Pinkroot (*Spigelia anthelmia*), had been found on site. This weed had not previously been recorded in Australia and ERA surveys have confirmed that the infestation is currently restricted to the Ranger mine operational areas. In consultation with the Northern Territory Weeds Branch, ERA is developing a management program for this weed which will include an ongoing program of surveying, internal and external communication strategies, the establishment of control zones and the development of a treatment and monitoring program. Stakeholders continue to monitor the implementation of these weed management strategies through the RPI process.

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

TABLE 13 SUMMARY OF SIGNIFICANT INCIDENTS

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

3.1.4 Radiation protection

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). The data presented below is summarised from ERA's 2018 radiation protection and atmospheric monitoring program.

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.

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. Dose constraints for the Ranger operation are revised annually and detailed in ERA's Annual Radiation and Atmospheric Monitoring Report. The monitoring results for 2018 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 14. For both designated and non-designated workers the 2018 dose was comparable to the 2017 dose as shown in Table 15 and Table 16 respectively.

TABLE 14 2018 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	7.0
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

TABLE 15 2018 DESIGNATED WORKER DOSE (mSV)		
	2018	**2017**
Occupational dose limit	20	20
Mean annual effective dose (% of dose limit)	1.23 (6.1%)	1.28 (6.4%)
Maximum annual effective dose (% dose limit)	3.64 (18.2%)	3.96 (19.8%)

TABLE 16 2018 NON-DESIGNATED WORKER DOSE (mSV)		
	2018	**2017**
Occupational dose limit	20	20
Mean annual effective dose (% of dose limit)	0.15 (0.75%)	0.14 (0.7%)
Maximum annual effective dose (% dose limit)	1.08 (5.4%)	1.13 (5.7%)

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

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 17 provides a summary of annual average radon progeny potential alpha energy concentration (PAEC) in air and estimated doses to the public in 2018. The mine-derived annual dose from radon progeny in air has been estimated to be 0.022 mSv at Jabiru town which is 2.2% of the public dose limit of 1 mSv in a year and comparable to the 2017 dose of 0.023 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. In 2018 the International Commission on Radiological Protection changed the recommended new radon dose conversion factors for radon however these have yet to be formally adopted in Australia. It is likely that when adopted, these new dose conversion factors will increase the reported annual dose and mine derived dose from radon progeny. When the new dose conversion factor is applied to the 2018 monitoring results, the mine derived dose to the public from radon progeny increases from 0.022 mSv to 0.06 mSv which is still well below the dose limit of 1 mSv.

TABLE 17 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN

	2018	2017
Annual average PAEC [µJ m^{-3}]	0.044	0.043
Total annual dose [mSv][1]	0.423	0.414
Mine-derived dose* [mSv]]	0.022	0.023

[1]The radon progeny PAEC difference used in the mine-derived dose calculation was 0.017 µJ/m^3 for 2018 and 0.013 µJ/m^3 for 2017

ERA uses high volume air samplers to monitor airborne concentrations of LLAA in the township of Jabiru and at Jabiru East. Table 18 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 m^3 h^{-1} and assumed full year occupancy of 8,760 hours.

TABLE 18 LLAA RADIONUCLIDE CONCENTRATIONS IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN

	2018	2017
Annual average concentration ($Bq_{\alpha}^{-1}m^{-3}$)	1.5×10^{-4}	1.3×10^{-4}
Total annual dose (mSv)	0.006	0.005
Mine-derived dose* (mSv)	3.1×10^{-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 the lease will not expire until August 2024, and may be subject to renewal.

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 was conducted by ERA at Jabiluka and Djarr Djarr in June 2018 to assess the 5-year survival rates of vegetation planted in 2013. This survey included assessment of species specific density, recruitment, growth, survival rates where possible and general ecosystem health with a report on this survey currently being developed. During 2018, ERA commenced mulch trials at Jabiluka in areas where higher mortality rates had resulted in minimal success of revegetation.

ERA uses herbicide to actively manage weeds at the Jabiluka mineral lease. In 2018-19, 456 hours of weed spraying activities were undertaken at the Jabiluka and Djarr Djarr sites. This is a significant increase from the 2017-18 where 321 hours of weed spraying activity were undertaken. The ERA survey results for the 2018-19 weed spraying season indicate that both Djarr Djarr and Jabiluka show a decrease in weed density, compared to the 2017-18 survey. This decrease in weed density is in part attributed to the increased weed spraying hours undertaken in 2018-19. Due to the reduction in the use of glyphosphate for 'blanket spraying' and the use of more targeted residual herbicides it was noted that native grass abundance has increased, particularly at Djarr Djarr.

ERA undertakes annual fuel-reduction burning around the Djarr Djarr and Jabiluka sites to reduce the effects of wildfires on the revegetated areas. In May 2019, controlled burns were conducted around the perimeter of the Jabiluka and Djarr Djarr rehabilitated area to protect the sites revegetation. A follow up burn was conducted at the end of June

2019 at Jabiluka. Spear grass that has established within the Jabiluka fenced area is planned to be burnt during the 2019-20 wet season.

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 for the 2018-19 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 coarse 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 2018–19, 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. In July 2018 SSB reviewed the hydrogeological information available on the Mine Valley Bores and provided recommendations for additional groundwater monitoring to be conducted. This monitoring determine if a contamination plume is present and would assist in improving understanding of the hydraulic gradients in the Mine Valley area.

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 two times during 2018–19 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 2018–19 pre-wet season inspection was conducted on 16 November 2018 and focussed on landform stability, general vegetation health and the status of groundwater and surface water monitoring sites. The inspection identified that some debris had accumulated in the JSCTN2 and JSCTC2 surface water monitoring sites and monitoring equipment had yet to be installed by ERA. Follow up through the MTC meeting in January 2019 confirmed these matters had been dealt with prior to the commencement of significant 2018-19 wet season rains. Stakeholders also noted that the wet season

burning and early dry season weed spraying conducted during 2018 at Djarr Djarr continued to result in a noticeable reduction in weeds observed on-site.

The 2018–19 post-wet season inspection was conducted on 18 April 2019. It was noted that minor maintenance of the site access tracks was required and that minor gullying within some areas of the rehabilitated areas had increased as preferential drainage lines continue to develop. Weed and fire management over the 2019 dry season to promote successful revegetation remain the ERA management priorities at Jabiluka.

No environmental incidents have been reported for Jabiluka during 2018–19.

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 tube stock mortality. Feral animals and wild cattle are believed to contribute to tube stock mortality with DevEx repairing the mine perimeter fence, and in consultation with local ranger groups, implementing a program to eradicate these animals within the fenced area during 2018–19.

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 spraying recommenced in January 2019, however due to equipment failure was not as comprehensive as planned. Controlled burns around the perimeter of the Naberlek mine area were also conducted in January 2019 by DMED Rangers.

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 a temporal assessment of weed density and distribution across the lease, helping to evaluate the effectiveness of DevEx's weed management program. Further weed mapping was undertaken in January 2019 which is currently being assessed by DevEx. Observations on the ground in 2018-19 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 2019 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. Further groundwater monitoring was undertaken in September 2018 which has yet to be reported to stakeholders and additional groundwater monitoring is planned for September 2019.

At the beginning of the 2016-17 wet season SSB deployed three continuous EC sensors, one in Kadjirrikamarnda Creek downstream of the former minesite, and two in Cooper Creek at sites upstream and downstream of the former minesite. The 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 and SSB will continue to monitor EC 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. DevEx intends to submit an application for the remediation of the RAA to the regulator later in 2019. 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 (MMP) for 2018 dry season works was submitted in July 2018 with a subsequent amendment submitted in October 2018. The proposed work program for 2018 included further geophysical surveying and a small drilling program. Following assessment this work program was supported by SSB in November 2018. Due to operational matters, including the ongoing consultation between DevEx and the NLC regarding ownership and liability of some residual infrastructure on-site, the 2018 work program was deferred until the second half of 2019. DevEx was granted approval to carry over the 2018 MMP work program to the 2019 field season by DPIR in May 2019. An updated MMP detailing the status of rehabilitation activities at Nabarlek is expected to be submitted later in 2019.

3.3.3 Assessment activities

Due to the minimal nature of the work activities that were proposed by DevEx during 2018, a stakeholder inspection was not conducted. However, a site inspection was undertaken opportunistically by SSB as part of a pre-wet season site visit to install water quality loggers on 20 December 2018. The main objective of the site inspection was to determine whether the exploration and rehabilitation activities planned for the 2018 dry season as detailed in the DevEx 2018 MMP had been undertaken. The inspection indicated that proposed repair works to damaged fencing and groundwater monitoring bore collars identified during the 2017 stakeholder inspection had yet to be undertaken. It was also noted that that some areas of the site had been recently burnt. In June 2019 DPIR and NLC undertook an inspection and MMP compliance assessment of drilling activities occurring on the Devex exploration leases adjacent to the former Nabarlek mine (discussed in Section 3.4.2.2). During this inspection aerial drone surveys of the Nabarlek mine were undertaken and the site status was reviewed. No significant issues were identified and the completion of repair works to damaged fencing was confirmed.

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. The 2019 Nabarlek MTC has been delayed until later in 2019 to allow DevEx to finalise and present their preferred remediation strategy for the RAA to MTC stakeholders.

There were no environmental incidents reported for Nabarlek during 2018-19.

3.4 Other activities in the Alligator Rivers Region

3.4.1 Uranium rehabilitation projects

3.4.1.1 South Alligator Valley uranium mines and containment facility

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. In May 2019 SSB inspected the facility with representatives from Parks Australia. It was noted during this inspection that mission grass continues to be a concern in the containment facility with a noticeable increase in spatial distribution and density compared to previous inspections. A build-up of grass-related fuel load around the perimeter of the facility which posed a risk to the revegetation was also noted during this inspection. An expanded weed spraying program and continuation of a program of late wet season/early dry season low intensity burns to reduce fuel load and protect monitoring equipment was recommended from the SSB inspection.

3.4.2 Uranium exploration projects

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

In 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.

In June 2018, Vimy Resources submitted a MMP for their 2018 dry season exploration program for the Wellington Range and King River Joint Venture (WRKRJV) Project which included 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. Following assessment, this was supported by SSB and subsequently approved by DPIR in August 2018. In May 2019, Vimy Resources submitted an updated MMP for their 2019 work program which included drilling of 61 RC/diamond drill holes and construction of three additional groundwater extraction bores. This was assessed by SSB and approved by DPIR in June 2019.

The environmental audit of the WRKRJV project was undertaken from 4 October to 5 October 2018. The audit team was made up of personnel from SSB, NLC and DPIR and the subject of this audit was to assess compliance to selected environmental management commitments contained within the approved WRKRJV Project 2018 MMP.

The audit comprised 37 commitments from the WRKRJV MMP across a range of environmental management aspects including radiation, flora and fauna, land disturbance, fire and weeds. The audit found that generally Vimy had well developed and implemented environmental management systems with no non-compliances determined during the audit.

Four conditional findings were identified, where the audit team felt improvement was needed or management practices did not fully align with the relevant commitments within the MMP. These conditional findings related to weed mapping and reporting, ground disturbance sign-off, mapping of historical domestic waste pits and incident reporting.

Eight observations were provided by the audit team for consideration by Vimy aimed at improving the systems or activities relevant to the commitment. There was also one question on notice regarding non-return valves at the refuelling station and one commitment related to triennial weed management audits that was unable to be verified.

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 company's ARR projects occurred as a result of this name change.

The MMP for the 2018 dry season works was submitted by DevEx in June 2018 and SSB supported the acceptance of this updated MMP in August 2018. The exploration program for 2018 involved induced polarisation (IP) surveys. Reverse circulation and

diamond drilling proposed within the MMP was not undertaken. Due to the non-invasive nature of the exploration undertaken and limited time on-site, SSB has not undertaken any site inspections or audits of this project during the 2018.

An updated MMP for the 2019 field season was submitted by DevEx in May 2019 and following assessment by SSB, approved by DPIR in June 2019. This work program comprised non-invasive geophysical work and drilling of up to 18 RC and diamond drill holes. An inspection and MMP compliance assessment for these drilling activities was conducted by DPIR and NLC from 27-28 June 2019. This assessment identified no significant incidences of non-compliance with the approved MMP, and concluded that the drilling activities were being undertaken in a manner that did not pose a significant environmental risk. The inspection also identified improvement opportunities relating to drill site housekeeping and additional bunding of hydrocarbon sources.

3.4.2.3 Alligator Energy Tin Camp Creek Project and Beatrice Project

The 2018 MMP for the Tin Camp Creek and Beatrice Projects were submitted in June 2018 and following review, the SSB supported acceptance of the plan in July 2018. The 2018 work program comprised further surface sample collection and geophysical surveys during a small campaign scheduled for later in 2018. Subject to the results of these geophysical surveys a small drilling program of up to 4 drill holes at the Beatrice Project and 10 drill holes at the Tin Camp Creek Project were proposed. The MMPs for these projects were assessed and an amended MMP for the Tin Camp Creek Project was submitted in August 2018 for the establishment of a fly camp near the area where drilling would occur. Following assessment, SSB supported this amendment at the end of August 2018. An updated MMP for the 2019 work programs for the Beatrice Project and Tin Camp Creek Project were submitted in June and July 2019 respectively. No significant disturbances were proposed, with surface sampling and re-logging of historical drill cores the primary focus of the 2019 field season.

The 2018 audit of Alligator Energy's Tin Camp Creek and Beatrice Projects was undertaken from 11–12 October 2018 to coincide with drilling activities. The objective of this audit was to assess the progressive rehabilitation of the 2018 drilling activities and to assess the environmental management controls described within the approved 2018 MMP. The audit found that Alligator Energy had well developed and implemented environmental management systems with no non-compliances or conditional findings determined during the audit. A number of recommendations were made for consideration in the development of future MMPs pertaining to clearance activities, radiation monitoring and internal sit inspections.

3.4.2.4 UXA Resources Nabarlek Group Project

No exploration activities were proposed or carried out at this site during 2018 or are proposed in 2019, therefore SSB has not undertaken any site inspections or audits during the 2018–19 reporting period.

Plate 5 SSB field team deploying underwater cameras in Georgetown Billabong

4 MONITORING

4.1 Ranger mine environmental monitoring

In order to ensure protection of the environment and the people of the ARR, ERA is required to achieve specific Water Quality Objectives (WQOs) for both Magela and Gulungul creeks (Figure 3). Because these WQOs are largely based on site-specific biological effects data, their achievement provides a high level of 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 incorporate a tiered management response framework, with a hierarchy of risk-based trigger values for the key contaminants of concern, each trigger value initiating a different degree of active management and reporting:

Focus Trigger Values – Values that are above the *Focus level* but below the *Action level* will result in a *watching brief*, which involves precautionary ongoing data assessment and possibly further sampling if required.

Action Trigger Values – Values that are above the *Action level* but below the *Guideline/Limit* will result in a *data assessment,* and where the data shows the value represents a trend away from background ERA must undertake:

- An *investigation* into the cause of the exceedance; and
- *Correction* of the cause if it is deemed to be mining related.

Investigation, Guideline and Limit Trigger Values – Values that are above the *Limit* will result in a *full investigation*, including:

- Determining the cause of the exceedance;
- Collecting further samples and data; and
- Undertaking immediate *correction* of the cause if it is deemed to be mining related.

Values that are higher than the *Guideline* are treated the same as an exceedance in the *Limit* value, except:

- When there is a corresponding increase at the upstream site; and
- For Mn only, when the flow is less than five cumecs.

Under the above circumstances a *Guideline* exceedance will be treated as for an *Action* exceedance.

In addition to ERA's statutory monitoring program, SSB conducts an independent routine environmental monitoring program that uses multiple lines-of-evidence, including water quality indicators, to prevent and detect environmental impacts.

Two broad approaches are used by SSB to detect and assess possible environmental impacts from mine water input to receiving surface waters around the minesite, including: (1) monitoring for early detection and impact prevention, and (2) monitoring for assessment of long-term ecosystem-level responses.

Methods used for early detection of water quality deterioration and prevention of impacts include:

(i) Real-time continuous monitoring – through measurement of chemical and physical indicators in surface water;

(ii) In situ toxicity monitoring - through assessment of freshwater snail reproduction rate; and

(iii) Bioaccumulation monitoring - through assessment of metals and radionuclides in freshwater mussels.

Methods used for the long-term assessment of ecosystem-level responses include comparison benthic macroinvertebrate and fish community data from late wet season sampling in Magela and Gulungul Creek sites with historical data and data from control sites in streams unaffected by mining.

The dates of wet season flow commencement and cessation, since the 2009–10 wet season, are shown in Table 19.

TABLE 19 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
2018-19	14 Dec 2018	28 Jun 2019	196	14 Jan 2019	31 May 2019	137

In any circumstances where the water quality in Magela or Gulungul Creeks is observed to deteriorate the Supervising Scientist is able to undertake specific environmental investigations. No such investigations were undertaken during the 2018-19 wet season, and no environmental impacts from Ranger mine's operations to the off-site environment were observed through SSB's monitoring program. All monitoring results are presented in more detail below.

4.1.1 Early detection monitoring in Magela Creek

Chemical and physical monitoring

Magela Creek flows to the north-west of the Ranger minesite and receives clean runoff and actively and passively treated mine waters via Retention Pond 1, the former Djalkmara Billabong and Georgetown Creek (Figure 3). The water quality monitoring program carried out by SSB showed that all water quality objectives for Magela Creek were met during the 2018–19 wet season. The electrical conductivity (EC) measured in Magela Creek downstream of the mine inputs were similar to previous wet seasons (Figure 10), and the Investigation Trigger value was not exceeded (Figure 11).

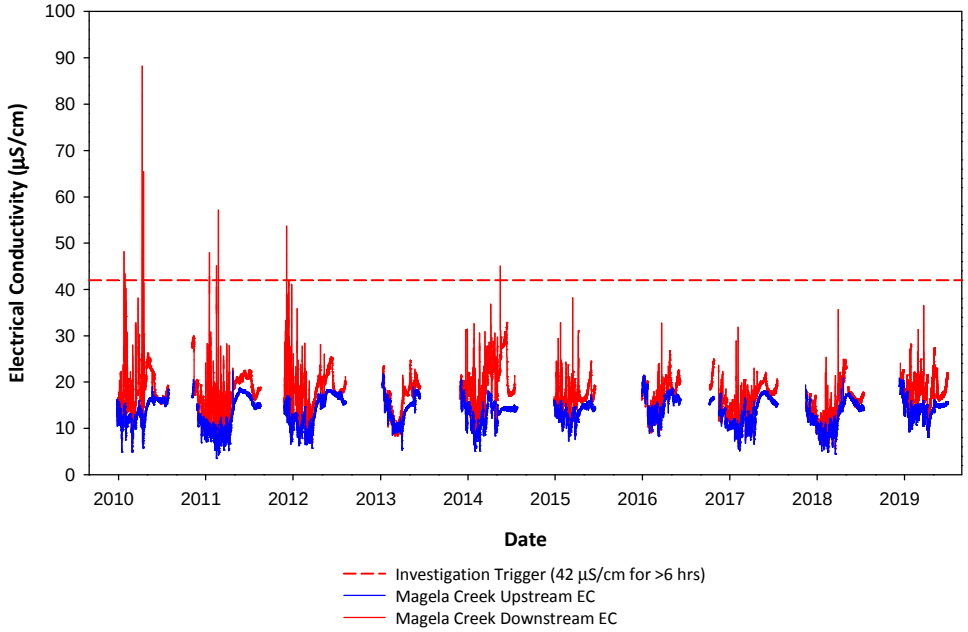


Figure 10 Magela Creek electrical conductivity (EC) data measured during the wet season 2010-19.

The seasonal geometric mean difference in ^{226}Ra concentrations measured in Magela Creek upstream and downstream of the minesite remained below the Limit of 3 mBq/L for the 2018-19 wet season (Figure 12).

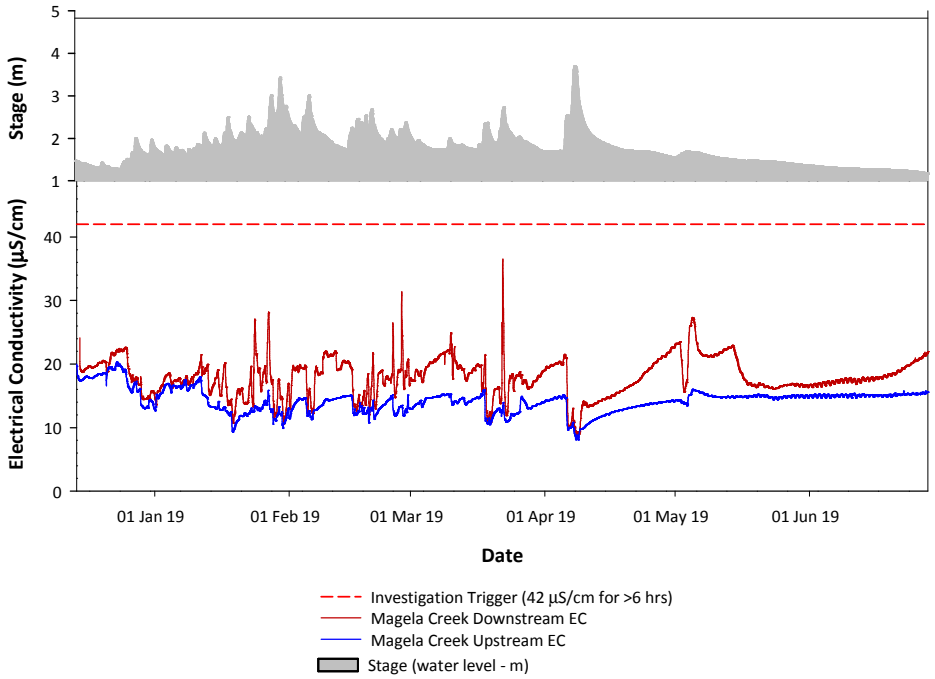


Figure 11 Magela Creek electrical conductivity (EC) and water level (stage) data measured during the 2018-19 wet season.

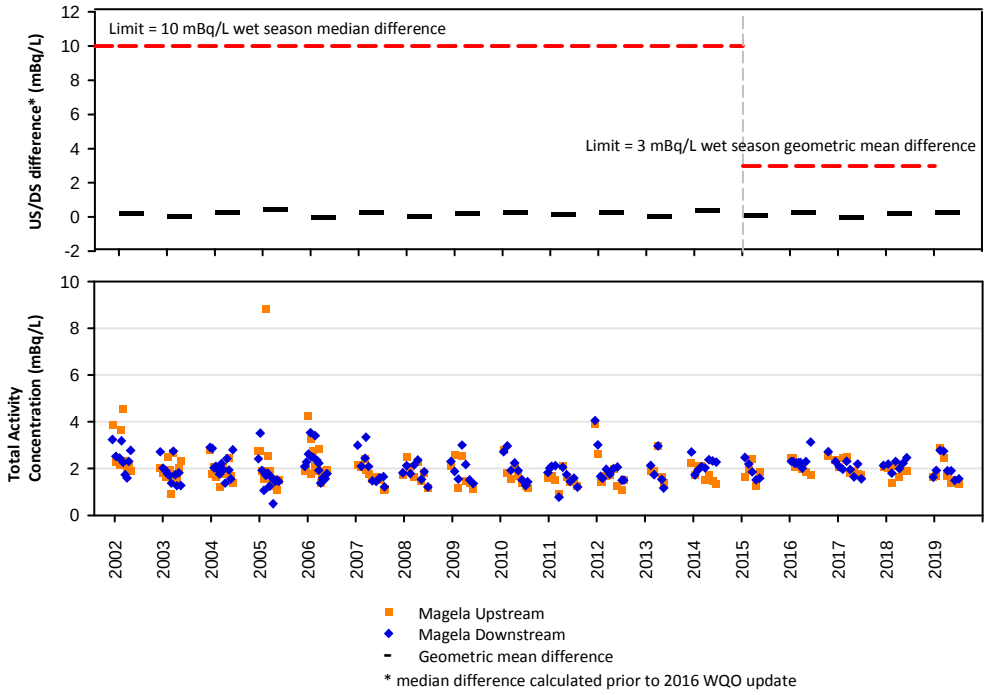


Figure 12 Magela Creek ^{226}Ra and geometric mean difference measured during the wet season 2002–19.

Biological monitoring

Toxicity monitoring

Seven in-situ toxicity monitoring tests using the freshwater snail reproduction response were conducted in Magela Creek over the 2018–19 wet season, spanning the period 4 January 2019 to 12 March 2019. In recent wet seasons, Magela testing has alternated on a weekly basis with testing in Gulungul Creek. However, for the 2018–19 wet season, back-to-back tests were conducted in Magela Creek over this period due to lack of any testing in Gulungul Creek at this time where work health and safety concerns were being addressed.

Of note during the 2018–19 wet season, there was unusually lower snail egg production at the downstream site of Magela Creek compared to the upstream site for the third test of the season (Figure 13). This returned to the more typical pattern observed of higher egg production downstream in the last two tests. For the prevailing electrical conductivity and water temperature conditions for the third test – median upstream and downstream water temperatures were both 28.5°C and median upstream and downstream electrical conductivity of 14.3 and 19.3 µS/cm respectively – higher downstream egg production would have been expected (see Gulungul Creek toxicity monitoring below). Thus the cause of the lower snail egg production at the downstream Magela site remains unknown. Analysis Of Variance (ANOVA) testing showed that egg difference values between the sites were not significantly different for the 2018–19 wet season compared to all previous wet seasons, demonstrating that detrimental impacts to sensitive aquatic organisms (exemplified in the snail reproduction response) in Magela Creek were highly unlikely during the 2018-19 wet season.

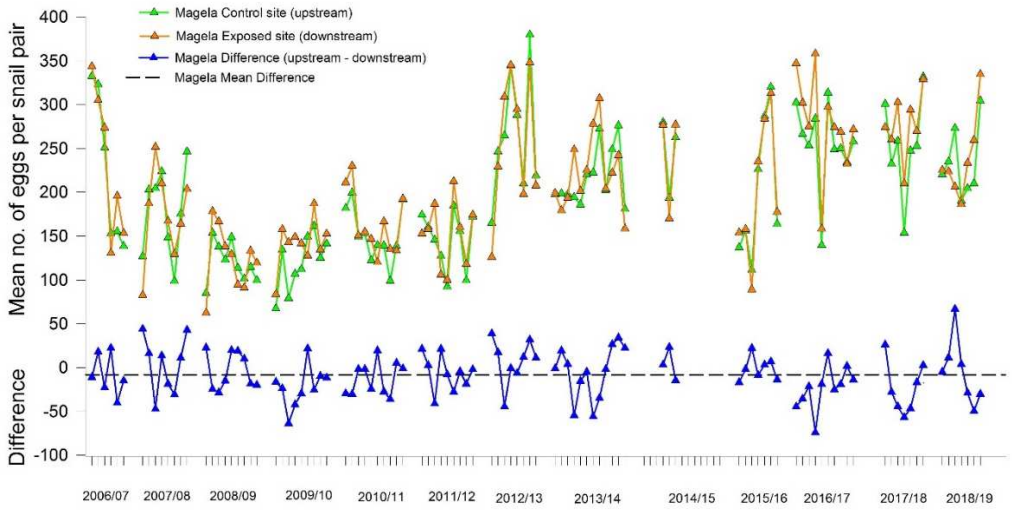


Figure 13 Time series of in-situ snail egg production data from toxicity monitoring tests conducted in Magela Creek.

Bioaccumulation in freshwater mussels

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. SSB monitors the bioaccumulation of ^{226}Ra in mussels by measuring its activity concentrations in the flesh of mussels collected annually from Mudginberri Billabong (since 2000) and triennially from Sandy Billabong (since 2002) (Figure 4).

Freshwater mussels were collected from both Mudginberri Billabong and Sandy Billabong in October 2018. Figure 14 shows ^{226}Ra activity concentrations in mussel flesh from the 2018 collection and compares the concentrations with the average and range of values measured in mussels in Mudginberri and Sandy Billabongs over time. Mussel ^{226}Ra activity concentrations in 2018 were within the range of previously measured values, albeit at the lower end of the range for 5 to 7 year-old mussels from Mudginberri Billabong.

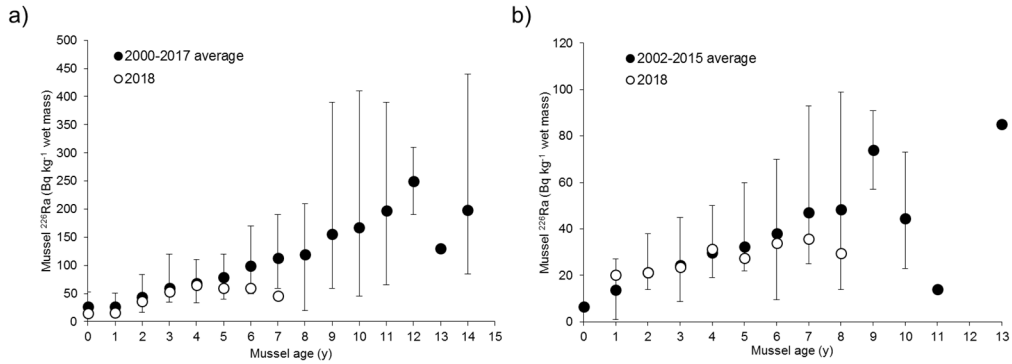


Figure 14 Flesh ^{226}Ra activity concentrations in mussels collected from a) Mudginberri Billabong and b) Sandy Billabong. The error bars represent the ^{226}Ra activity concentration range in each age class.

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 2018 Mudginberri Billabong measurements. This is lower compared to the average annual committed effective dose of 0.15 mSv (based on all Mudginberri Billabong ^{226}Ra measurements from 2000 to 2017), suggesting an overall decrease in the level ^{226}Ra in Mudginberri mussels during 2018.

The radiation dose to traditional owners from freshwater mussels collected from Mudginberri Billabong is almost exclusively from natural background sources 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

Chemical and physical monitoring

Gulungul Creek flows along the western boundary of the Ranger Project Area (Figure 3). 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. This contribution of mine water has lead variable water quality in Gulungul Creek over the years.

Since the 2012-13 wet season water quality at the original Gulungul Creek upstream control site, GCUS (Figure 3), has deteriorated. High EC events were initially observed at the site during the 2012-13 wet season and since this time the baseline EC has been gradually increasing. Investigations conducted by ERA concluded that the elevated EC at GCUS was linked to irrigation activities in the Corridor Creek Land Application Area (CCLAA). The possible mine effect on EC at GCUS made it an ineffective control site, and because of this a new control site, GCNUS, was installed upstream of GCUS. Figure 15 compares the EC measured at GCNUS and GCUS since the 2015-16 wet season. The higher EC observed at GCUS indicates that there is an ongoing source of solutes entering the creek between the two sites. ERA have been irrigating in the CCLAA under a modified regime, however it is likely that there is a plume of higher EC groundwater gradually moving towards Gulungul Creek, which expresses into surface water in the upper tributaries during the wet season. SSB is undertaking additional monitoring to in the upper tributaries of the Gulungul Creek catchment to track the solutes, and to improve understanding of the hydrodynamics of the catchment.

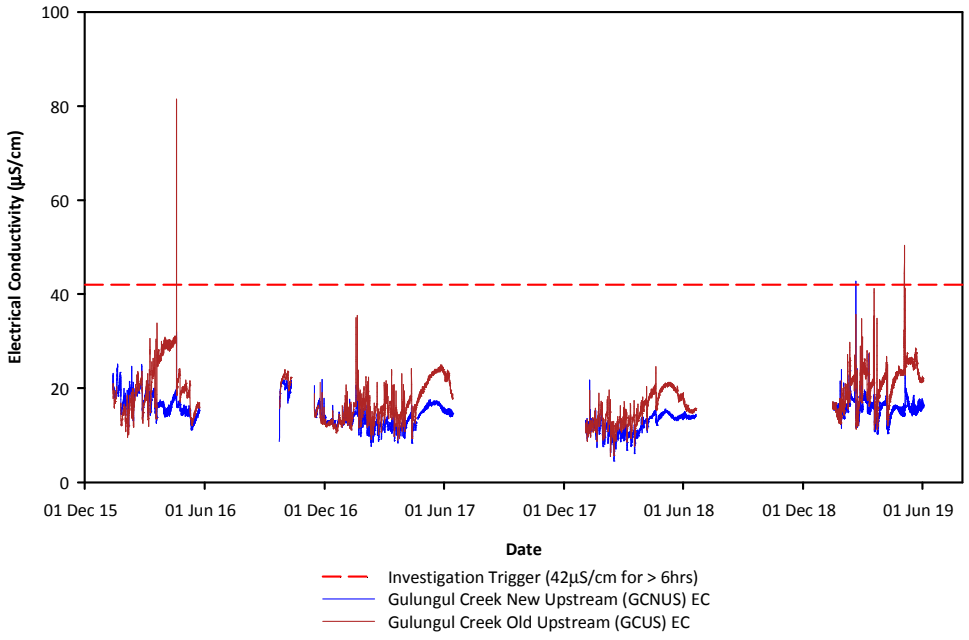


Figure 15 Comparison of EC values measured in Gulungul Creek upstream of the mine since the 2015-16 wet season, at the original control site (GCUS) and the current control site (GCNUS).

Throughout the 2018-19 wet season there were no exceedances of the Investigation Trigger value in Gulungul Creek (Figure 16), and the EC measured at the upstream control site (GCNUS) and the downstream compliance site (GCLB) was similar to that measured in the previous wet season (Figure 17). Overall, this is reflects an improvement in water quality in the Gulungul Creek system compared to previous years. However on the 18th February 2019 the EC at GCNUS reached 42.78µS/cm. This was most likely attributed to heavy rainfall which occurred in the upper catchment moving water from small pools in the Gulungul Creek tributaries into the main creek channel. These pools typically have a higher EC compared to the main creek channel due to evapo-concentration between rainfall events, which would have been particularly pronounced during the 2018-19 wet season given the intermittent rainfall. The EC peak was short-lived and the corresponding peak measured at the downstream monitoring site was 29.36 µS/cm. SSB continues to undertake additional monitoring to better delineate the source, improve understanding of the general behaviour, of solutes in the upper Gulungul catchment.

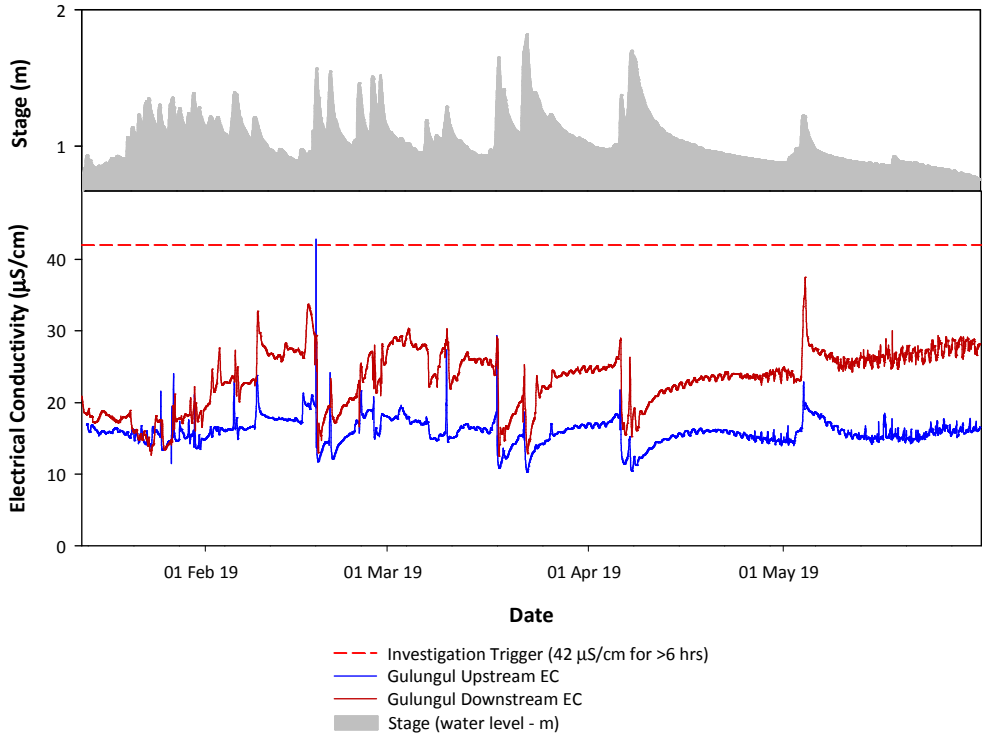


Figure 16 Gulungul Creek electrical conductivity (EC) and water level (stage) data measured during the 2018–19 wet season at Gulungul Upstream (GCNUS) and Gulungul Downstream (GCLB).

The improved EC measured at the Gulungul Creek downstream compliance site continues to reflect the significant amount of mitigation work that has been undertaken by ERA to actively manage surface and shallow groundwater to the west of the TSF.

This includes the seepage interception and extraction system adjacent to the north-western wall of the TSF, which collects shallow groundwater and surface water and transfers it to the pond water system for treatment prior to release. During the 2018-19 wet season, 12,076 m^3 of poor quality water was extracted by the interception system. 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 and extraction system. The average EC of the base flow in the GCT2 tributary has maintained a downwards trend since mitigation measures were put in place in 2014 (Figure 18). The SSB will continue to measure the EC at GCT2RST which will enable ongoing tracking of the effectiveness of mitigation.

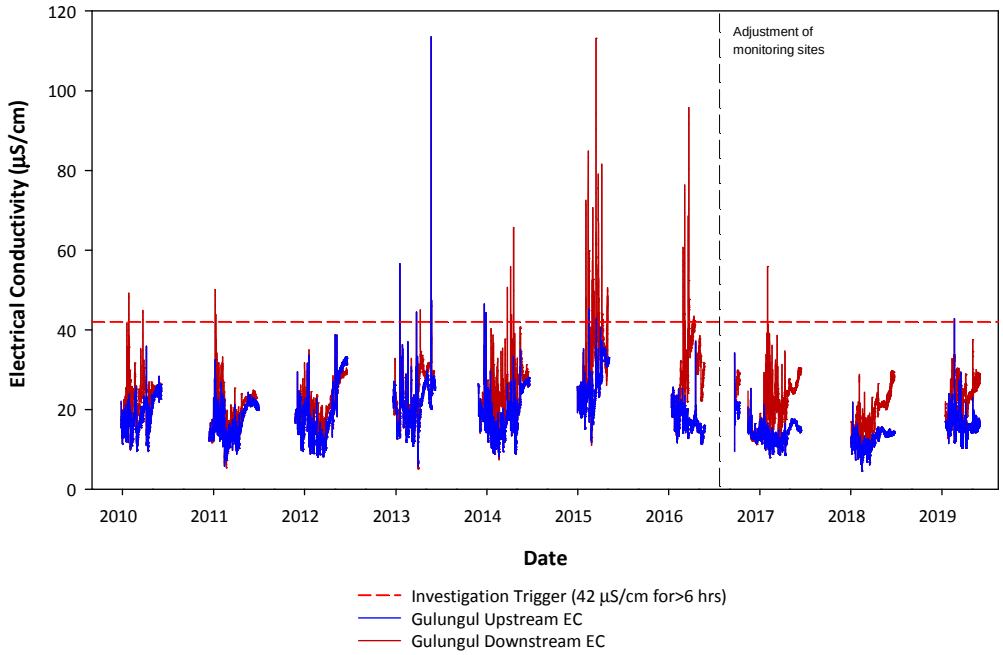


Figure 17 Gulungul Creek electrical conductivity (EC) data measured during the wet season 2010-19

The seasonal geometric mean 226Ra concentrations measured in Gulungul Creek upstream and downstream of the minesite remained below the Limit of 3 mBq/L for the 2018-19 wet season (Figure 19).

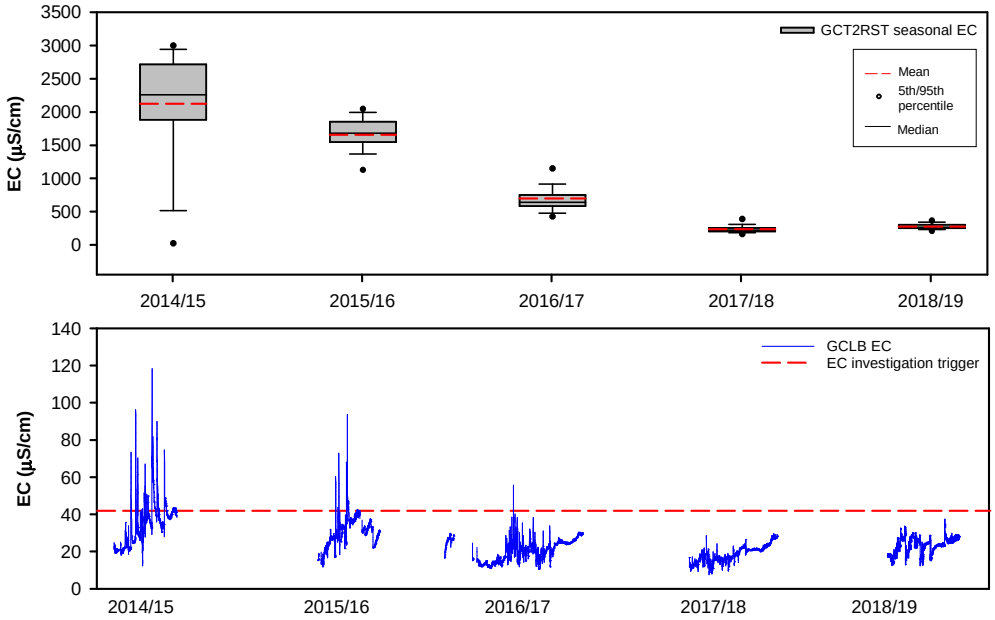


Figure 18 Electrical conductivity measured within Gulungul Creek Tributary 2 (GCT2RST) (top) and Gulungul Creek downstream compliance site (GCLB).

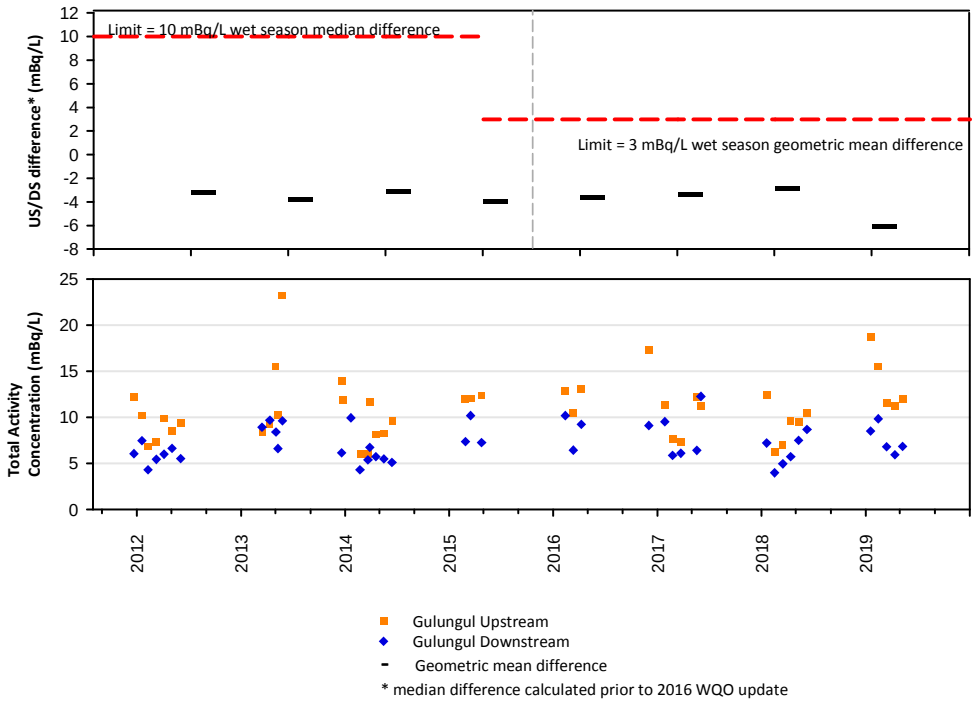


Figure 19 Gulungul Creek 226Ra and geometric mean measured during the wet season 2012-19.

Biological monitoring

Toxicity monitoring

Since 2009–10 toxicity monitoring using the freshwater snail reproduction response has been conducted at the Gulungul Creek upstream (GCUS) and downstream (GCDS) sites. A midstream site (GCLB) was included from 2015 to measure any water quality-related effects arising from contaminated surface water in the GCT2 tributary (see 'Gulungul Creek Tributary 2 Investigation' above). This year the midstream site was moved 40 meters downstream, closer to the water quality monitoring station, for work health and safety reasons. Increased crocodile activity in Gulungul Creek and interference with in situ monitoring equipment by a crocodile resulted in one invalid test at the beginning of the season. Thereafter, testing ceased and only recommenced once the offending crocodile had been captured and relocated. This resulted in a late start to testing. Five valid in situ toxicity tests were conducted in Gulungul Creek spanning the period 15 March 2017 to 16 April 2018 (Figures 20 and 21).

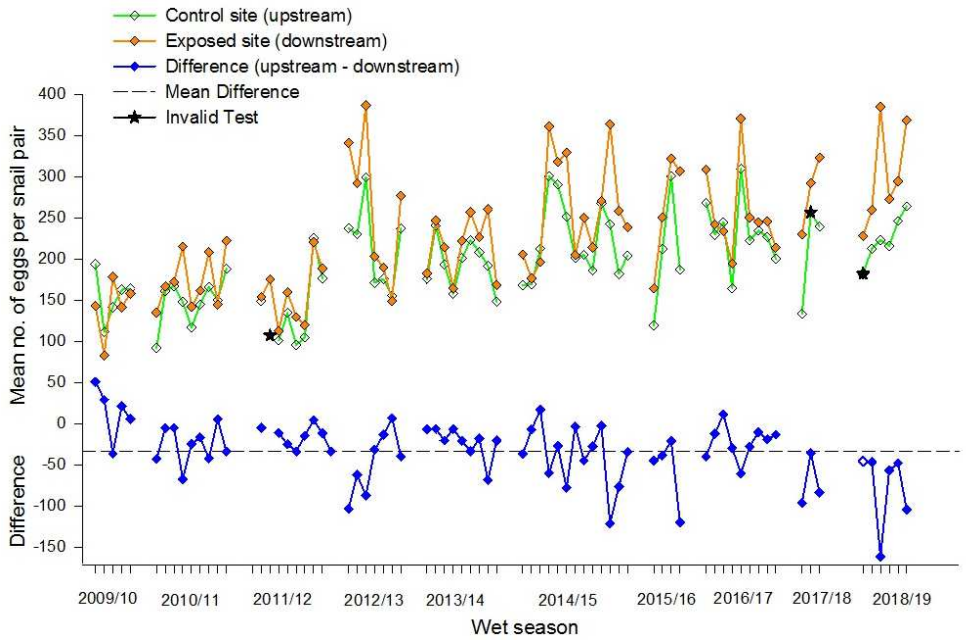


Figure 20 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek.

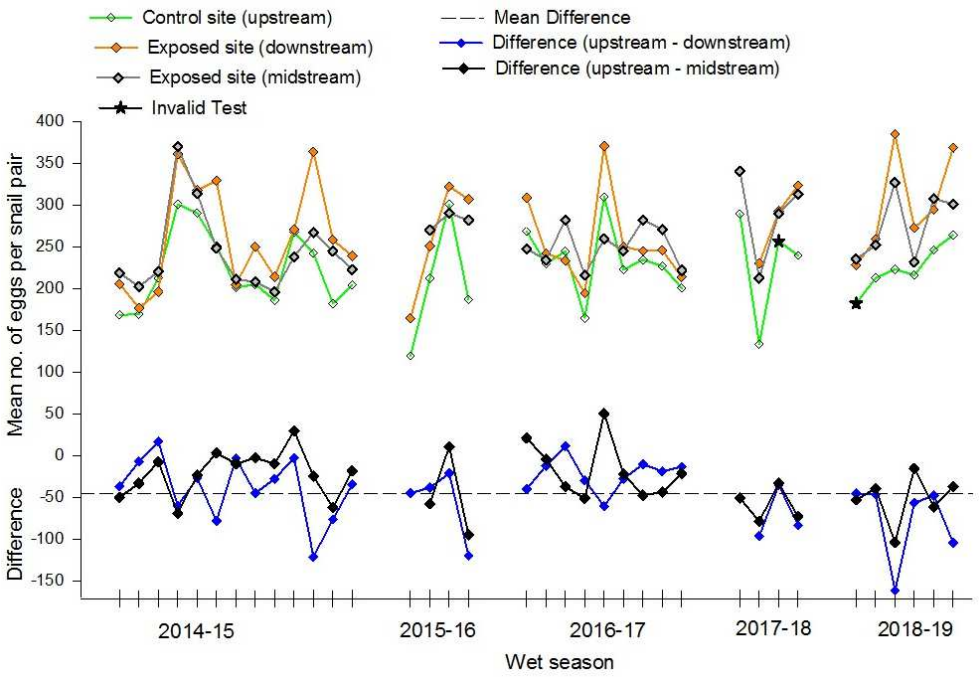


Figure 21 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek since 2015.

ANOVA testing showed that egg difference values between the routine GCUS and either GCDS or GCLB sites were not significantly different for the 2018–19 wet season compared to all previous wet seasons. Of note, nevertheless, the greater egg production at the midstream and downstream sites for both the 2017–18 and 2018–19 wet seasons compared to that measured at the upstream site, was more pronounced over that recorded in previous wet seasons (Figures 20 and 21). Thus upstream-downstream (or upstream-midstream) difference values were *all* negative. This can be explained by the timing of toxicity monitoring in Gulungul Creek which, in the 2018–19 wet season at least, was late in the season, i.e. from mid-March to mid-April. These late wet season tests exposed snails to generally cooler water temperatures, less than 30ºC. Findings from previous wet seasons (see Figure 4.7, *Supervising Scientist Annual Report 2013–14*) have shown a positive association between egg production and electrical conductivity at water temperatures less than 30ºC, not evident when water temperatures exceed 30ºC. While water temperatures in Magela and Gulungul Creeks commonly exceed 30ºC, particularly during periods of minimal rainfall, these were not the conditions for testing in Gulungul Creek during the 2017–18 and 2018–19 wet seasons. Confirming the earlier findings from previous wet seasons, and with most testing conducted in Gulungul Creek at water temperatures <30ºC, even small differences in electrical conductivity between sites of just several units (µS/cm) can result in appreciable differences in snail egg production – see Figure 22. Under the water temperature conditions prevailing for most toxicity monitoring tests in Gulungul Creek conducted in the 2017–18 and 2018–19 wet seasons, elevations in electrical conductivity associated with minesite runoff resulted in some

stimulation of egg production in freshwater snails. Consistent with previous reporting where stimulation in egg production at the monitoring sites downstream of Ranger is common, results for the 2018–19 wet season provide no evidence of environmental impact to sensitive aquatic organisms (exemplified in the snail reproduction response) in Gulungul Creek.

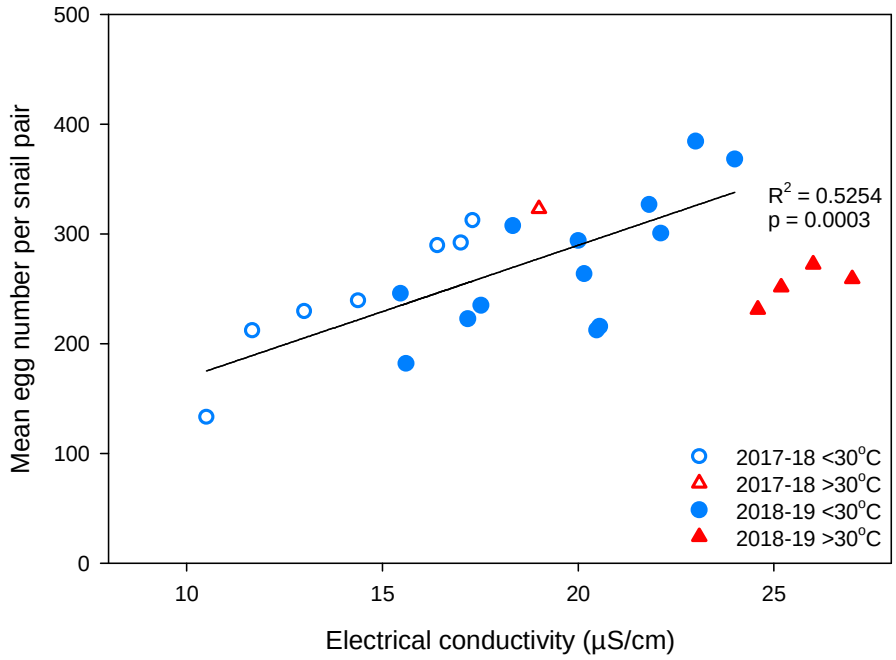


Figure 22 Relationship between mean snail egg number for sites in Gulungul Creek, and ambient electrical conductivity and water temperature over the four-day exposure test periods for 2017–18 and 2018–19 wet seasons. Regression relationship derived only for data <30ºC.

4.1.3. Ecosystem monitoring

Macroinvertebrate communities

During the recessional flow period of each wet season, macroinvertebrate communities are sampled in 'exposed' streams; Magela and Gulungul Creek, at sites upstream and downstream of the mine, and from similarly configured paired sites within control streams, Burdulba and Nourlangie Creek.

In 2015 and thereafter, an additional site located just downstream of the GCT2 junction with Gulungul Creek (GCT2GCC), was included in the annual sampling regime. This additional site was established in response to the 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 from two separate monitoring periods are reported:

1. At the time of the corresponding reporting period in 2018, only samples from sites in 'exposed' streams, Gulungul and Magela Creek (including GCT2GCC), were available for analysis and were subsequently reported on in the 2017–18 Annual Technical Report. Currently the full dataset from the 2017–18 wet season, including control stream data, is available for analysis and can be reported.
2. Data from all samples collected after the 2018–19 wet season are available for analysis and are reported on here (i.e. Magela, Gulungul, Burdulba and Nourlangie creeks). However, the present analysis and reporting should be regarded as preliminary because samples have not yet undergone a quality control assessment due to time limitations.

Results for the full 2017–18 dataset

Compilation of, and analyses for, the full macroinvertebrate dataset from 1988 to 2018 has been completed. Multi-factor ANOVA was applied to the replicate, paired-site dissimilarity values shown in Figure 23 to test for changes between exposed and control streams over time. The ANOVA showed no significant change from the before (pre 2018) to the after (2018) periods in the magnitude of upstream-downstream dissimilarity between the control and exposed streams (for BA and BA*Exposure interaction respectively). This result is unsurprising given that the dissimilarity values for all four creeks for 2018 plot at similar values to those recorded in most previous years (Figure 23).

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 24 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 2018), relative to Magela and Gulungul upstream (control) sites for 2018, and all other control sites sampled up to 2018 (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 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. This result was further confirmed by PERMANOVA (PERmutational Multivariate Analysis Of Variance) testing on the individual sites (compared to paired site dissimilarity for the ANOVA calculated above) for the exposed streams Magela and Gulungul.

Relative to control sites, impacted sites are typically associated with significantly higher dissimilarity values. Dissimilarity values for 2018 Magela and Gulungul paired sites (including GCT2GCC paired with the upstream Gulungul) were comparable to those from that year's control streams and previous years, suggesting that no significant alteration of macroinvertebrate community structure had occurred at the downstream exposed sites (Figure 23).

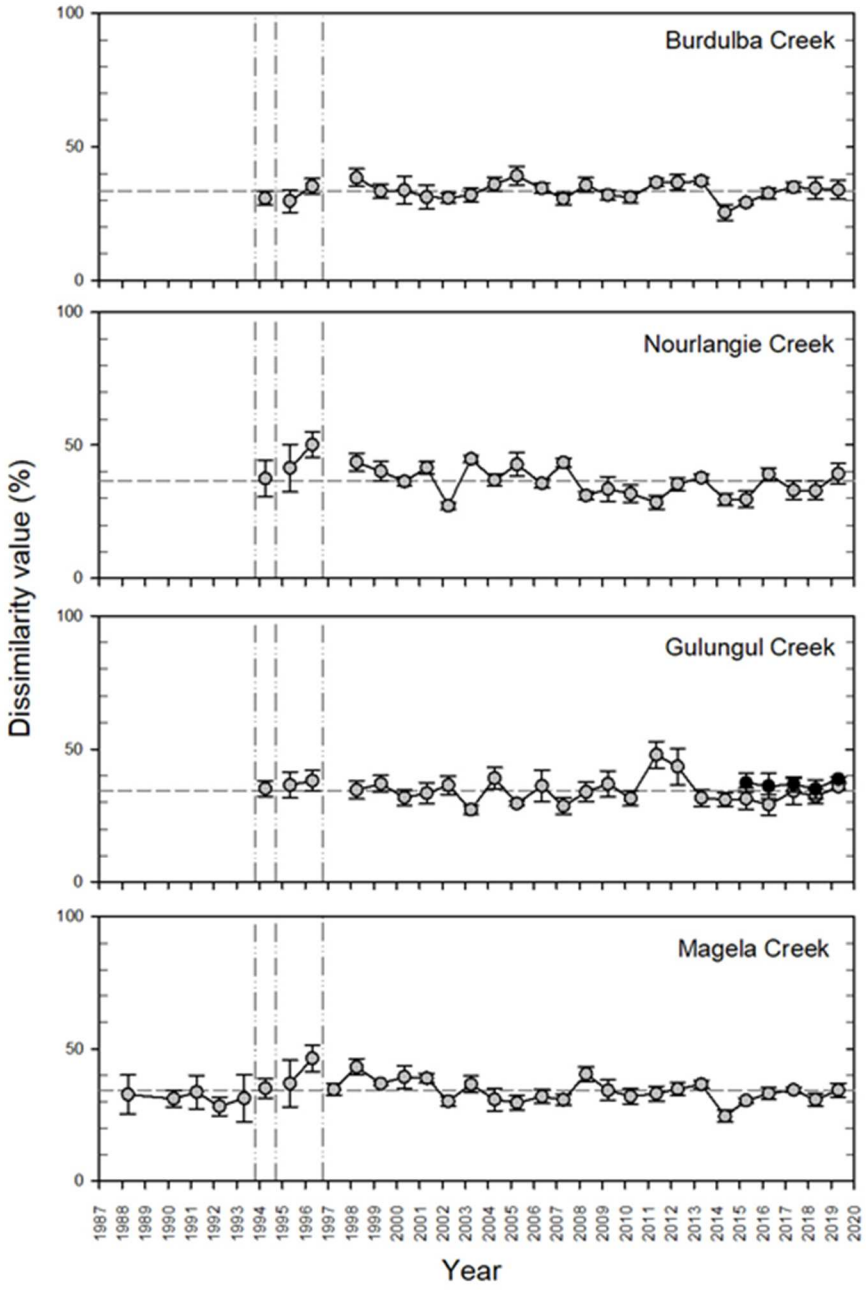


Figure 23 Paired upstream-downstream Bray-Curtis dissimilarity values using family-level (log transformed) data for macroinvertebrate community structure.

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

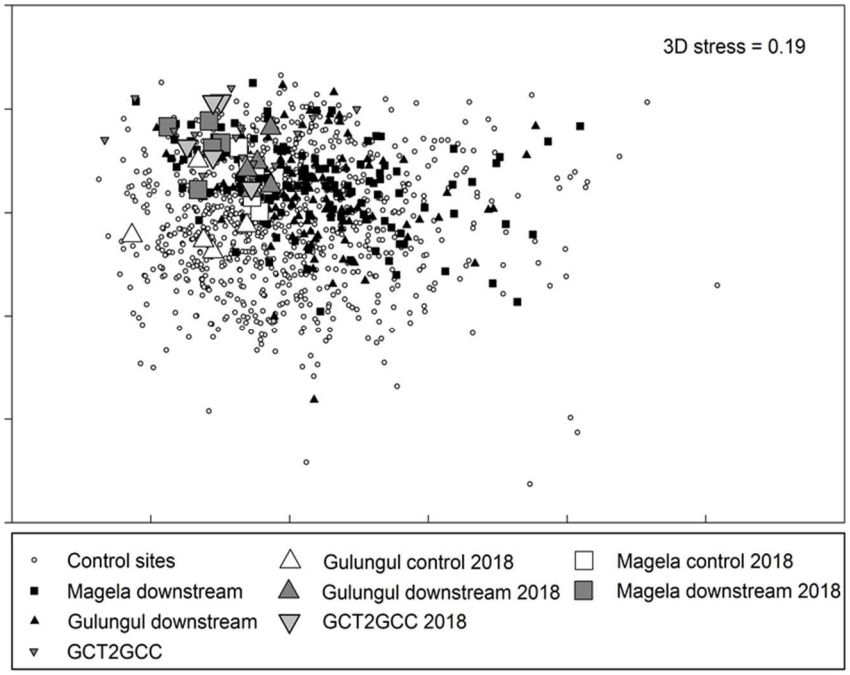


Figure 24 Ordination plot (axis 1 and 2) of macroinvertebrate community structure**.**

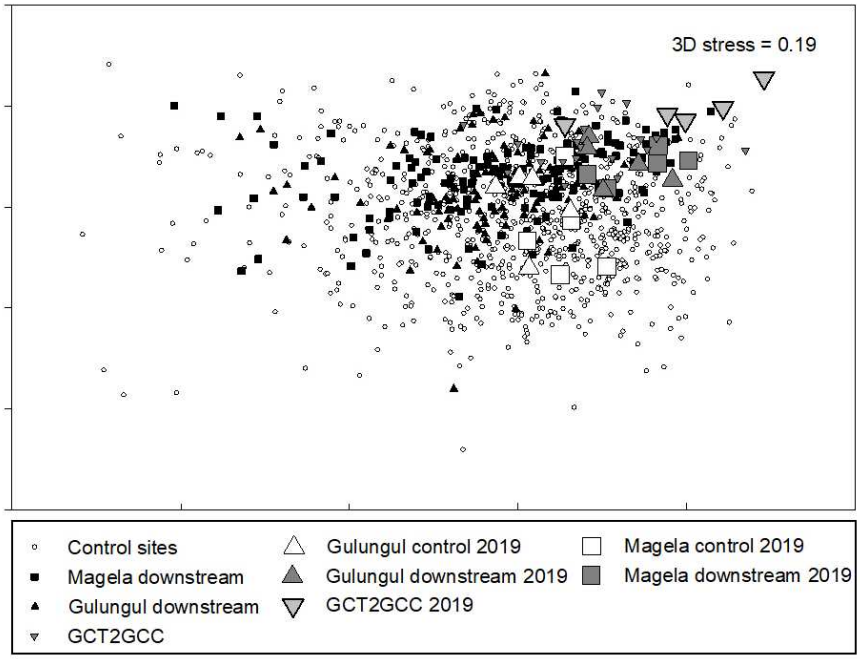


Figure 25 Ordination plot (axis 1 and 2) of macroinvertebrate community structure.

These collective results provide confidence that changes to water quality downstream of Ranger mine as a consequence of mining during the period 1994 to 2018 have not adversely affected macroinvertebrate communities.

Preliminary results 2018–19

The following analysis is provisional until samples have been quality-control checked. Any revisions to the present account will be reported on in the Supervising Scientist's 2019–2020 Annual Technical Report.

A multi-factor ANOVA was applied to the replicate, paired-site dissimilarity values shown in Figure 23 to test for changes between exposed and control streams over time. The ANOVA showed no significant change from the before (pre 2019) to after (2019) 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 2019 with downstream data from previous years, and no significant difference between the upstream data separately from 2019 with upstream data from previous years. Again, this result is unsurprising given that the dissimilarity values for both creeks for 2019 plot at similar values to those recorded in most previous years (Figure 23).

Figure 25 shows the multivariate ordination using replicate within-site macroinvertebrate data for Magela and Gulungul creeks sampled downstream (including GCT2GCC) of Ranger mine for each year of study (to 2019), relative to Magela and Gulungul upstream (control) sites for 2019, and all other control sites sampled prior to 2018 (previous years Magela and Gulungul sites, all sites in Burdulba and Nourlangie). Data points associated with the 2019 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 of the GCT2GCC site replicates was an outlier in ordination space. This was attributed to higher macroinvertebrate abundance and a lack of flow dependent taxa due to denser macrophyte cover and low water flow at the location at which this replicate sample was collected. This replicate was located on the western side of the creek, away from the other four replicate samples collected at this site.

These collective results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2019 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 2018-19 wet season, however, no high EC events at GCT2GCC were evident (see Figure 18). The dissimilarity values for the 2018-19 wet season are more comparable with dissimilarity values calculated for Gulungul upstream vs downstream pairing in most previous years (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 risk of crocodile attack has led to a reassessment of the risk associated with the sampling methodology used for this program. As a result, this program will now no longer be undertaken in its current form (using 'pop-nets'). A research project is currently underway 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) multivariate dissimilarity between fish community structures in Mudginberri Billabong (directly exposed site downstream of Ranger in Magela Creek catchment) and Sandy Billabong (control site in Nourlangie Creek catchment, Figure 4), and (ii) rainbowfish abundance in the same two billabongs.

Annual mean paired-site dissimilarity for 2019 was similar to 2017 and 2018 (Figure 26). Mean dissimilarity was also within the range of dissimilarity reported in all previous years although a research project that has been underway since 2013 (RES-2013-016, Appendix 2) is determining the degree of comparability in this metric between the earlier and new monitoring approaches.

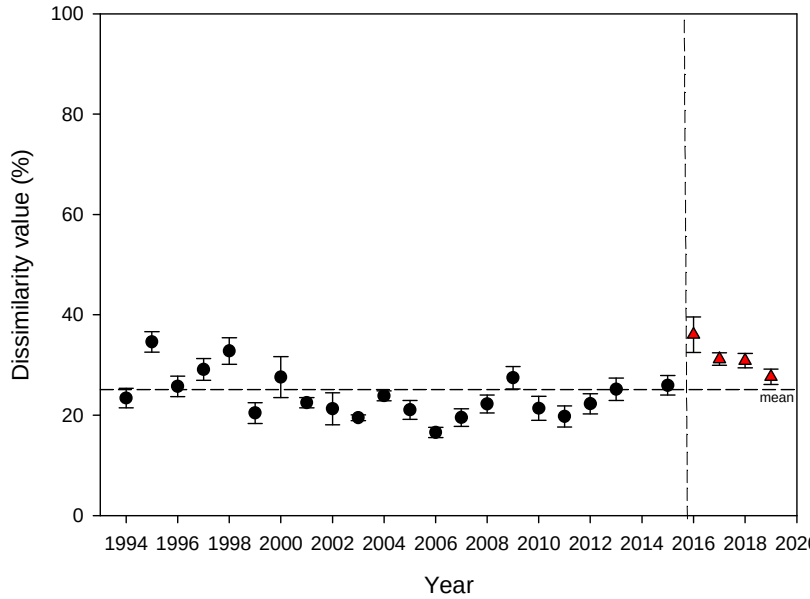


Figure 26 Paired control-exposed dissimilarity values for fish community structure.

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

The 2019 results also indicated there were twice as many rainbowfish in Mudginberri Billabong compared to Sandy Billabong, with average maximum number of fish in the imagery frame ("MaxN") of 4.4 and 2.1 for the billabongs respectively (Figure 27). With lower than average rainfall and Magela Creek discharge for the 2018-19 wet season, this result follows the natural relationship reported for earlier years (see 2008-09 Supervising Scientist Annual Report), i.e. a negative correlation between rainbowfish abundance in Mudginberri Billabong and the magnitude of antecedent wet season discharge in Magela Creek. This relationship is evident for the four years for which videography has been adopted for this monitoring program (Figure 27).

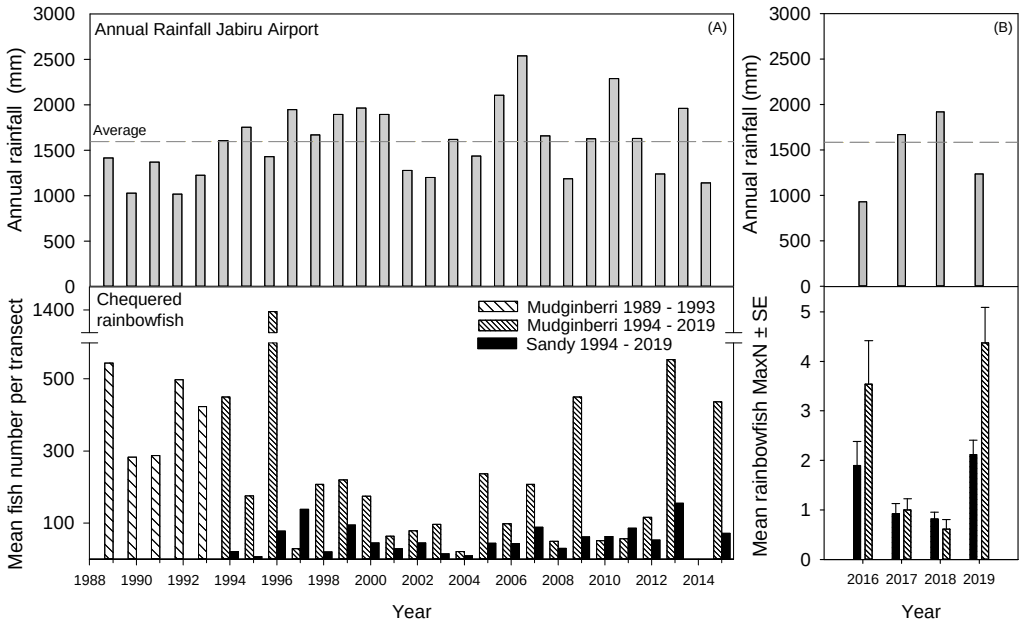


Figure 27 Relative abundance of chequered rainbowfish in Mudginberri and Sandy Billabongs in relation to antecedent annual wet season rainfall recorded at Jabiru Airport: (A) results from 1989 to 2015 using visual observations; (B) results for mean abundance (MaxN) from 2016 to 2019 using videography.

Plate 6 Native wasps in Kakadu National Park

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 2018-19 research program

The 2018–19 SSB research program was endorsed by ARRTC at its 40th meeting in May 2018. The SSB research and monitoring program for 2018-19 included 37 active or proposed research projects and eight monitoring projects. Of the research projects, 12 were new or proposed projects while 25 were continuing projects. The program represented a return to a similar workload from previous years, where research project numbers have typically numbered around 30-33. The decrease in research projects (from 54 projects reported to ARRTC 39) was mainly due to the increased capacity in ERA groundwater expertise, with SSB's groundwater assessments now being assisted with external expertise as well. Figure 28 (A, B, C, D) provides various perspectives on the work program, particularly for the research program.

Other changes that have occurred to projects amongst SSB's work programs (from Figure 28) include:

(i) A reduction in projects listed for Radiation between 2017 and 2018 associated with project completion and research staff loss (11 to 5 projects)

(ii) Consolidation (mainly) of Landform projects (14 to 8 projects)

(iii) A small increase in Ecosystem restoration projects (10 to 13 projects) with two new collaborative *National Environmental Science Program* (NESP) projects managed by this SSB program (see below)

(iv) A small increase in Water and sediment quality projects (21 to 23) with some carry over 2017-18 projects and new projects where information is required to meet rehabilitation assessments (in early 2019).

At the highest level, the current status of the research and monitoring program for active projects as of November 2018 was as follows:

- On track: 34 projects (85%)
- Behind schedule or delayed: 6 projects (15%)
- Scheduled but unable to commence in 2018-19: 0 projects (0%)

With ERA submitting its application for Pit 1 rehabilitation (and revisions to) over 2018, the Landform and Ecosystem restoration projects (i.e. those related to landform properties that will enable the establishment of sustainable vegetation and faunal communities) continue to be of highest priority. A key focus is the revegetation plans being developed by ERA and research projects being undertaken by ERA and SSB.

Resource constraints have resulted in a number of projects being suspended in order to focus on projects for which information was required in a shorter time frame. As of November 2018, 11 projects were suspended. These suspended projects may be re-activated in future years in line with the schedule for information requirement. Seven projects have also been assigned 'superseded' to denote the information is either no longer required or the research is being subsumed in other active projects.

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. Over one-third (13) of the 37 active or proposed 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.

Key Knowledge Needs

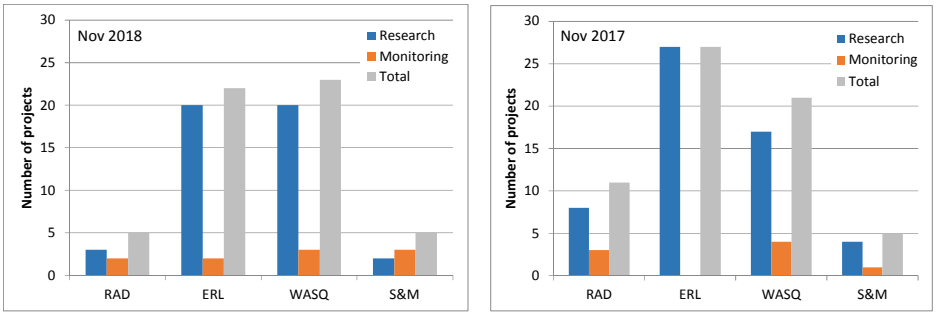
A KKN consolidation process was undertaken over the 2017-18 period to more closely align the scientific research being undertaken by both SSB and ERA with the Ranger Environmental Requirements, avoid repetition and simplify the way in which the knowledge needs are structured. The consolidation process reduced the total number of KKNs across the five rehabilitation themes (i.e. Landform, Water and Sediment, Health Impacts of Radiation and Contaminants, Ecosystem Restoration and Cross-themes)

from 125 to 32, while still retaining the required information from the original KKNs (Supervising Scientist 2017)[1].

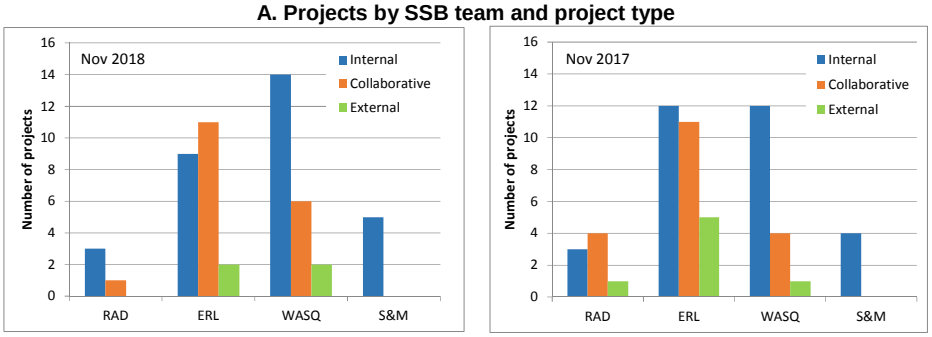
At the ARRTC meeting held in November 2018 (ARRTC 41), the Committee endorsed the revised, consolidated list of KKNs. This version of the KKNs (but not the narrative descriptions) has been uploaded to SSB's website. Subsequent to ARRTC 41, the Committee, together with SSB and ERA, have refined the KKNs, with minor changes and expanded narrative to improve their clarity. After agreement with ERA, these KKNs will be finalized, distributed to ARRTC and re-loaded to the website. Going forward, SSB proposes to update the KKNs on its website regularly after KKN close outs and amendments.

The KKN close out and amendment process was approved by ARRTC in May 2018 (ARRTC 40). This process will be ongoing for close outs, amendments, removals and additions of new KKNs. The supporting evidence for these close outs and amendments is currently being compiled for stakeholder consideration through a formal amendment process (ERA/SSB agreement, then MTC, then ARRTC).

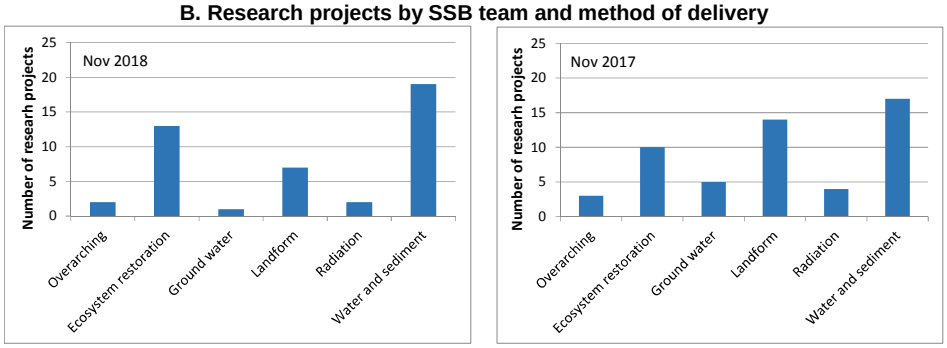
[1] Supervising Scientist 2017. *Alligator Rivers Region Technical Committee: Key Knowledge Needs: Uranium Mining in the Alligator Rivers Region*. Supervising Scientist Report 213, Supervising Scientist, Darwin NT.



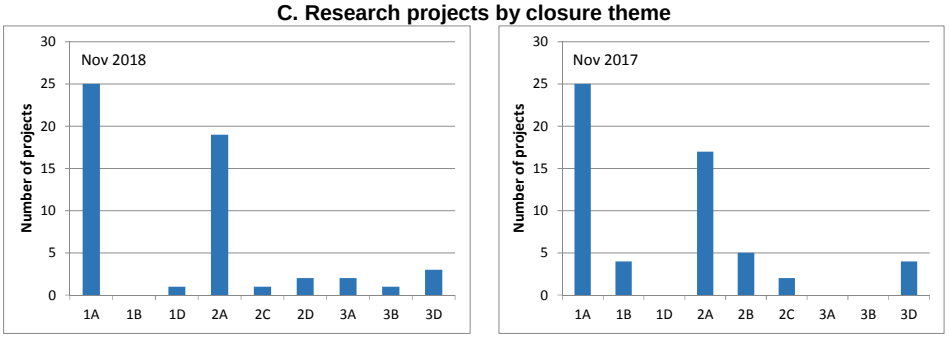
A. Projects by SSB team and project type



B. Research projects by SSB team and method of delivery



C. Research projects by closure theme



D. Research projects by priority (see Attachment A for priority descriptions)

Figure 28 (A, B, C, D) Summary plots for the status of the Supervising Scientist Branch 2018-2019 research and monitoring program as of November 2018 in comparison to the same information for 2017-18 reported in November 2017.Team codes in A and B are: RAD, Radiation; ERL, Ecosystem Restoration and Landform; WASQ, Water and Sediment Quality; S&M, Supervision and Monitoring.

Rehabilitation standards

The rehabilitation standards that are being developed represent the Supervising Scientist's view of what is required to achieve the environmental objectives detailed in the Ranger Environmental Requirements. They will enable clear visibility of the science underpinning each standard, and will provide a scientifically robust basis for decisions. The majority of the Standards were published and provided publicly on SSB's website in September 2018 and are shown in Table 20.

TABLE 20 REHABILITATION STANDARDS

Closure theme	Rehabilitation standard
Water and sediment	Magnesium (surface water)
	Uranium and Manganese (surface water)
	Ammonia (surface water)
	Sulfate – acid sulphate soils (surface water)
	Other metals (surface water)
Landform	Landform – stability and erosion
Ecosystem restoration	Ecosystem restoration (flora, fauna, ecological processes)
Radiation	Environmental Radiation Protection
	Public Radiation Protection

ERA and ARRTC's reviews of the Standards identified a requirement to revise the magnesium and other metals standards – additional toxicity testing was required for the magnesium and manganese standard, while the application, including statistical treatment, of the metals standard required review. These revisions have now been undertaken or are near completion, and do not alter in any significant way the values proposed in current versions of the respective Standards. The current web-based Standards will be updated between Q2 and Q3 2019 accordingly.

In previous summaries of the status of drafting of the Standards (ATR and ARRTC research updates), Standards for turbidity (surface water) and sedimentation, uranium in sediment, nutrients and herbicides in surface water or sediment, were indicated as outstanding. The status of this work may be summarised:

- The proposed approach to drafting the turbidity and sedimentation Standard (for aquatic ecosystem protection) was presented to the Ranger Closure Consultative Forum in March 2019. With a management objective of no mine-related sedimentation in backflow billabongs during decommissioning and post-closure, further knowledge may be needed to stipulate a delivery rate of suspended sediment to these waterbodies sufficiently small to meet the objective.

- An assessment of the approach to apply to turbidity and sedimentation (for ecosystem protection, from above) has identified the potential need to revise (simplify) the Landform Stability Standard (pertaining to erosion characteristics which, as far as can reasonably be achieved, do not vary from those of comparable landforms in surrounding undisturbed areas). This review is underway.
- A Standard for uranium in sediment will now not be published. SSB previously advised that the uranium in surface water Standard would be revised if necessary if the surface water value (for sustained exposures) is deemed not sufficiently protective of sediments (i.e. uranium accumulating to values that would lead to toxicity in sediment or, potential for de-adsorption from sediments back to surface waters at unacceptable concentrations). The results of a uranium partitioning consultancy study received in Q1 2019 (RES-2016-013, Appendix 2) show no risk of increase in sediment uranium with the current Standard for surface waters, negating need to revise the surface water value.
- Rehabilitation standards for nutrients (associated with nitrogen-based fertilisers) and herbicides in surface water and sediment have been discontinued due to an assessment of the risks that these COPCs will most likely be a shorter term practice associated with the vegetation establishment, i.e. a post-rehabilitation active management phase rather than a long-term closure issue. However, water quality limits for nutrients and herbicides might still be required as part of the post-rehabilitation water quality compliance program.

NESP projects

Three projects related to Ranger rehabilitation have been included in the NESP Northern Australia Environmental Resources (NAER) Hub's version 4 research plan that commenced in 2018. The projects and current status are:

- *Ecohydrology and sensitivity of riparian vegetation* (Water and Sediment closure theme) – The project is designed to fill knowledge gaps relating to the potential groundwater dependence of riparian ecosystems within the Ranger Mine site area, and to quantify risks posed to those ecosystems from surface and groundwater egress of mine-related contaminants. Field work commenced in late 2018 and pot trials to determine possible toxicity of magnesium to riparian tree species commenced in shade-house facilities at CDU in April 2019.

- *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 information on the performance of different revegetation practices in terms of broader ecosystem restoration. The project focuses on sampling of soil fauna (and respective functional groups) from non-mine disturbed and Ranger trial landform survey sites, together with the provision of recommendations on suitable monitoring methods for terrestrial

vertebrates. Field work commenced in the second half of 2018. A draft final report was submitted in March 2019.

- *Effects of surface and ground water 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 sufficiently protective of organism movements in the creek channels. In particular, the project is investigating the extent to which plumes of salts (magnesium sulfate) in Magela Creek from mine waste rock could interfere with the migrations of native fish populations, which need to be able to move between the river, floodplain and escarpment country upstream and downstream of the minesite. The project commenced in November 2018. Fish tracking and imaging technologies are being used to enumerate and characterise fish migration and residence in Magela Creek both upstream and downstream of the Ranger mine. Where possible, the results will be linked to surface and groundwater solute modelling and additional risk assessments to assess the likely effects of surface and ground water egress on fish migration and to develop future monitoring strategies.

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

Technical Advice memoranda

To improve collaborative working relationships between SSB and ERA, the timely communication of KKN research outcomes and sharing of information between respective research groups are critical. This is particularly important given the increasing number of Applications ERA is preparing and for informing or meeting closure objectives and criteria. The need for such knowledge sharing was also recognised at the November 2018 ARRTC meeting (ARRTC 41). To facilitate and expedite this process into the future, SSB has initiated the writing of technical advice memoranda to provide to key ERA staff as research outcomes are completed or as significant information arises throughout SSB's review processes. The intent is to provide short, concise and clear information and advice which can be used to inform ERA planning in a timely manner.

Five technical advice memoranda have been prepared and provided to ERA in the period between 2 January and 24 April 2019. The subject titles are:

1. Technical Advice #001: Feedback on INTERA numerical groundwater model presentations at ARRTC 41
2. Technical Advice #002: Runoff coefficients relevant to the Ranger waste rock landforms
3. Technical Advice #003: Potential risks associated with compaction layers
4. Technical Advice #004: Initial assessment of the FLV6.2 landform
5. Technical Advice #005: Waste rock particle size on the Trial landform

The technical advice memoranda have also been shared with ARRTC through Govdex.

5.2 Water and Sediment Quality

The Water and Sediment Quality team is developing, or has developed, Rehabilitation Standards for the key contaminants of potential concern for receiving waters, including standards for magnesium, uranium, manganese, sulfate, ammonia and other metals. A Standard for turbidity and sedimentation is also currently being developed. The results of other program work will be used to assess modelled water quality in receiving waters post-mine closure (GCT2 study, mixture toxicity, seasonal sensitivities, Magela saturated sands water quality and fauna, fish migration) and cumulative risks to aquatic ecosystems after rehabilitation, and to optimize biological monitoring techniques (genomics, fish videography, snail egg counts).

Active project work undertaken in the reporting period included:

1. Publication of a journal manuscript on the influence of pH on ammonia toxicity to local freshwater species. Publication of ammonia toxicity data for local tropical species to improve the dataset used for derivation of the site-specific water guideline value for ammonia.

2. Working from a detailed internal report, publication of a journal manuscript documenting the toxicity of contaminated waters from Gulungul Creek Tributary 2 (GCT2) in 2015 and 2016.

3. Data analysis and preparation of a journal publication examining fish and vegetation populations in shallow lowland billabongs.

4. Assessment of the toxicity of mixtures of contaminants of potential concern (both at their operational limits and also as they occur in representative mine site surface and ground waters) to local freshwater species. These toxicity assessments have been completed and results are currently being analysed and compiled to be included in a technical memos and a journal paper).

5. 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. These results have been published. The sensitivity of the mussels to magnesium has also been assessed. The EC10s (10% effect concentrations) from 14-day exposures using two mussel species have been incorporated into revised Species Sensitivity Distributions to provide an updated guideline value of higher reliability for ammonia.

6. 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 has now been established. This new test protocol has also been used to conduct chronic exposures to Mg and Mn. These data will also be included in a relevant publication associated with the protocol.

7. Digitisation of snail egg counting to improve efficiencies of laboratory and in situ snail toxicity testing. This technique is being used successfully for in situ snail toxicity monitoring. It is being adapted slightly to make the counting of egg masses

more automated (to have the software recognise embryos so they do not need to be manually selected by the user). The technique will be adopted in the laboratory whenever snail testing recommences for a particular toxicity project.

8. Continued collaboration with Macquarie University on development of a DNA library for aquatic macroinvertebrates in the ARR. This library will be used as a biomonitoring tool to detect potential mine-related changes to macroinvertebrate communities.

9. Commencement of a 'seasonal sensitivity' project, which aims to characterise and assess the relative sensitivity of macroinvertebrate fauna to magnesium sulfate in Magela Creek, for different phases of the creek hydrograph. Exposures of macroinvertebrates to magnesium commenced in the 2018-19 wet season. Laboratory exposures are being carried out at the Jabiru Field Station.

10. Collaborative work with NESP/CDU examining migratory behaviour of fish in the Magela Creek channel and assessing potential for saline water entering Magela Creek to inhibit this ecological process.

11. 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.

12. 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 (two completed) in crocodile-free environments to quantify the change in data collection methods.

13. Following a pilot study in 2016, a PhD project commenced in 2017 to characterise the chemistry and biota of the dry season, shallow 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. Three years of chemistry and biological data are now available, with sampling in 2018 also including sites in Nourlangie Creek for conservation assessment purposes. These results will inform assessments of saline water egress to the creeks during and following mine site rehabilitation.

14. A cumulative ecological risk assessment (CERA) to examine the cumulative risks to on-site and off-site aquatic ecosystems during the decommissioning and post-decommissioning phases of the Ranger uranium mine has been submitted by Dr Peter Bayliss from CSIRO, and is currently undergoing internal review.

5.3 Ecosystem Restoration and Landform

The Ecosystem Restoration and Landform team has developed Rehabilitation Standards for erosion and containment of tailings in relation to the final landform. Results of landform studies are now informing construction and performance of the reconstructed landforms at Ranger (viz erosion and modelling refinement). A Standard for ecosystem restoration (vegetation and fauna) has also been finalized and this is based on the Society for Ecological Restoration Australasia's 'National standards for the practice of ecological restoration in Australia'. The metrics that will apply to the similarity and sustainability attributes of the Standard are currently being derived. Cost effective techniques to derive and measure indicators for similarity and sustainability (e.g. species identification and densities, canopy cover) are being developed at scale through the use of drones.

Active project work undertaken in the reporting period included:

1. Publication of a journal manuscript on on the impact of rip lines on the final rehabilitated landform.
2. Publication of a journal manuscript on validating CAEASR modelling using a pre-mine landform.
3. 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.
4. Collaborative work with the University of Hull (Professor Tom Coulthard) to conduct a sensitivity analysis of CAESAR-Lisflood model parameters.
5. Technical Advice has been provided to ERA on: (i) runoff coefficients calculated from data collected for various waste rock surfaces at Ranger mine site; (ii) issues to consider for ecosystem restoration in relation to compaction layers in the final landform; (iii) an initial assessment of the FLV6.2 landform; and (iv) particle size on the trial landform.
6. Publication of a journal manuscript on a method to assess and monitor minesite revegetation using drone imagery.
7. Publication of a journal manuscript on the historical reference site data for overstorey vegetation and their use in guiding ecosystem restoration at Ranger mine site.
8. Publication of a journal manuscript on the use of drones for identifying species and monitoring understorey.
9. Collaborative work has continued with the Centre for Mined Land Rehabilitation (CMLR) and, in particular, Associate Professor Peter Erskine, on projects to inform the Ecosystem Restoration Rehabilitation Standard. Most recently work has commenced to investigate the effects of spatial scale on deriving and assessing ecosystem closure criteria, through the establishment and survey of two site in the Georgetown reference ecosystem.

10. Twelve lowland savanna sites have been established and surveyed, and a further 4 seasonally inundated savanna reference sites are currently being established. These reference sites are being used to provide interim 1 ha closure criteria for species composition and community structure.
11. Final report received on faunal closure criteria from Professor Alan Andersen (Northern Australia Environmental Resources Hub- NESP).
12. Collaborative work has commenced with CSIRO (Darwin) and, in particular, Dr Anna Richards. An expert workshop was convened 29-30 April 2019 to develop a restoration trajectory for Ranger mine site. In preparation for the workshop, a field survey was conducted with Professor Kingsley Dixon (ARRTC) of rehabilitated former mine sites to provide examples of trajectories from the region.

5.4 Radiation

The Radiation team has developed Rehabilitation Standards for radiation protection of the public and the environment based on world's best practice standards for radiation protection. Project work is aimed at assessing the achievement of the Rehabilitation Standards, including modelling and analyses of public radiation exposure pathways and the derivation of parameter values for estimating radiation exposure to wildlife.

Active project work undertaken in the reporting period included:

1. Modelling the dispersion of radon-222 and radionuclides in dust from the Ranger final landform to inform estimates of radiation dose to the public from inhalation exposure pathways. The results have been published.
2. Calculation of gamma radiation dose rates from surface waste rock on the Ranger final landform to inform estimates of radiation dose to the public from the external exposure pathway. A manuscript is in preparation for journal publication.
3. Derivation of coefficients to convert tissue radionuclide activity concentrations to whole organism to support wildlife dose assessments for the Ranger final landform. The coefficients have been published.
4. Derivation of whole organism concentration ratios of radionuclides in freshwater organisms and a water radiological quality guideline value to support wildlife dose assessments for the Ranger final landform. The results have been published.
5. Derivation of whole organism concentration ratios of radionuclides in terrestrial vertebrates to support wildlife dose assessments for the Ranger final landform. The results have been submitted for publication.
6. Continued collaboration with Queensland Health and Australian National University on a PhD project aimed at developing new radiochemistry methods for measuring actinium-227 and protactinium-231 in environmental samples.

7. Continued participation in international programs (IAEA, MODARIA II, see Section 2.6) to ensure research of the Radiation team, which provides the scientific basis for demonstrating achievement of the Rehabilitation Standards, 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 2018 to June 2019

Doering, C. (2019). Whole organism concentration ratios of radionuclides and metals in terrestrial vertebrates of an Australian tropical savanna environment. *Journal of Environmental Radioactivity*, 207, 7-14. doi:https://doi.org/10.1016/j.jenvrad.2019.05.016

Doering, C., Carpenter, J., Orr, B., & Urban, D. (2019). 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*, 198, 27-35. doi:https://doi.org/10.1016/j.jenvrad.2018.12.011

Doering, C., McMaster, S. A., & Johansen, M. P. (2019). Modelling the dispersion of radionuclides in dust from a landform covered by low uranium grade waste rock. *Journal of Environmental Radioactivity*, 202, 51-58. doi:https://doi.org/10.1016/j.jenvrad.2019.02.006

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 PD, Bartolo R, McKenna P & Humphrey C. 2019. Using reference sites to guide ecological engineering and restoration of an internationally significant uranium mine in the Northern Territory, Australia. *Ecological Engineering* 129, 61-70.

Ferreira-Rodríguez N, Yoshihiro AB, Aksenova OV, Araujo R, Barnhart MC, Bespalaya YV, Bogan AE, Bolotov IN, Budha PB, Clavijo C, Clearwater SJ, Darrigran G, Do VT, Douda K, Froufe E, Gumpinger C, Henrikson L, Humphrey CL, Johnson NA, Klishkos O, Klunzingert MW, Kovitvadhiw S, Kovitvadhix U, Lajtnery J, Lopes-Limaz M, Moorkensaa EA, Nagayamaab S, Nagelac K-O, Nakano M, Negishiaf JN, Ondina P, Oulasvirtaah P, Prié V, Riccardiaj N, Rudzīte M, Sheldon F, Sousa R, Strayer DL, Takeuchiap M, Taskinen J, Teixeira A, Tiemann JS, Urbańska M, Varandas S, Vinarski MV, Wicklow BJ, Zając T, Vaughn CC 2019. Research priorities for freshwater mussel conservation assessment. *Biological Conservation* 231, 77–87

Gaw, S, Harford, A, Pettigrove, V, Sevicke-Jones, G , Manning, T, Ataria, J, Dafforn, K, Leusch, F, Moggridge, B, Cameron, M, Chapman, J, Coates, G, Colville, A, Death, C, Hageman, K, Hassell, K, Hoak, M, Gadd, J, Jolley, D, Karami, A, Kotzakoulakis, K, Lim, R, McRae, N, Metzeling, L, Mooney, T, Myers, J, Pearson, A, Saaristo, M, Sharley, D, Stuthe, J, Sutherland, O, Thomas, O, Tremblay, L, Wood, W, Boxall, A, Rudd, M and Brooks, B (2019), Towards sustainable environmental quality: Priority research questions for the Australasian region of Oceania. *Integrated Environmental Assessment and Management*. In press. Accepted Author Manuscript. doi:10.1002/ieam.4180

Hernandez LH, Rudge, ML, Bartolo RE & Erskine PD. 2019. Identifying species and monitoring understorey from UAS-derived data: A literature review and future directions. *Drones* 3, 9, https://doi.org/10.3390/drones3010009

Kleinhenz LS, Humphrey CL, Mooney TJ, Trenfield MA, van Dam RA, Nugegoda D & Harford A.J. 2019. Chronic ammonia toxicity to juveniles of 2 tropical AustralianA freshwater mussels (velesunio spp.): Toxicity test optimization and implications for water quality guideline values. *Environmental toxicology and chemistry* 38, 841–851.

Lowry JBC, Narayan M, Hancock, GR & Evans KG. 2019. Understanding post-mining landforms: Utilising pre-mine geomorphology to improve rehabilitation outcomes. *Geomorphology* 328, 93-107.

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.

Medley, P., Tims, S. G., Froehlich, M. B., Fifield, L. K., Bollhöfer, A., Wallner, A., & Pavetich, S. (2019). 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*, 438, 66-69. doi:https://doi.org/10.1016/j.nimb.2018.07.030

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.

Mooney, Thomas J., Ceiwen J. Pease, Alicia C. Hogan, Melanie Trenfield, Linda S. Kleinhenz, Chris Humphrey, Rick A. van Dam, and Andrew J. Harford. "Freshwater chronic ammonia toxicity: A tropical-to-temperate comparison." *Environmental toxicology and chemistry* 38, no. 1 (2019): 177-189.

Peters A, Merrington G, Schlekat C, De Schamphelaere K, Stauber J, Batley G, Harford A, van Dam R, Pease C & Mooney T 2018. Validation of the nickel biotic ligand model for locally relevant species in Australian freshwaters. *Environmental toxicology and chemistry* 37, 2566-2574.

Saynor MJ, Lowry JBC & Boyden J. 2019. Assessment of rip lines using CAESAR-Lisflood on a trial landform at the Ranger Uranium Mine. *Land Degrad Dev*, DOI: 10.1002/ldr.3242

Supervising Scientist 2018. *Annual Technical Report 2017–18*, Commonwealth of Australia, Darwin.

Sutcliffe B, Hose G, Harford A, Midgley D, Greenfield P, Paulsen I & Chariton A 2019. Microbial communities are sensitive indicators for freshwater sediment copper contamination. *Environmental Pollution* 247, 1028-1038.

Trenfield MA, Harford AJ, Mooney T, Ellis M, Humphrey C, & van Dam RA 2018. Integrating laboratory and field studies to assess impacts of discharge from a uranium mine and validate a water quality guideline value for magnesium. *Integrated environmental assessment and management*. 15, 64–76

van Dam JW, Trenfield MA, Streten C, Harford AJ, Parry D & van Dam RA 2018. Assessing chronic toxicity of aluminium, gallium and molybdenum in tropical marine waters using a novel bioassay for larvae of the hermit crab *coenobita variabilis*. *Ecotoxicology and environmental safety* 165, 349-356.

van Dam RA, Hogan AC, Harford AJ & Humphrey CL 2019. How specific is site-specific? A review and guidance for selecting and evaluating approaches for deriving local water quality benchmarks. In press, DOI:10.1002/ieam.4181

Appendix 2 Summaries of research projects active or completed in 2018–2019

Ranger–Operational phase (and decommissioning)

1 Research (5 projects)

Ranger - Rehabilitation

1 Closure criteria theme: Cross-themes (2 projects)

2 Closure criteria theme: Water and sediment (9 projects)

3 Closure criteria theme: Landform (7 projects)

4 Closure criteria theme: Health impacts of radiation and contaminants (5 projects)

5 Closure criteria theme: Ecosystem restoration (14 projects)

Other sites

1 Monitoring (1 project)

Ranger

Operational phase (and decommissioning)

1 Research

Research projects (5 projects)

Project Title	Toxicity of ammonia and other key contaminants of potential concern to freshwater mussels		
KKN Theme	Water and sediment		
KKN Title	WS6. Determining the impact of nutrients in surface water on aquatic biodiversity and ecosystem health		
KKN Question	WS6A. What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?		
Project Status	Completed		
Project number	RES-2015-025	**Project commencement date**	01/09/2015
Project duration (months)	46	**Estimated completion date**	31/07/2019
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

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 *Vilosa* (both genera of freshwater mussel) were the most sensitive to the effects of ammonia. Unionid mussel feeding includes filtration of surface and pore water, suspended sediment, and sediment-associated fine particles, which may increase their exposure to ammonia in their surrounding media (Augspurger et al. 2003). Two species of hyriid freshwater mussels (*Velesunio*) 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 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 has been completed.
- A study on different toxicity responses of *Velesunio* spp. populations from different sites has been conducted using acute copper toxicity testing
- Journal papers describing the acute and chronic toxicity test methods have been published and a paper on the toxicity of magnesum to *Velesunio* spp. has been accepted pending minor review
- Journal papers describing the genetic work and the toxicity of uranium 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 (small) 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 $MgSO_4$. This places this species 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 $MgSO_4$.

Workplan for 2019–20

- N/a, project completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Toxicity estimates for mine-related contaminants: ammonia, U, Mn and Mg
- Standard Operating Protocols developed for acute and chronic toxicity tests using larvae and juveniles of freshwater mussels

The outcomes that this project will achieve are:

- The addition of another local aquatic species that can be used in routine monitoring if necessary, providing better representation across trophic levels
- Greater reliability of site-specific guidelines generated for key contaminants of concern, through the addition of the mussel species to the suite of test organisms.

Planned communication activities

The primary communication activities for the project are:

- Four journal papers covering different aspects of the project
- Oral presentations at SETAC conferences (2016, 2017 & 2019)
- 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 LS, Humphrey CL, Mooney TM, Trenfield MA, van Dam RA, Nugegoda D, Harford AJ. 2019. Chronic ammonia toxicity to juveniles of two tropical Australian freshwater mussels (Velesunio spp.): toxicity test optimization and implications for water quality guideline values. *Environ Toxicol Chem* 38(4):841-851. (DOI: 10.1002/etc.4370).

Kleinhenz LS, Trenfield MA, Mooney TJ, Nugegoda D, Humphrey CL, van Dam RA, D, Harford AJ. 2019. Acute and chronic toxicity of magnesium to the early life stages of two tropical freshwater mussel species. *Ecotox. Environ. Safety*. Accepted.

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.

Oral presentations

Kleinhenz L, Nugegoda D, Trenfield MA, Harford AJ & van Dam RA 2019. The freshwater mussel Velesunio spp is a valuable test species for assessing the acute and chronic toxicity of contaminants in tropical environments. Proceedings of the SETAC Australasia Conference, 7-10 July 2019, Darwin, 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 L, Nugegoda D, Trenfield MA, Harford AJ & van Dam RA 2016. Development of an acute and chronic toxicity test for the freshwater mussel *Velesunio angasi* and an assessment of ammonia toxicity. Proceedings of the 4th SETAC – Australasia Conference, 4-7 October 2016, Hobart, Australia.

Project Title	Developing videography-based methods for monitoring fish communities (CDU and SSB)		
KKN Theme	Water and sediment		
KKN Title	WS9. Optimisation of water quality monitoring programs and assessment methods		
KKN Question	WS9A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Project Status	Active		
Project number	RES-2013-016	**Project commencement date**	01/03/2013
Project duration (months)	89	**Estimated completion date**	30/06/2020
Lead team	WASQ	**Date required**	01/01/2026
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

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

Background

For monitoring and assessment of potential mine-related changes to biodiversity downstream of Ranger, an annual visual fish monitoring technique 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 were 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 and 2018 to assess the implications of the change in methodology. These comparative studies will be repeated in 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 were undertaken in May 2019.
- 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 year 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 vidoegraphy 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 are 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 2019 channel billabong monitoring are reported in the Environmental Monitoring section of the current (2018-19) Annual Technical Report.

Workplan for 2019–20

- A third and final year of side-by-side comparison between the traditional observation and new videography method will be conducted in August, 2019.
- The results of this study will quantify any differences between methods for three annual meaurement events.
- Data collected over the three years will be analsyed and published in a scientific journal.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A SOP for continued videographic-based fish monitoring in channel billabongs,
- Reporting of results of the observer-based and videographic technique comparisons.

The outcome that this project will achieve is:

- The establishment of a replacement monitoring method to that used previously, enabling continued public assurance of environmental protection associated with mining at Ranger.

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

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

King, A. J., George, A., Buckle, D. J., Novak, P. A., & Fulton, C. J. (2018). Efficacy of remote underwater video cameras for monitoring tropical wetland fishes. *Hydrobiologia*, 807(1), 145-164.

Project Title	Genomics-based identification of freshwater macroinvertebrates to species level		
KKN Theme	Water and sediment		
KKN Title	WS9. Optimisation of water quality monitoring programs and assessment methods		
KKN Question	WS9A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Project Status	Active		
Project number	RES-2015-019	**Project commencement date**	01/04/2015
Project duration (months)	58	**Estimated completion date**	12/01/2026
Lead team	WASQ	**Date required**	01/01/2026
In-house or outsourced	Collaboration	**Supporting team(s)**	Anthony Chariton Grant Hose Peter Dostine

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). Other macroinvertebrate groups will be processed and analysed after these three initial groups have been well described locally.
- 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.

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.
- 300 macroinvertebrate species have been collected and sent to Macquarie University for DNA extraction and sequencing
- DNA extractions have yielded both low and high quality DNA; however, sequenciung trials have demonstrated that most samples yield sufficient DNA for sequencing

Key findings

- There are no key findings to date.

Workplan for 2019–20

- A final batch of samples will be collected and sent to Macquarie University for DNA extraction and sequencing.

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 outcome that this project will achieve is:

- Accurate and cost effective species-level identifications of freshwater macroinvertebrates used as indicators of water quality in the ARR.

Planned communication activities

The primary communication activities for the project are:

- 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 publications to date.

Project Title	Developing a short-term chronic toxicity test for the fish, *Mogurnda mogurnda*		
KKN Theme	Water and sediment		
KKN Title	WS9. Optimisation of water quality monitoring programs and assessment methods		
KKN Question	WS9A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Project Status	Active		
Project number	RES-2015-028	**Project commencement date**	01/06/2015
Project duration (months)	54	**Estimated completion date**	31/10/2019
Lead team	WASQ	**Date required**	01/01/2026
In-house or outsourced	In-house	**Supporting team(s)**	

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.
- At least two toxicity tests have been completed for each of ammonia, uranium, magnesium and manganese. This new method has also been used for Direct Toxicity Assessments (DTAs) of mine site waters.
- 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 μg L^{-1} U with upper and lower confidence limits (UCL, LCL) of 1050 and 1919 μg L^{-1} is comparable with the EC50 derived by Cheng et al's (2010) earlier 28-d test of 1130 (LCL:1020, UCL: 1240) μg L^{-1}.
- The 7-d EC50s for magnesium and manganese are more sensitive than the previous acute data (chronic data - Mg: 409 mg L^{-1}, Mn: 986 μg L^{-1}, acute data - Mg: 4 g L^{-1}, Mn: 240 mg L^{-1}).

Workplan for 2019–20

- Complete write-up of manuscript for publication in a peer reviewed journal.

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 outcome that this project will achieve is:

- An improved toxicity testing program for assessing the sub-lethal effects of contaminants on local aquatic biota and, hence, improved site-specific water quality guideline values.

Planned communication activities

The primary communication activities for the project are:

- Presentation at the SETAC Australasia conferences
- Peer reviewed journal article.
- Annual reporting of results on the Supervising Scientist website
- Reports and presentations for ARRTC and ARRAC meetings.

Project publications to date (if applicable)

No project publications to date.

Project Title	Develop a technique for automating snail egg counts for toxicity testing and monitoring		
KKN Theme	Water and sediment		
KKN Title	WS9. Optimisation of water quality monitoring programs and assessment methods		
KKN Question	WS9A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?		
Project Status	Active		
Project number	RES-2012-006	**Project commencement date**	31/10/2017
Project duration (months)	24	**Estimated completion date**	30/10/2019
Lead team	WASQ	**Date required**	01/01/2026
In-house or outsourced	In-house	**Supporting team(s)**	

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 species native to Kakadu National Park that is used in 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 cyclindrical egg chambers and which can be removed for digital image analysis has successfully been developed. Laboratory testing has determined that the egg-laying surface, a thin and flexible clear polycarbonate plastic, has no significant impact on *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.
- This new method was used for the first time during the 2018-19 wet season. Progress has been made using the computer image software 'Matlab' to automate counting. The software can successfully recognise and count number of egg masses and embryos using a combinations of light thresholding, size and shape criteria. Using all images taken from the 2018-19 season of egg masses, the software One field test has been performed to test the process while more tests are planned.

Key findings

- A suitable egg-laying substrate has been identified which does not impact on *A. cumingi* egg laying rates and numbers.
- It is possible to capture high resolution images of all egg masses on the egg-laying surface.
- A computer code capable of identifying the egg mass and embryo number for each replicate has been derived.

Workplan for 2019–20

- The computer code developed for automating egg mass and embryo counting will be tested and refined by processing approximately 550 images collected from the 2018-19 season. After each image is processed by the software, an analyst will confirm the count and quantify any difference between automatic and manual counting.
- The overall error rate associated with the code will be determined, and must fall below 5% to meet current quality control criteria. Possible improvements to the code, based on visual inspection of counts, will be undertaken to ensure achievement of the greatest possible accuracy.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- An internal report describing the new methodology
- A peer-reviewed journal paper
- Annual reporting to ARRTC

The outcome that this project will achieve is:

- Increased efficiency and accuracy of snail egg counts arising from in-situ monitoring and toxicity testing.

Planned communication activities

The primary communication activities for the project are:

- Presentation at the biannual SETAC Australasia conference (July 2019)
- Reports/presentations tailored to key stakeholders as required.

Project publications to date (if applicable)

There are no publications for this project 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: Health impacts of radiation and contaminants

5 Closure Criteria theme: Ecosystem restoration

Ranger – Rehabilitation

CC theme: Cross-themes (2 projects)

Project Title	Cumulative risk assessment for Ranger mine site rehabilitation and closure-Phase 2 (aquatic pathways)		
KKN Theme	Cross theme		
KKN Title	CT1. Assessing the cumulative risks to the success of rehabilitation on-site and to the protection of the off-site environment.		
KKN Question	CT1A. What are the cumulative risks to the success of rehabilitation on-site and to the off-site environment?		
Project Status	Active		
Project number	RES-2017-032	**Project commencement date**	01/03/2018
Project duration (months)	22	**Estimated completion date**	28/12/2019
Lead team	WASQ	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

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 able to 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 in Q3 2019. 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 a number of 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 (see RES-2017-001) 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 was engaged under a cost-sharing arrangement 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 ecosytems and the effect of perturbations. A report has been completed.
- A comprehensive review of relevant datasets has been conducted. The datasets have been collated and catalogued.
- A quantitative cumulative risk assessment model has been built and was tested using historical exposure datasets.
- The model is ready for exposure data outputs from the surface water modelling being conducted by ERA once these outputs become available.

Key findings

- The qualitative modelling provided knowledge concerning the cumulative impacts to aquatic ecosystems arising from trophic interaction perturbations.
- A trophic level and habitat based qualitative model indicated that the higher-level Environmental Values could be adversely affected by impacts to some lower-level organisms.
- It highlighted the trophic groups that have potential as key indicators of whole-of-ecosystem health, e.g. phytoplankton.
- The quantitative modelling provided knowledge about cumulative impacts associated with combined multiple stressors.
- The additive model combines all the risks of the contaminants of potential concern (COPCs) that have biological effects data.
- It was tested with historical exposures and showed no cumulative risk from the COPCs discharged from the mine.
- It will be used to test the cumulative risk of COPCs predicted to enter the creek in the future.

Workplan for 2019–20

- Assessment of the Surface Water modelling outputs from ERA (expected August 2019).
- Completion of papers.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- 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 Ranger rehabilitation.
- 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.

The outcome that this project will achieve is:

- The knowledge will be used to determine if there are risks to the off-site environment following mine site closure and to determine if and/or when impacts will be expected on-site.

Planned communication activities

The primary communication activities for the project are:

- Presentation to ARRTC.
- A journal article arising from the qualitative modelling.
- 1-2 journal articles arising from 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)

Dambacher JM, Bayliss P, Harford AJ, Bartolo RE (in prep) Qualitative Mathematical Models to Support Ecological Risk Assessment for Rehabilitation and Closure of Ranger Uranium Mine, Australia.

Bayliss P, Harford AJ, Trenfield (in prep) Assessing cumulative ecological risks to aquatic ecosystems on Kakadu National Park from the Ranger uranium mine in northern Australia: application to rehabilitation.

Project Title	Cataloguing the natural World Heritage values on the Ranger Project Area		
KKN Theme	Cross theme		
KKN Title	CT2. Characterising key conservation and biodiversity values of the Ranger Project Area		
KKN Question	CT2A. What faunal community structure (composition, relative abundance, functional groups) is present in the areas surrounding the RPA?		
Project Status	Active		
Project number	RES-2017-004	**Project commencement date**	01/07/2017
Project duration (months)	23	**Estimated completion date**	30/05/2019
Lead team	ERL	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

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 habitats in the RPA, 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. In particular, 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

- The current natural values for which Kakadu National Park were inscribed on the World Heritage List were assessed for their occurrence on the Ranger Project Area using GIS data layers. Each natural value found on the RPA was reported against the relevant World Heritage criterion as follows:

  Criterion vii) To contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance – represented by landscapes, view fields, integrity of the site, vegetation and habitats, and scale of undisturbed landscape.

  Criterion ix) To be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals – represented by floodplains and wetlands, waterways, landscapes, integrity of the site, vegetation and habitats, diversity of species, and ecological processes.

  Criterion x) To contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation – represented by vegetation and habitats, flora and fauna species of conservation significance, and endemic species.
- The focus of this work was on the natural Wold Heritage values. Further work should be undertaken to account for similarly of the cultural World Heritage values, and any other relevant conservation and biodiversity values.

Workplan for 2019–20

- Finalise internal review of report.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A report on the locations and spatial extent of natural values (for which Kakadu National Park is World Heritage listed for) occurring on the Ranger Project Area.
- Spatial database of core datasets used in the project

The outcome that this project will achieve is:

- Listed and quantified natural World Heritage values currently existing on the Ranger Project Area that inform the potential incorporation of the site post-closure into Kakadu National Park.

Planned communication activities

The primary communication activities for the project are:

- Internal report
- Supervising Scientist Branch Coffee Break seminar
- Input to workshops determining ALARA and BPT on the RPA

Project publications to date (if applicable)

Nil

Ranger – Rehabilitation

CC theme: Water and sediment (9 projects)

Project Title	Predicting uranium accumulation in sediments		
KKN Theme	Water and sediment		
KKN Title	WS3. Predicting transport of contaminants in surface water		
KKN Question	WS3G. To what extent will the interaction of contaminants between sediment and surface water affect their respective qualities?		
Project Status	Active		
Project number	RES-2016-013	**Project commencement date**	01/06/2018
Project duration (months)	11	**Estimated completion date**	30/04/2019
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	Collaboration	**Supporting team(s)**	Barry Noller

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 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 coefficient of U, which can be used to make predictions regarding the effect of water column U concentrations on sediment concentrations.

Progress against plan

- Water and sediment quality data provided to consultant, Dr Barry Noller, Centre for Mined Land Rehabilitation.
- Consultant has provided a report with indicative results.
- An internal review has been completed and the model tested with additional water and sediment quality data from Ranger and surrounds.

Key findings

- Speciation studies showed thermodynamically favourable formation of UO2-OM within the water chemistry found around the RPA.
- Strong Freundlich isotherm correlation for U in water and sediment fractions in samples collected.
- Using Freundlich isotherm fit to experimental data, U sediment AEM when water column [U] = 2.8 μg L^{-1} was predicted to be 54.8 ± 25.1 mg kg^{-1}.

Workplan for 2019–20

- Finalise Internal Report

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Estimation of the accumulation of uranium (U) in sediments for various water column concentrations.
- Internal Report describing the derivation of sediment U partition fractions from empirical and experimental data

The outcome that this project will achieve is:

- This project provides assurance that the site-specific uranium water quality guideline will not result in an accumulation of U in sediments to a level of concern.

Planned communication activities

The primary communication activities for the project are:

- Report to ARRTC at end of year meeting.
- Report to SSB Supervision and Monitoring any findings that significantly change the rehabilitation standard.

Project publications to date (if applicable)

Noller, B (2018) Review of Water - Sediment partitioning. Consultancy report from Centre For Mine Land Rehabilitation for the Environmental Research Institute of the Supervising Scientist (ERISS),

McMaster, SA, Humphrey CL, Harford AJ(in prep) Uranium Partitioning in Waterbodies Near the Ranger Project Area. Internal Report. Supervising Scientist, Darwin NT.

Project Title	Assess the ecological risks of mine water contaminants in the dry season, subsurface waters of Magela sand channel		
KKN Theme	Water and sediment		
KKN Title	WS4. Characterising baseline aquatic biodiversity and ecosystem health		
KKN Question	WS4A. What are the nature and extent of baseline surface water, hyporheic and stygofauna communities, as well as other groundwater dependent ecosystems, and their associated environmental conditions?		
Project Status	Active		
Project number	RES-2016-012	**Project commencement date**	31/03/2017
Project duration (months)	36	**Estimated completion date**	01/05/2020
Lead team	WASQ	**Date required**	01/05/2020
In-house or outsourced	Collaboration	**Supporting team(s)**	Jenny Davis (Charles Darwin University - primary supervisor) Grant Hose (Macquarie University)

Aims

- To characterise the groundwater communities and associated habitat and water quality in Magela Creek, by:
  - i) describing the community structure and function of groundwater fauna and environmental conditions (water quality, habitat) in Magela Creek sand channel, and
  - ii) 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 (MgSO4) derived from the waste rock landform and pit capping. Solute egress modelling predicts that within 10 years of closure, groundwater with MgSO4 concentrations greater than the current chronic exposure limit (3 mg/L) will reach Magela Creek and that concentrations above this limit will remain for 10,000 years.

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

During the dry season, and when there are no longer surface waters, there is a reported resident fauna in the dry and moist surface sands of Magela Creek. Through re-wetting experiments, Paltridge et al (1997) observed invertebrates in the top 20 cm of the sands that were a mix of (i) dormant taxa commonly observed in the surface waters and associated benthos, as well as (ii) groundwater (presumably obligate) specialists (i.e. stygofauna). A pilot study was undertaken in 2016 to characterise fauna and water quality in subsurface sands of Magela Creek during the dry season. The results are reported in Chandler et al (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 and 2018 dry season sampling completed - initial water chemistry analysis and sorting of biota samples advanced.
- DNA extraction of 2017 metagenomic samples completed May 2018, and sequencing completed February 2019 - preliminary examination of results undertaken and presented at SETAC 2019.
- DNA extraction of 2018 metagenomic samples completed May 2019 and sequencing completed June 2019

Key findings

- Examination of water chemistry data indicates contamination gradient around Coonjimba Billabong reported in 2016 pilot still present bteween 2017 and 2019.

- Elevated EC, magnesium and sulfate concentrations were recorded at sites adjacent to Coonjimba Billabong, with maximum values recorded in October 2017 (416 µS/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 due to mine derived contamination.
- Continuous data recorded maximum EC values of 605 µS/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.
- Preliminary investigations of the 2017 eDNA data indicate microbial (prokaryotic) communities at exposed sites are significantly different to the unexposed sites, and this variation is strongly correlated with the elevated levels of $MgSO_4$ at the exposed sites near Coonjimba Billabong.
- Eukaryotic communites are also significantly different between the exposed and unexposed sites. However, although variation is correlated to elevated levels of $MgSO_4$ at the exposed sites, other physical variables such as depth to water table (standing water level) may also be influencing the variation seen in the community data.

Workplan for 2019–20

- Processing remaining stygofauna samples
- Analysis of the 2017 and 2018 water chemistry data
- Analysis of 2017 and 2018 sequencing data
- Production of 4 papers/chapters for publication and PhD thesis

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Characterisation of the dry season subsurface faunal communities in Magela Creek sandbed.
- Characterisation of the dry season surface and subsurface water quality in Magela Creek.
- Relationships between environmental variables (including mine-derived COPCs) and biological communities

The outcomes that this project will achieve are:

- An understanding of spatial and temporal patterns in 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

The primary communication activities for the project are:

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

Project publications to date (if applicable)

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 Title	Review of acid sulfate soil knowledge and development of a rehabilitation standard for sulfate		
KKN Theme	Water and sediment		
KKN Title	WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health		
KKN Question	WS5A. Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?		
Project Status	Completed		
Project number	RES-2016-010	**Project commencement date**	30/03/2017
Project duration (months)	36	**Estimated completion date**	30/03/2020
Lead team	WASQ	**Date required**	
In-house or outsourced	Collaboration	**Supporting team(s)**	Dr Darren Baldwin, Rivers and Wetlands

Aims

- To review and assist with development of SSB's Rehabilitation Standard for sulfate.
- To review ERA's Ranger Acid Sulfate Soils (ASS) investigation reports, SSB's draft dry season Magela Creek (sub-surface) water quality report and long-term water quality datasets for Coonjimba Billabong and Retention Pond 1 (RP1).

Background

There is a need to develop a Rehabilitation Standard for sulfate in the context of ongoing issues associated with 'mine-generated' acid sulfate soils (ASS). A Standard has been developed but requires the review of a specialist ASS expert for completion. Further, there is a need to review ERA's recent studies on ASS in Coonjimba Billabong, where significant acid events have been occurring in the early wet season since 2012. SSB contracted Dr Darren Baldwin to advice on these ASS matters.

Progress against plan

- SSB's consultant, Dr Darren Baldwin, has reviewed and reported on all SSB and ERA's reports after being provided with reported, relevant site information and chemistry data.
- Dr Baldwin reviewed ERA's response to the ASS rehabilitation standard and participated in meetings to negotiate the standard.

Key findings

- The antecedent conditions in Coonjimba Billabong and RP1 leading to acid sulfate events were consistent with the need to maintain the long term sulfate concentrations in surface waters below 10 mg/L. This threshold is consistent with national guidelines.

Workplan for 2019–20

- Assessment of sulfate exposure mapping, which is being conducted by ERA consultants
- Assess design and results from billabong sampling project being conducted by ERA

Planned project outputs and associated outcomes

The primary output for the project is:

- Review of relevant ERA/SSB reports and long-term water quality datasets to develop a Rehabilitation Standard for sulfate.

The outcome that this project will achieve is:

- The knowledge will be used to assess the risk of Acid Sulfate Sediment generation off-site and on-site.

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Baldwin DS, (2017) Understanding acid sulfate soils in Coonjimba Billabong. Prepared for the Supervising Scientist Branch, the Department of Environment and Energy by Rivers and Wetlands, May 2017, 24 pp. Baldwin DS, (2017) Review of Supervising Scientist Branch Rehabilitation Standard for Sulfate. Prepared for the Supervising Scientist Branch, the Department of Environment and Energy by Rivers and Wetlands, June 2017, 8 pp.

Project Title	The toxicity of U to sediment biota of Gulungul Billabong		
KKN Theme	Water and sediment		
KKN Title	WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health		
KKN Question	WS5A. Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?		
Project Status	Completed		
Project number	RES-2009-002	**Project commencement date**	01/07/2008
Project duration (months)	131	**Estimated completion date**	30/09/2019
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

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

Background

This project aims to derive a sediment Guideline Value (GV) for uranium (U) and has been ongoing 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 in 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. Analyses of new data acquired since 2018 have been underway to corroborate or refine the original conclusions. The results will be published 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.
- Results have been communicated to ERA.
- 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 has been undertaken with data analysis underway 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 2019–20

- Final data analysis and journal publication

Planned project outputs and associated outcomes

The primary output for the project is:

- A sediment quality GV for U, which can be used as closure criteria for the rehabilaition of on-site billabongs.

The outcome that this project will achieve is:

- The project indicates that U in billabong sediments has a low bioavailability and that the risk of adverse effects is low under natural water quality conditions prevailaing over the seasons.

Planned communication activities

The primary communication activities for the project are:

- Four papers published in peer-reviewed journals.
- Reports in annual research summaries and presentations to key stakeholders such as ERA and ARRTC.

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 2010–2011Jones 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 Title	Deriving a candidate Mg guideline value based on a mesocosm study (re-analysis of 2002 PhD data)		
KKN Theme	Water and sediment		
KKN Title	WS7. Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health		
KKN Question	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures, modifying factors and different exposure scenarios?		
Project Status	Active		
Project number	RES-2017-031	**Project commencement date**	01/04/2016
Project duration (months)	39	**Estimated completion date**	01/06/2019
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

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 C McCullough's PhD thesis "A multi-scale assessment of the ecological risk of magnesium sulphate 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, 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 incoporated with other laboratory and field evidence in a weight of evidence evaluation to derive a Mg standard for Ranger mine-site closure. In 2019, phytoplankton data gathered from mine and reference waterbodies in 2009 and 2011 were analysed. Some major algal groups were shown to respond strongly (and negatively) to magnesium, supporting the chlorophyll result reported in the mesocosm study.

Workplan for 2019–20

- Manuscript is currently going through internal review

Planned project outputs and associated outcomes

The primary output for the project is:

- Field community-based toxicity estimate(s) for Mg arising from an earlier (2002) mesocosm study

The outcome that this project will achieve is:

- An additional line of evidence for the weight of evidence assessment deriving a magnesium standard for Ranger receiving waters

Planned communication activities

The primary communication activities for the project are:

- 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 Title	Assessing the toxicity of mine water mixtures for operational and closure scenarios		
KKN Theme	Water and sediment		
KKN Title	WS7. Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health		
KKN Question	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures, modifying factors and different exposure scenarios?		
Project Status	Active		
Project number	RES-2017-001	**Project commencement date**	01/05/2017
Project duration (months)	24	**Estimated completion date**	20/12/2019
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

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 test whole mine waters to establish the protectiveness of the derived GVs when in natural waters as mixtures.
- If testing indicates that the derived GVs are not protective, to develop the capacity to predict the toxicity of a given mine site water with particular physicochemical conditions using statistical modelling.
- To assess the toxicity of the mixture predicted to emanate to surface waters 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 GVs 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 GVs 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.
- For Aim 2, four whole mine waters were initially selected for testing, TDWW, PJ, RP2 and GCT2. Toxicity testing is complete and an additional shallow seepage water SIS2 has also been tested. TDWW was also tested at an adjusted pH (6). An additional source of shallow seepage water may be tested
- Aim 3 is mostly complete with advice provided by modelling experts (Peter Bayliss, Angus Webb and Joe Myers) on the best approach to analysing the complex data set. Metal speciation modelling has also been used to ensure we are considering only the predicted bioavailable fractions of each contaminant.
- Aim 4 is awaiting the predicted composition of the final waters from the surface-ground water modelling.

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 freshwater species of WASQ's routine laboratory-based monitoring suite. 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.
- Process water from TDWW 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 duckweed least affected (EC10 = 0.4% strength water).
- Process water from PJ was less toxic than TDWW but with the snail again the most sensitive species (EC10 = 0.01%) and duckweed growth stimulated at up to 1% strength.
- Pond water from RP2 (Mg:Ca = 4:1) was less toxic than the process water (as anticipated) with the most sensitive species being the snail (EC10 = 2%) and the cladoceran (EC10 = 6%).
- Shallow seepage water from SIS2 with a Mg:Ca ratio of 4:1 was most toxic to the snail (EC10 = 1% strength) and the alga (EC10 = 5%).
- Speciation modelling of the waters and the use of Hazard Indices tools, show that for the process water, the contaminant that is most bioavailable and of most concern is manganese. For the shallow seepage water this is magnesium.
- Modelling of the process and shallow seepage water mixture toxicity shows that in most cases, toxicity can be predicted using Concentration Addition. There are only

several instances (for the alga and the snail in TDWW) where those species would be underprotected using such a prediction, where toxicity is greater than that predicted by adding the exposure concentrations of each of the contaminants.
- This synergism in the process water suggests that interaction is possibly occurring in this water type due to its complex composition.

Workplan for 2019–20

2019

- Work on journal paper publication
- Conduct additional laboratory toxicity testing with the shallow seepage water (SIS2) using water which has been concentrated to allow for full response curves to be produced for all species. (Results to date did not result in full effects for any species in this water due to the lower levels of contaminants compared to pond and process waters).

2020

- If chemisty from other shallow seepage water sites (for example water from bores around the northern stockpile) appears to be different from that of SIS2, toxicity of another shallow seepage water source could be tested to increase the representativeness of results for this water type. If water chemistry is similar between SIS2 and other sampled shallow seepage waters, it will be unnecessary to conduct additional testing.
- If toxicity cannot be predicted for the mixture that is representative of the predicted water composition of concern, toxicity testing of such a water would be necessary.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- 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.

The outcome that this project will achieve is:

- Increased confidence in, and justification for, the proposed rehabilitation standards

Planned communication activities

The primary communication activities for the project are:

- Journal manuscript.
- Conference presentation at SETAC US meeting 2017 and SETAC AU conference 2019.
- Internal presentation to Chemicals & Assessment Branch 2018.

- Discussions with key stakeholders as appropriate.
- Progress report presented to ARRTC members (Jenny Stauber & Fran Sheldon) prior to 2019 ARRTC meeting. Subsequent advice incorporated into the project design.

Project publications to date (if applicable)

Nil

Project Title	Hazard and risk assessments for potential / emerging water quality contaminants and toxicity modifying factors		
KKN Theme	Water and sediment		
KKN Title	WS7. Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health		
KKN Question	WS7B. What is the risk associated with emerging contaminants?		
Project Status	Active		
Project number	RES-2018-005	**Project commencement date**	01/03/2019
Project duration (months)	34	**Estimated completion date**	30/12/2021
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

- To conduct a hazard assessment on existing water quality monitoring data and if relevant, modelled water quality data for post-closure scenarios, to:
  i) determine if concentrations of contaminants which have not been assessed and tested for toxicity are increasing/will increase in concentration e.g. K, HCO_3 and herbicides.
  ii) determine if toxicity modifying stressors such as temperature and pH have potential to contribute direct or indirect (modifying) toxic effects.
- To undertake laboratory assessments to quantify risk where hazards are identified

Background

Changes in lentic macroinvertebrate communities in Ranger mine site waterbodies (Georgetown Billabong, Coonjimba Billabong and RP1) over time (1979-2013) can predominately be attributed to Mg increase. However, changes in macroinvertebrate responses over this time span were also strongly correlated with potassium, calcium and carbonate. Little is known about the toxicity of potassium and carbonate, and their interaction with other COPCs, to tropical species resident in soft-waters. Thus further investigation may be required to determine how the toxicity of these ions, and other stressors such a pH and temperature, are contributing to the direct and indirect effects on macroinvertebrates observed. The project will be phased by way of initial hazard assessment, followed by toxicity assessment should emerging COPCs or stressors be deemed sufficiently important to warrant further assessment. The hazard assessment will include ions and toxicity modifying factors currently measured in surface waters,

but also contaminants identified from modelling of future water quality post closure together with those that may play a role in ecosystem establishment, including herbicides.

Progress against plan

- Desktop reviews have been completed for 3 of the 6 issues identified: 1) herbicides (glyphosate, oxyfluorfen & sulfometuron-methyl), 2) major ions and 3) hydrocarbons.
- Reviews in progress are for 4) additional metals in tailings and brine that are not considered to be key COPCs, 5) nutrients, and 6) stressors such as suspended sediment and increasing water temperature.

Key findings

- Nil to report

Workplan for 2019–20

- 2019: desktop reviews
- 2020: any laboratory assessment work if this is deemed necessary based on desktop reviews

Planned project outputs and associated outcomes

The primary outputs for the project are:

- An understanding of the potential hazards from emerging contaminants or physical stressors of potential concern in order to prioritise these for further risk assessment.
- Where necessary, provide quantitative assessments and aquatic effects data for any hazards.

The outcome that this project will achieve is:

- Potential risks to the aquatic ecosystem.

Planned communication activities

The primary communication activities for the project are:

- Reports to ARRTC and ARRAC
- A journal article/internal report
- Presentation of the findings as an oral presentation or poster presentation at a SETAC conference

Project publications to date (if applicable)

Nil

Project Title	'Seasonal sensitivity' (to Mg) profile for organisms in the Magela creek channel		
KKN Theme	Water and sediment		
KKN Title	WS7. Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health		
KKN Question	WS7C. Are current guideline values appropriate to protect the key groups of aquatic organisms that have not been represented in laboratory and field toxicity assessments (e.g. flow-dependent insects, hyporheic biota and stygofauna)?		
Project Status	Active		
Project number	RES-2018-006	**Project commencement date**	01/07/2018
Project duration (months)	27	**Estimated completion date**	30/09/2020
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

- To identify phases of the hydrological cycle in Magela Creek channels when, after mine site closure, receiving surface water ecosystems will be exposed to surface water runoff and exfiltrating groundwater with significant elevated electrical conductivity (EC).
- To characterise the macroinvertebrate fauna in Magela creek channel receiving waters across different key phases of the hydrological cycle.
- To determine the sensitivity of macroinvertebrate fauna of Magela creek channel receiving waters to magnesium by conducting laboratory toxicity tests on field-collected macroinvertebrates from different phases of the hydrological cycle.

Background

The magnesium rehabilitation standard has been derived from laboratory and field (mesocosm phytoplankton and zooplankon, and lentic macroinvertebrates) lines of evidence that do not include stream macroinvertebrates, especially forms that depend on flowing water. Inclusion of additional information on sensitivities of flow-dependent communities, which include some species known to be sensitive to salts, would further increase our level of confidence in the magnesium (Mg). Rehabilitation Standard. Such knowledge will also enable an impact assessment of solutes transported

via groundwater to these communities. This study will identify phases of the hydrological cycle in Magela and Gulungul creek channels when, after mine site closure, receiving surface water ecosystems will be exposed to surface water runoff and exfiltrating groundwater with significant elevated electrical conductivity (EC). This information in turn would guide further work needed to characterise the associated macroinvertebrate fauna in the creek channel receiving waters. Using this information, selected macroinvertebrate taxa, including those known to be salt-sensitive, from different phases of the hydrological cycle would be used in rapid toxicity tests to rank their sensitivities to salts ($MgSO_4$). Such rapid testing protocols have been developed and applied elsewhere in Australia and enable identification of sensitive taxa quickly and effectively. Additionally, incorporating selected taxa routinely assessed in the laboratory in the rapid toxicity testing program will allow for a qualitative comparative assessment of macroinvertebrate taxa tested. The ranked sensitivities, coupled with the information on the phases of the hydrological cycle most at risk from elevated EC, will be used to assess the risk of Mg throughout the key phases of the hydrological cycle, as well as the adequacy of the existing rehabilitation standard.

Progress against plan

- Macroinvertebrate communities were sampled at four periods of the hydrograph (from early wet season flow to dry season pool formation) using sweep nets and artificial substrates.
- Single species acute toxicity tests were conducted using macroinvertebrates commonly found during each sampling round.

Key findings

- Data are currently being analysed and there are no key findings to report at this stage.

Workplan for 2019–20

- Complete macroinvertebrate identifications for samples collected in the 2018/2019 wet season.
- Analyse data collected over the 2018/2019 wet season.
- Repeat macroinvertebrate sampling and toxicity testing over the 2019/2020 wet season.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Assess the relative sensitivities of resident aquatic insects to Mg across different phases of stream flow in Magela Creek.
- From ERA's surface water modelling, identify phases of the hydrological cycle in Magela and Gulungul creek channels which will be exposed to surface water runoff and expressed groundwater with significant elevated electrical conductivity (EC).
- Using the information from dot-points 1 and 2, undertake a risk assessment identifying phases of the hydrological cycle most at risk from Mg.

The outcomes that this project will achieve are:

- The macroinvertebrate assemblages of Magela Creek channel resident during different hydrological phases.
- The relative risks of mine waters discharged from Ranger uranium mine to resident macroinvertebrate communities during different hydrological phases

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Nil

Project Title	Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity (NESP fish migration)		
KKN Theme	Water and sediment		
KKN Title	WS7. Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health		
KKN Question	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)?		
Project Status	Active		
Project number	RES-2018-002	**Project commencement date**	01/07/2018
Project duration (months)	25	**Estimated completion date**	01/07/2020
Lead team	WASQ	**Date required**	01/03/2020
In-house or outsourced	In-house	**Supporting team(s)**	

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

- Late 2018 and 2018/2019 wet season field work were successfully completed. Approximately 55 fish were tagged in Bowerbird Billabong in late 2018 before Magela Creek started flowing and approximately 35 fish were tagged at Magela crossing and Mudginberri Billabong during recessional flow (2019). Fish communities were monitored in Bowerbird and Mudginberri Billabongs throughout the wet season using sonar imaging.
- A preliminary download of two receivers at Bowerbird Billabong showed that the transmitters implanted in fish were being successfully detected and that tagged fish were moving between receivers. Final testing of the ARIS 1800 sonar unit was conducted in November 2018 and sonar surveys of fish assemblages were conducted in Bowerbird and Mudjinberri billabongs in December 2018.
- Analysis of the sonar data commenced in January 2019. Early indications are that the sonar will have utility for obtaining data on fish assemblage composition, length frequency distributions and fish behaviour as expected.

Key findings

- None yet to report

Workplan for 2019–20

- Fish tagged in Bowerbird billabong will continue to be tracked during the 2019/2020 wetseason.
- Potential avoidance behaviour of fish will be monitored at key mine water release points in the 2019/20 wet season using videography and sonar imaging.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Understanding of dry 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
- Where possible, quantification of the inhibition/avoidance of migrating fish species to current mine water releases from Ranger.
- From above dot-points, identification of key periods when different species may be at risk from mine-derived solutes associated with solute egress to Magela Creek after Ranger mine rehabilitation.

The outcomes that this project will achieve are:

- 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

The primary communication activities for the project are:

- 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)

Nil

Ranger – Rehabilitation

CC theme: Landform (7 projects)

Project Title	Determining and testing representativeness of long-term rainfall patterns for use in final landform modelling		
KKN Theme	Landform		
KKN Title	LAN3. Predicting erosion of the rehabilitated landform		
KKN Question	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)?		
Project Status	Active		
Project number	RES-2014-006	**Project commencement date**	20/05/2015
Project duration (months)	50	**Estimated completion date**	01/07/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	

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 ensure the derived long term rainfall data set used in erosion modelling captures extreme flood events occurring in the recent (Holocene) past.

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), are 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 River 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 were sent away for dating by Optically stimulated luminescence (OSL).
- A journal paper has been prepared and is currently circulating amongst authors prior to submission

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.Nine very large floods, of about the same magnitude, occurred during the past 8,400 years in the East Alligator River (determined by dating). The latest, in 2007, had about the same specific discharge as the calculated Probable Maximum Flood in Magela Creek and hence the East Alligator R and Magela Ck floods can be considered as a single set. These floods have magnitudes larger than the Australian flood envelope curve and an Annual Exceedance Probability of 0.3% which can be assumed to be the probability of the Maximum Probable Rainfall at Ranger. The 2007 flood was, therefore, an extreme, and perhaps the most extreme, flood (and associated rainfall) likely to occur in the vicinity of Ranger.
- The recorded rainfall during the large rainfall event in 2007 has been incorporated into the synthetic rainfall data to be used in the CAESAR-Lisflood model. Rainfall from the largest three day rainfall recorded in Australia at Bellenden Ker has also been included in the wet scenario of the synthetic rainfall record.

Workplan for 2019–20

- Submit the journal paper for publication

Planned project outputs and associated outcomes

The primary output for the project is:

- Knowledge of the number and magnitude of large floods that have occured in the East Alligator River during the Holocene (10000 years).
- Two journal publications from this investigation

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

- The derived long term rainfall data set used in erosion modelling captures extreme flood events occurring in the recent (Holocene) past.

Planned communication activities

The primary communication activities for the project are:

- Journal publication.
- Presentations and discussions with relevant working groups, committees and ARRTC.
- Internal reports (data) and annual research summaries.

Project publications to date (if applicable)

Saynor MJ, Wasson RJ, ERskine WD & Lam D (In Prep). Palaeohydrology of the East Alligator River and Mine site rehabilitation, Northern Australia: Are all the floods PMFs?

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 Title	Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to the rehabilitated Ranger mine - Gulungul Creek scale		
KKN Theme	Landform		
KKN Title	LAN3. Predicting erosion of the rehabilitated landform		
KKN Question	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)?		
Project Status	Active		
Project number	RES-2016-002	**Project commencement date**	01/07/2016
Project duration (months)	33	**Estimated completion date**	30/05/2019
Lead team	ERL	**Date required**	30/06/2018
In-house or outsourced	Collaboration	**Supporting team(s)**	Charles Darwin University - Professor Ken Evans University of Newcastle- Associate Professor Greg Hancock

Aims

- To calibrate and validate the CAESAR-Lisflood model outputs of suspended sediment load at the catchment scale.
- To improve understanding of the range of parameters and variables that should be employed in the CAESAR-Lisflood model for landform modelling purposes.

Background

This project will assist withthe calibration of the CAESAR-Lisflood model by comparing simulated (modelled) outputs of suspended sediment with field measured (observed) values at a catchment (versus plot) scale . Further, this study will determine if the model can reliably predict the quantity of suspended sediment material that may be produced by the rehabilitated landform of the Ranger uranium mine under a range of scenarios. 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.The project is currently (since 2018-19) being undertakenas a contract to 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 May 2019 with the submission of a final report documenting the methods used to calibrate the model, initial simulation results and key findings regarding the limitations of the model when applied to the Gulungul catchment.

Key findings

- The CAESAR model modelled (with qualification) both discharge and sediment loads in Gulungul Creek.
- The model can be reliably used to assess discharge from inidividual storm events. However, running the model at high DEM resolution (i.e. 10 m or less) is not practical for centennial to millennial time scale modelling due to the length of time required to run the simulations.
- 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 distribution around the mine landform.

Workplan for 2019–20

- There is no workplan for 2019-20 as the project was completed in May 2019.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Final report by Greg Hancock describing the calibration of the CAESAR-Lisflood LEM for suspended sediment at the catchment scale.

The outcome that this project will achieve is:

- The project identified that without access to spatially distributed rainfall data across the catchment, the CAESAR-Lisflood model is unable to accurately predict discharge and therefore suspended sediment at the catchment scale.

Planned communication activities

The primary communication activities for the project are:

- Reporting to relevant technical working groups, committees and ARRTC

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.

Hancock G 2019. Hydrology and sediment transport in the monsoonal tropics - calibration and validation of a landscape evolution model. Final report by Aquaterra International for the Department of the Environment and Energy, 30 pages.

Project Title	Weathering of Ranger waste rock to inform landform evolution model predictions		
KKN Theme	Landform		
KKN Title	LAN3. Predicting erosion of the rehabilitated landform		
KKN Question	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)?		
Project Status	Completed		
Project number	RES-2017-013	**Project commencement date**	01/09/2017
Project duration (months)	15	**Estimated completion date**	10/12/2018
Lead team	ERL	**Date required**	30/06/2018
In-house or outsourced	In-house	**Supporting team(s)**	

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 placed ex-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 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 could potentially

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.

Complementary waste rock particle size information is being gathered from in-situ measurement of surface material on the trial landform - see project RES-2009-011.

Progress against plan

- The weights and photographic documentation of the breakdown of the rocks have been captured nearly annually. The data set is now 20 years old.
- Control rocks are stored in SSB's ERL laboratory in Darwin.
- Rocks were not weighed in 2018 due to access difficulties

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.
- Complementary results from project RES-2009-011, measuring (in-situ) rocks on the trial landform over nine wet seasons, also show competent rock with minimal weathering.
- Determined that chlorite schist from deeper zones of Pit 3 weathers at decadal time scales (not within several years) and pegmatite takes much longer.
- Results from this project showed that the weathering factor currently used in CAESAR-Lisflood that was developed for competent sandstone was suitable in the application at Ranger minesite.

Workplan for 2019–20

- This aspect of the project for weathering of waste rock to inform landform evolution modelling has been completed.
- Work on measurement of the ex-situ rocks and particle size determination (on the waste rock erosion plots) has been transferred RES-2009-011.
- It is recommend that the ex-situ rocks continue to be weighed and photographed to show their breakdown over decadal scales.
- Particle size on the trial landform waste rock plot will be re-measured in 2020.

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 that this project will achieve are:

- The weathering function that has been added to CAESAR-Lisflood Landform Evolution Model is suitable for long-term erosion modelling of the Ranger site
- Weathering rates of waste rock occur at longer time scales than suggested by Milnes et al 1989 (who suggested rudimentary soils develop in 3-5 years). This is important for understanding the time scales for soil formation on the rehabilitated landform.

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Milnes A, Riley G & Raven M 1986. Rock weathering, landscape development and the fate of uranium in waste-rock dumps and the low grade ore stockpile. In Rehabilitation of Waste Rock Dumps, Ranger no 1 mine Jabiru, N.T. Confidential Report for Ranger Uranium Mines Pty Ltd., eds AR Milnes & AB Armstrong, CSIRO, Division of Soils, Adelaide.

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.

Supervising Scientist 2019. Technical Advice #005 - Particle size on the trial landform, Supervising Scientist Branch.

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 Title	Assessing the geomorphic stability of the Ranger trial landform: calibrating model outputs		
KKN Theme	Landform		
KKN Title	LAN3. Predicting erosion of the rehabilitated landform		
KKN Question	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)?		
Project Status	Active		
Project number	RES-2010-007	**Project commencement date**	01/07/2017
Project duration (months)	27	**Estimated completion date**	30/09/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Tom Coulthard, University of Hull

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 from the Ranger trial landform for the same variables over comparable time periods.

Background

Modelling the geomorphic stability of the rehabilitated Ranger landform is undertaken using the CAESAR-Lisflood Landscape Evolution Model (LEM). The ability of the CAESAR-Lisflood model to predict erosion and sediment movement has been tested by comparing modelled predictions with measured observations from the erosion plots on the Ranger trial landform (TLF). Model predictions of bedload movement have demonstrated a good correspondence with measured observations since 2009. However, it has not been possible to compare modelled and observed suspended sediment outputs for the same period. While field data on suspended sediment were collected between 2009 and 2014, only recently has it been possible to compile the data in a form suitable to be used to calibrate model outputs. The focus of this project is now directed at calibrating the model to achieve the necessary correspondence

between model predictions and observed measurements of suspended sediment from the trial landform for the years where recorded data are available.

Progress against plan

- Calibration of the CAESAR-Lisflood LEM for suspended sediment from the trial landform was completed in May 2019, with testing showing a good correspondence between model prediction and field observations / 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 vegetation establishment treatment).
- A draft report documenting the methodology and initial results of the calibration of the model outputs of suspended sediment has been submitted for review.
- A sensitivity analysis of parameters affecting modelled sediment outputs has been completed and published in a peer-reviewed publication.

Key findings

- The revised parameters identified in this project within the past year have resulted in good agreement between field and modelled outputs for both bedload and suspended sediment from the trial landform for periods of up to five years.This complements work in previous years which found similar resultsfor bedload only.
- The results of the sensitivity analysis show that the selection of the appropriate sediment transport equation is the most important parameter in model simulations.

Workplan for 2019–20

- Produce peer-reviewed publication describing methods and results for calibrating the CAESAR-Lisflood model at the erosion-plot scale.
- Compare changes in surface of erosion plots on trial landform mapped by laser scanner in 2010 with LiDAR imagery captured in 2019 by calibrating both to same datum and resolution, and relate to results of calibrated landform modelling of erosion plot. The results of this analysis will be described in a peer-reviewed publication.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Report from Professor Coutlthard (University of Hull) showing outcomes of sensitivity analysis of different model parameters and identifying optimal parameters to be used for model simulations.
- Peer-reviewed publication on results of uncertainty analysis on model undertaken by the University of Hull.

- Peer-reviewed journal publication comparing model predictions of sediment loads from erosion plots on trial landform with observed measurements.

The outcome that this project will achieve is:

- Increased confidence in model predictions of sediment load (both suspended sediment and bedload) through ability to successfully calibrate landform evolution model at the erosion plot scale.

Planned communication activities

The primary communication activities for the project are:

- A research paper published in an international and peer reviewed scientific journal comparing model predictions of sediment loads from erosion plots on trial landform with observed measurements.
- 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.

Skinner CJ, Coulthard TJ, Schwanghart W, van de Wiel MJ & Hancock G 2018. Global sensitivity analysis of parameter uncertainty in landscape evolution models. *Geoscientific Model Development Discussions*,vol. 11, pp.4873-4888.

Project Title	Ranger trial landform erosion research		
KKN Theme	Landform		
KKN Title	LAN3. Predicting erosion of the rehabilitated landform		
KKN Question	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)?		
Project Status	Active		
Project number	RES-2009-011	**Project commencement date**	01/03/2018
Project duration (months)	29	**Estimated completion date**	30/06/2020
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

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 assist in knowledge needs for plant available water and terms for groundwater modelling through measurements of infiltration rates and particle size of surface material on the trial landform.

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 rainfall, runoff, water quality, bed load, suspended sediment load and solute load have been collected from the trial landform since the 2009-2010 wetseason.This directly informs erosion rates and solute loads leaving the erosion plots and informs infiltration rates using runoff coefficients.

In addition to the variables described above, additional data are also being gathered on particle size of surface material. (Particle size is also being measured ex situ, on Ranger waste rocks originally collected in 1998, placed in metal and plastic containers and exposed outdoors to weathering elements). The collective 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, infiltration and input for plant available water calculations.

Progress against plan

- Rainfall, runoff and bedload data have been collected for ten wet seasons 2009–2010 to 2018–19 with data from the 2018-19 wet season currently being analysed. The project was scaled back during the 2014–2015 wet season with only rainfall runoff and bedload collected during the subsequent wet seasons.
- Rainfall and runoff data have been cleaned, quality assessed and checked, and archived in Hydstra for all plots for the wet seasons 2009–2010 to 2017–2018.
- Bedload yields have been calculated for all four plots for nine wet seasons (2009–2010 through to 2017–2018).
- Continuous monitoring of EC, turbidity and stage height in calibrated flumes 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 has also been completed for the surface samples collected in 2009, 2012, 2014 and 2018 and the 2009 data has been reported in an internal report.

Key findings

- Suspended sediment appears to comprise less than 20% of the total sediment load for erosion plot1 (5 wet seasons 2009-2010 to 2013-2014). Model predictions for the trial landform of high initial sediment loads with a subsequent rapid decline are matched by the field result, providing confidence in the model predictions of CAESAR-Lisflood.
- 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.
- Rainfall and runoff data have been used to inform infiltration rates. Runoff coefficients show that most of the rainfall infiltrates the trial landform. Infiltration has also been measured directly by disk permeameter and this method confirms the high rates of infiltration. Rates from direct measurement need to be further analysed and compared with those reported in previous infiltration studies at the Ranger site.
- Results from particle size measurement of surface material measured in 2009. 2012, 2014 and 2018 indicate that there has been little change in particle size on the erosion plots (Plots 1 & 2 waste rock).

Workplan for 2019–20

- Write up suspended sediment results for journal publication.
- Weigh and measure particle sizes of the ex-situ rocks (see Background above, located on the roof at the Jabiru Field Station).

Planned project outputs and associated outcomes

The primary outputs for the project are:

- The outputs of this project are :
- Rainfall and runoff data sets for the four erosion plots on the trial landform. This part of the project has been incorporated into RES-2010-024.
- Determination ofparameters that will assist withthe validation of the CAESAR-Lisflood LEM modelling. The data and modelling validation will assist with the development of the rehabilitated landform.
- Annual bedload eroded and transported from the four erosion plots.
- Journal publications and technical advice to ERA.

The outcomes that this project will achieve are:

- The physical and chemical parameters on the Ranger Trial landform that will assist with:

  i) The assessment of whether different surface treatments and vegetation establishment strategies on the Ranger trial landform result in different erosion rates through measurements of hydrology and infiltration.

  ii) Knowledge needs for plant available water and terms for groundwater modelling through measurements of infiltration rates and particle size of surface material on the trial landform.

Planned communication activities

The primary communication activities for the project are:

- Presentations and discussions with the relevant technical working group for mine rehabilitation and ARRTC.
- Journal publications.
- Supervising Scientist Report.
- Internal reports and annual research summaries.

Project publications to date (if applicable)

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

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

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

Hancock GR, Saynor, MJ, Lowry JBC and Erskine WD Submitted. How to account for particle size effects in a landscape evolution model when there is a wide range of particle sizes, *Environmental Modelling and Software*.

Lowry J, SaynorM, 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 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.

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 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.

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 & Lowry JBC 2018. The impact of rip lines on erosion at the Ranger mine site, in Proceedings: Life-of-Mine 2018, The Australasian Institute of Mining and Metallurgy, Melbourne.

Saynor MJ, Lowry JBC & Boyden JM 2019. Assessment of rip lines using CAESAR-Lisflood on a trial landform at the Ranger Uranium Mine. *Land Degradation & Development*, 5, pp504-514.

Supervising Scientist 2019. Technical Advice #005 - Particle size on the trial landform, Supervising Scientist Branch.

Project Title	Assessing the geomorphic stability of mine landforms		
KKN Theme	Landform		
KKN Title	LAN3. Predicting erosion of the rehabilitated landform		
KKN Question	LAN3D. What are the erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, timeframe, groundwater expression and effectiveness of mitigations)?		
Project Status	Active		
Project number	RES-2017-010	**Project commencement date**	31/01/2018
Project duration (months)	17	**Estimated completion date**	01/05/2022
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Assoc. Prof. Greg Hancock, Uni. of Newcastle. Prof Tom Coulthard, Uni. of Hull

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 transported sediment; 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 project RES-2012-005 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 developing the capacity to model sub-surface layers on the Ranger rehabilitated landform; and enhancing the vegetation component through updating / revising the vegetation shear stress parameter.
- Extreme wet rainfall scenario modified to include the Jabiru - February 2007 rainfall events, based on findings of project RES-2014-006 (Determining and testing representativeness of long-term rainfall patterns for use in final landform modelling).
- New FLV6.1 landform assessed. Feedback provided to ERA, resulting in development of the FLV6.2 landform.
- Technical memo on assessment of FLV6.2 Corridor creek / Pit 1 Landform for a simulated period of 1,000 years completed and submitted to ERA.
- Awaiting receipt of final rehabilitated landform to commence modelling for simulated period of 10,000 years

Key findings

- Not yet applicable – final landform design not yet received.

Workplan for 2019–20

- Commence modelling assessment of final rehabilitated landform for simulated period of up to 10,000 years.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Technical advice to ERA on the stability of the final rehabilitated landform design (addressing its ability to contain tailings and produce erosion rates that match the surrounding landscape for a simulated period of 10,000 years).
- Peer-reviewed journal and conference papers describing the methods and results of modelling a rehabilitated landform for an extended period of 10,000 years.

The outcomes that this project will achieve are:

- Assessment of 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.

- An optimised 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.

Planned communication activities

The primary communication activities for the project are:

- Formal technical report for ERA assessing the long-term stability of the final conceptual landform.
- 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)

No publications have been produced by this project yet. The related precursor project has produced 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, Verdon-Kidd D & Lowry JBC 2017. Soil erosion predictions from a landscape evolution model – as assessment of a post-mining landform using spatial climate analogues. *Science of the Total Environment*, 601-602, pp109-121

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

Lowry JBC, Verdon-Kidd D, Hancock GR, Saynor MJ & Coulthard TJ 2016. Application of synthetic rainfall data to long-term modelling of a rehabilitated landform. In: Life-of-Mine 2016, Brisbane, Australasian Institute of Mining and Metallurgy, Vol N07/2016 pp 75-79.

Lowry J, Hancock G & Verdon-Kidd D 2017. Assessing the geomorphic stability of a rehabilitated landform using climate change analogues. In Enviromine 2017/ 5th International seminar on environmental issues in mining, 8-10 November Santiago Chile, Gecamin.

Lowry J, Narayan M, Evans K, Saynor M & Hancock G 2018. Modelling an undisturbed landform to enhance the assessment of a final rehabilitated landform design. In: 2nd International Congress on Planning for Closure of Mining Operations, Santiago Chile 7-9 November 2018, Gecamin.

Project Title	Development of a method for monitoring gully formation on the rehabilitated landform using stereopsis and LiDAR		
KKN Theme	Landform		
KKN Title	LAN4. Development of remote sensing methods for monitoring erosion		
KKN Question	LAN4A. How do we optimise methods to measure gully formation on the rehabilitated landform?		
Project Status	Active		
Project number	RES-2017-005	**Project commencement date**	01/12/2017
Project duration (months)	36	**Estimated completion date**	01/11/2020
Lead team	ERL	**Date required**	01/11/2020
In-house or outsourced	In-house	**Supporting team(s)**	

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; and
- 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 such as to expose the tailings. Given the large size of the final rehabilitated landform, RPAS (remotely piloted aircraft systems), commonly referred to as drones, are a potentially 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. Recently, the SSB have acquired a LiDAR sensor, which has the capacity to generate very high -resolution DEMs. The LiDAR data and sensor will supplement and complement DEMs derived from SfM (structure from motion) techniques which utilise optical sensors. Together, these technologies will be used to identify and monitor gullies located in the area adjacent to the South Alligator River Valley (SAV) containment facility. The increasing accuracies of these technologies and the ease of obtaining data, make LiDAR a valuable monitoring tool. Focussing on this site will enable SSB 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 and November 2018 over the area of the SAV Containment. Data have been processed from both flights.
- Comparisons between flights have identified the need to incorporate geoidal corrections into dataset processing, to reduce offset between base elevations recorded for the datasets flown on different dates.
- Field activities planned for the first half of 2019 have been delayed.

Key findings

- Due to delays in field work in 2019, there are no key findings to report.

Workplan for 2019–20

- Fly RPAS over SAV in September 2019
- Fly RPAS over the gullies adjacent to the SAV containment facility in December 2019 and May 2020.
- Process RPAS data to detect and measure gullies and determine changes to the gully dimensions as a result of the 2018-19 and 2019-20 wet seasons.
- Compare accuracy of gully digital elevation models determined from ground based (Digital SLR & LiDAR backpack) and different RPAS platforms and sensors

Planned project outputs and associated outcomes

The primary outputs for the project is:

- Peer-reviewed publication documenting and describing the development of an RPAS-based method for monitoring gully formation on the rehabilitated landform.

The outcome that this project will achieve is:

- Development of a robust and cost effective method for use in detecting and assessing gully development on the Ranger rehabilitated landform.

Planned communication activities

The primary communication activities for the project are:

- 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 have been produced to date.

Ranger – Rehabilitation

CC theme: Health impacts of radiation and contaminants (5 projects)

Project Title	Radon exhalation from waste rock on the Ranger trial landform		
KKN Theme	Radiation		
KKN Title	RAD3. Radon progeny in air		
KKN Question	RAD3A. What is the above-background concentration of radon and radon progeny in air from the rehabilitated site?		
Project Status	Active		
Project number	RES-2019-021	**Project commencement date**	01/05/2019
Project duration (months)	30	**Estimated completion date**	31/12/2021
Lead team	ENRAD	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

- To measure the exhalation flux of radon-222 from waste rock on the trial landform.
- To measure radium-226 in waste rock samples collected from the trial landform.
- To measure gamma dose rates on the trial landform.
- To determine the radon-222 exhalation flux density normalised to waste rock radium-226 activity concentration (i.e. $R_{E\text{-}R}$).
- To determine whether the $R_{E\text{-}R}$ has increased since 2014, when radon exhalation flux from waste rock on the trial landform was last measured.

Background

Radon exhaled from waste rock and transported in the atmosphere by wind represents a radiation exposure pathway to the public from the Ranger final landform. Estimates of public radiation dose from radon require its exhalation flux from waste rock to be quantified. The Ranger trial landform provides a unique opportunity to acquire site-specific data on radon exhalation flux from waste rock, including its seasonal and long-term variability. Measurements of radon exhalation flux on the trial landform from

2009 to 2014 showed a potential increase in dry season values over time, which may have implications for estimating dose rates to the public from the final landform. This project will provide data to confirm whether any further increase in the radon exhalation flux from waste rock has been occurring during the five years since measurements were last made.

Progress against plan

- The first set of radon exhalation measurements was conducted in May 2019. The measurements included deploying 17 canisters containing activated charcoal onto each of the four erosion plots on the Ranger trial landform for a period of 3 days. The canisters were then analysed by gamma spectrometry to determine the radon radioactivity and exhalation rates.

Key findings

- No change in radon exhalation rates was detected in the first set of measurements conducted in May 2019, though these were taken at the end of the wet season when radon exhalation rates are normally low due to high soil moisture content. The measured exhalation rates were similar to those measured at this time of year in previous sampling conducted between 2009 and 2014.

Workplan for 2019–20

- Additional measurements of radon exhalation rates on the trial landform are planned to occur at approximately 3 month intervals during 2019-20.

Planned project outputs and associated outcomes

The primary output for the project is:

- Data on radon exhalation flux from waste rock to confirm whether any changes have occurred since 2014 when the last measurements were made.

The outcome that this project will achieve is:

- Enhanced knowledge of radon exhalation from waste rock that can be used in radiation dose modelling of radon exposure to the public from the Ranger final landform.

Planned communication activities

The primary communication activities for the project are:

- Research paper.
- Presentations to stakeholders on request.
- Presentations to the broader scientific community at conferences.

Project publications to date (if applicable)

Nil

Project Title	Modelling the atmospheric dispersion of radionuclides in dust from the Ranger final landform		
KKN Theme	Radiation		
KKN Title	RAD4. Radionuclides in dust		
KKN Question	RAD4B. What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?		
Project Status	Completed		
Project number	RES-2017-025	**Project commencement date**	01/03/2018
Project duration (months)	10	**Estimated completion date**	31/12/2018
Lead team	ENRAD	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Mathew Johansen (ANSTO)

Aims

- To model the atmospheric dispersion of radionuclides in dust from the Ranger final landform.
- To develop dose rate contour maps for assessing public radiation doses from radionuclides in dust.

Background

The inhalation of radionuclides in dust represents one of the potential radiation exposure pathways to the public from the Ranger final landform. This pathway needs assessing as part of the overall radiation dose assessment for the final landform to demonstrate and provide assurance that radiation doses to the public will be below the statutory dose limit.

Progress against plan

- The dispersion of radionuclides in dust from the final landform has been modelled for wet and dry seasons using RESRAD-OFFSITE. The atmospheric transport component of the model was parameterised using a 20-year meteorological dataset, which enabled the average dispersion and variability to be assessed. A sensitivity analysis of the influence of model parameters (especially meteorological parameters) on the results was also conducted.

- Contour maps of the inhalation dose rate within a 10 km radius of the landform were developed from the modelling and used to estimate the annual above-background radiation dose to the public for a number of hypothetical exposure scenarios. The scenarios included residents of Jabiru town and Mudginberri community and a worst case scenario of a person permanently occupying the final landform.
- The modelling methods and results (including the dose rate contour maps and dose estimates) have been published as a research paper in Journal of Environmental Radioactivity, marking the completion of the project.

Key findings

- Radionuclides in dust do not represent a significant radiation exposure pathway to the public from the Ranger final landform. The estimated radiation dose via this pathway for the worst case exposure scenario of a person permanently occupying the final landform was 0.0053 mSv on average and is less than 1% of the public dose limit. Doses to residents at Jabiru town and Mudginberri community were substantially lower.
- The year-to-year variability in dose rates from radionuclides in dust due to variability in meteorological conditions was no more than a factor of three. Also, the meteorological parameters within the model that were most influential on the results were atmospheric stability class, precipitation and wind speed. Higher atmospheric stability led to higher dose rates from radionuclides in dust due to reduced atmospheric mixing, whereas higher precipitation and wind speed led to lower dose rates due to increased washout of dust from the atmosphere and faster movement of the dust plume, respectively.

Workplan for 2019–20

- n/a - project completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Dose rate contour maps for the radionuclide in dust exposure pathway to a distance of 10 km from the Ranger final landform.
- Estimates of annual radiation dose above natural background to the public from exposure to radionuclides in dust.
- Information on variability of radiation doses from radionuclides in dust due to variability in meteorological conditions.
- Information on the sensitivity of radiation dose estimates for radionuclides in dust to model parameters.

The outcome that this project will achieve is:

- Enhanced knowledge of public radiation exposure that could be used to inform decision-making on the achievement of closure criteria for the Ranger mine.

Planned communication activities

The primary communication activities for the project are:

- Published research paper.
- Presentations to stakeholders on request.
- Presentations to the broader scientific community at conferences.

Project publications to date (if applicable)

Modelling the dispersion of radionuclides in dust from a landform covered by low uranium grade waste rock. *Journal of Environmental Radioactivity* 202, 51–58.

Project Title	Environmental fate and transport of Ac-227 and Pa-231		
KKN Theme	Radiation		
KKN Title	RAD5. Radionuclides in bushfoods		
KKN Question	RAD5A. What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?		
Project Status	Active		
Project number	RES-2015-014	**Project commencement date**	01/02/2015
Project duration (months)	72	**Estimated completion date**	01/02/2021
Lead team	ENRAD	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Peter Medley (ANU)

Aims

- To develop new methods for measuring actinium-227 and protactinium-231 in environmental samples.
- To measure actinium-227 and protactinium-231 in environmental samples and determine concentration ratios between the measured activity concentration in bush foods and wildlife and that in soil or water.
- To estimate radiation dose contributions to the public and wildlife from actinium-227 and protactinium-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 – protactinium-231 and actinium-227 – are limited and prone to technical difficulties (particularly in the chemical separation steps). It is also argued that the activity concentration of uranium-235, at the head of the actinium decay series, is ~20 times below that of uranium-238 for natural uranium and therefore presents fewer radiological risks. However, actinium-227 dose coefficients are typically higher than those for the uranium decay series radionuclides, with ingestion dose coefficients similar to those of polonium-210, 1.6 times higher than lead-210 and 4 times higher than radium-226. Inhalation dose coefficients for both actinium-227 and protactinium-231 are higher than those for

polonium-210, lead-210 and radium-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 protactinium-231 and actinium-227, and the potential mobility of these isotopes in aquatic and terrestrial environments in the vicinity of the Ranger mine.

Progress against plan

- A working method to separate and measure protactinium-231 in environmental samples has been developed using accelerator mas spectrometry. The method was successfully piloted on freshwater mussel samples, with the method and results published in Nuclear Instruments and Methods in Physics Research B.
- A method to separate and measure actinium-227 has been developed, but not yet applied to environmental samples. The separation method uses micro-precipitation and does not require hydrofluoric acid, which enhances the safety aspects of its use. The measurement method uses alpha spectrometry to indirectly measure actinium-227 through the radioactivity of its decay products thorium-227 and radium-223. A research paper describing the separation and measurement methods has been drafted and submitted to Journal of Environmental Radioactivity.

Key findings

- Protactinium-233 can be effectively separated from neptunium-237 for use as a tracer isotope for protactinium-231 measurement in environmental samples via accelerator mass spectrometry.
- Using the injection species of PaO_2 is the most efficient in the 14UD accelerator mass spectrometer for measurement of protactinium-231 and reduces interference from uranium-233 to non-significant levels.
- Sufficient activity of protactinium-231 is present in freshwater mussels of the Alligator Rivers Region to enable the use of current sample preparation methods for analysis of protactinium-231.
- Source preparation of actinium-227 as a lanthanide hydroxide for alpha spectrometry resulted in chemical recoveries of more than 90% with a resolution of less than 40 keV at full width half maximum in the alpha-particle spectrum.
- Autoradiography of alpha sources prepared for actinium-227 analysis showed a reproducible distribution of actinium-227 on the sources.

Workplan for 2019–20

- The Supervising Scientist is a collaborator on this work, which is being undertaken as a PhD project through the Australian National University. The Supervising

Scientist provides materials, data and advice on an as-needs basis and will continue to provide this support throughout 2019-20.

- The research workplan for 2019-20 and out years includes refining the already developed separation and measurement methods for actinium-227 and protactinium-231 and applying them to environmental samples to determine activity concentrations and concentrations ratios. These data will in turn be used to inform radiation dose estimates for the Ranger final landform, particularly for the bush food ingestion exposure pathway to the public and radiation dose estimates for wildlife.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- New radiochemistry and measurement techniques for actinium-227 and protactinium-231 in environmental samples.
- Data on actinium-227 and protactinium-231 activity concentrations in animals, plants, soil and water.
- Concentration ratios for actinium-227 and protactinium-231 in selected bush foods and wildlife.
- Tissue to whole organism activity concentration conversion factors for actinium-227 and protactinium-231 for selected wildlife.
- Estimates of radiation doses to people and wildlife from actinium-227 and protactinium-231.

The outcomes that this project will achieve are:

- Knowledge of the radiological importance of actinium-227 and protactinium-231.
- Enhanced knowledge of public and environmental radiation exposure that could be used to inform decision-making on the achievement of closure criteria for the Ranger mine.

Planned communication activities

The primary communication activities for the project are:

- PhD thesis.
- Research papers.
- Presentations to stakeholders on request.
- Presentations to the broader scientific community at conferences.

Project publications to date (if applicable)

Medley P, Tims, SG, Froehlich MB, Fifield LK, Bollhöfer A, Wallner A & Pavetich S 2019. Development of ^{231}Pa AMS measurements to improve radiological dose assessment from uranium mining and milling. *Nuclear Instrumentation and Methods in Physics Research B* 438, 66–69.

Project Title	Gamma radiation dose rates to the public from the Ranger final landform		
KKN Theme	Radiation		
KKN Title	RAD7. Radiation dose to the public		
KKN Question	RAD7A. What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?		
Project Status	Active		
Project number	RES-2019-018	**Project commencement date**	01/04/2019
Project duration (months)	3	**Estimated completion date**	30/06/2019
Lead team	ENRAD	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

- To estimate gamma radiation dose rates to the public based on the uranium radioactivity of surface waste rock.
- To assess whether annual doses from gamma radiation could potentially restrict future land use scenarios for the final landform.

Background

Low uranium grade waste rock is planned to be used as the surface substrate on the Ranger final landform. The activity concentration of uranium-238 and uranium-235 decay series radionuclides in this waste rock is elevated compared to the surrounding environment and pre-mining radiological conditions of the site. Gamma radiation emitted from uranium-238 and uranium-235 decay series radionuclides in surface waste rock represents one of the potential radiation exposure pathways to the public from the Ranger final landform. Analysis of this pathway forms part of the overall radiation dose assessment for the Ranger final landform to determine whether doses above natural background to the public are likely to exceed the dose limit and whether restrictions on future land use may be necessary.

Progress against plan

- Gamma radiation dose rates due to waste rock material on the surface of the Ranger final landform were calculated from reference dose coefficients of the USEPA.

Contributions from both uranium-238 and uranium-235 decay series radionuclides were included in the calculation.
- The annual above-background radiation dose to the public accessing the final landform was estimated for hypothetical exposure scenarios.
- A research paper describing the asessment of the gamma radiation exposure pathway (including estimated doses for various land use scenarios) has been drafted and is undergoing internal review prior to journal submission.

Key findings

- Dose rates from gamma radiation on the final landform are predicted to be one and two orders of magnitude higher than those from radon progeny and radionuclides in dust, respectively.
- The predicted gamma radiation dose rates on the final landfrom would result in an above-background dose equal to the statutory dose limit of 1 mSv per year after a continuous exposure time of about 6 months. However, when the currently envisioned land use is averaged over the entire Ranger project area, the annual above-background dose from gamma radiation is a small fraction (~4%) of the statutory dose limit.

Workplan for 2019–20

- The remaining task for this project in 2019-20 is to finalise the research paper and submit it for journal publication.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Data on radiation dose rates to the public from gamma radiation emitted from uranium-238 and uranium-235 decay series radionuclides in waste rock on the Ranger final landform.

The outcome that this project will achieve is:

- Enhanced knowledge of public radiation exposure that could be used to inform decision-making on the achievement of closure criteria for the Ranger mine.

Planned communication activities

The primary communication activities for the project are:

- Research paper.
- Presentations to stakeholders on request.
- Presentations to the broader scientific community at conferences.

Project publications to date (if applicable)

Nil

Project Title	Deriving site-specific concentration factors for metals in bush foods to inform human health risk assessments for the Ranger final landform		
KKN Theme	Radiation		
KKN Title	RAD9. Impacts of contaminants on human health		
KKN Question	RAD9B. What are the concentration factors for contaminants in bush foods?		
Project Status	Active		
Project number	RES-2017-024	**Project commencement date**	01/03/2018
Project duration (months)	16	**Estimated completion date**	30/09/2019
Lead team	ENRAD	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

- To derive bioaccumulation factors for metal contaiminates in bush foods consumed by the indigenous population within the ARR.
- If possible, derive maximum allowable concentrations of metals in soil and water that would give rise to site-specific, food safety guidelines for metals.

Background

Ingestion of elevated concentrations of some metals can be harmful to humans. The Food and Agriculture Organisation/World health organisation (FAO/WHO) have set guideline limits for: Al, As, Cd, Cu, Fe, Pb, Hg, Sn and Zn as metal contaminants of potential concern in foods.The Environmental Requirements for the Ranger mine stipulate that its rehabilitation must 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 bioaccumulation factors between the concentrations of metals in bush foods and those in soil and water. If possible, the bioaccumulation 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

- Tolerable daily intake limits for metals commonly found within the ARR have been tabulated from the literature.
- Metal bioaccumulation factors forAl, As, Cd, Cu, Fe, Pb, Hg, Sn and Zn have beenderived for various bush foods comprising the traditional diet of Aboriginal people of the ARR.
- A method for deriving maximum allowable concentrations of metals in water and soil (equivalent to tolerable daily intake limits) has been established.
- An internal report describing the methods for deriving metal bioaccumulation factors and maximum allowable concentrations is currently in draft.

Key findings

- Abundant data was available for mussels, fruit and fish. This allowed for increased accuracy and decreased uncertainty in Bioaccumulation Factors (BAF). For the bush food groups crocodile, file snake, magpie goose, turtle waterlily, water buffalo and goanna limited measurements had been collected. This meant that BAFs had a high degree of uncertainty or could not be derived at all.The bush food groups with limited metal concentration data were also the bush food groups which made up the majority of the traditional bush food diet. This resulted in the derived water and soil guideline values having limited usefulness.Additionally, as limited data on the extractable (analogous to bioavailable) metal fraction was available for soils, total metal concentrations were used to derive BAFs for Al, As, Ba, U and Th. Using total metal concentrations can result in an overly conservative BAFs and hence limit their value.Recommendations on the bush food groups which require additional sampling have been proposed. Additionally, a standardised method for measurement of extractable metal fraction in soils based on ANNZECC/ARMCANZ has also been suggested.

Workplan for 2019–20

- The remaining task for this project in 2019-20 is to finalise the internal report.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Bioaccumulation factors for metals in bush foods.
- Estimate of dietary exposures to metals released from the Ranger final landform into the environment.

The outcomes that this project will achieve are:

- Recommendations on design of future bush food sampling and metal analysis studies.
- Enhanced knowledge of public exposure to metals that could potentially be used to inform decision-making on the achievement of closure criteria for the Ranger mine.

Planned communication activities

The primary communication activities for the project are:

- Internal report.
- Presentations to stakeholders on request.

Project publications to date (if applicable)

Nil

Ranger – Rehabilitation

CC theme: Ecosystem restoration (14 projects)

Project Title	Quantifying spatial and temporal change in savanna		
KKN Theme	Ecosystem restoration		
KKN Title	ESR1. Determining the characteristics of ecosystems in the areas surrounding the RPA.		
KKN Question	ESR1A. What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally-inundated savanna) surrounding the RPA, and how do they vary spatially and temporally?		
Project Status	Active		
Project number	RES-2013-002	**Project commencement date**	01/09/2013
Project duration (months)	68	**Estimated completion date**	01/07/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

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 reviewed for publication to a peer-reviewed journal.
- A manuscript describing the time-series analysis of the woody cover change analysis has been being drafted for submission to a peer-reviewed journal for publication.
- A manuscript for artefact removal from digital aerial photography has been completed
- Technical advice memo has been drafted and will be provided to ERA early in 2019-20.

Key findings

- Results indicate that overall canopy cover in the area has been stable over long time scales with no temporal trends evident. Over the entire study area for the period 1950-2016, the average percentage woody cover per ha was 36%.

- At finer temporal and spatial resolution, woody cover can be more variable. Amongst years there werefluctuations between 40% in 1950 and 28% in 1978 and 2016.
- The long term stability and resilience of woody cover in the savanna adjacent to the Ranger mine provide a robust basis to inform ecosystem restoration targets.

Workplan for 2019–20

- Submission of artefact removal manuscript for journal publication (August 2019)
- Complete and submit journal paper on time series analysis (July-August 2019)
- Complete technical advice memo to ERA (July-August 2019)

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 Ranger mine between 1950 and 2016.
- Peer reviewed publications

The outcome that this project will achieve is:

- Change in woody cover can be used to inform revegetation trajectories and will provide a closure measure for canopy cover for Ranger mine rehabilitation.

Planned communication activities

The primary communication activities for the project are:

- Timeline of landscape change.
- Report to the relevant Ecosystem Restoration 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)

Whiteside, TG, Esparon, AJ & Bartolo, RE (in review)A semi-automated approach for quantitative mapping of woody cover from historical time series aerial photography and satellite imagery. *Ecological Informatics*.

Project Title	Assessment of historical vegetation reference site information for use in ecological restoration at Ranger mine site		
KKN Theme	Ecosystem restoration		
KKN Title	ESR1. Determining the characteristics of ecosystems in the areas surrounding the RPA.		
KKN Question	ESR1A. What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally-inundated savanna) surrounding the RPA, and how do they vary spatially and temporally?		
Project Status	Completed		
Project number	RES-2014-002	**Project commencement date**	01/02/2014
Project duration (months)	59	**Estimated completion date**	17/12/2018
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	University of Queensland

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 characteristcs, as opposed to the realtively 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 extraploate 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.
- Journal publication submitted and published.

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 2019–20

- Project completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Review of existing reference ecosystem information to determine its suitability for informing ecosystem restoration at Ranger.
- Journal publication on the findings of the review from above, "Using reference sites to guide ecological engineering and restoration of an inetrnationally significant uranium mine in the Northern Territory, Australia".
- Scoping and planning for studies on understorey to derive relevant information for closure criteria.

The outcome that this project will achieve is:

- Clear guidance on the use of reference site data for informing ecosystem restoration at Ranger mine site, including the identification of key areas for further research

Planned communication activities

The primary communication activities for the project are:

- 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)

Esrkine P D, Bartolo R, McKenna P & Humphrey C 2019. Using reference sites to guide ecological engineering and restoration of an internationally significant uranium mine in the Northern Territory, Australia. *Ecological Engineering* 129, 61-70.

Project Title	Assessing the effect spatial scale has on species composition and community structure for revegetation planning		
KKN Theme	Ecosystem restoration		
KKN Title	ESR1. Determining the characteristics of ecosystems in the areas surrounding the RPA.		
KKN Question	ESR1A. What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally-inundated savanna) surrounding the RPA, and how do they vary spatially and temporally?		
Project Status	Active		
Project number	RES-2019-013	**Project commencement date**	04/03/2019
Project duration (months)	4	**Estimated completion date**	28/06/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Peter Erskine, Lorna Hernandez-Santin

Aims

- To select and establish two 1 ha reference site plots in the Georgetown area of the Ranger Project Area for quantifying vegetation
- To compare existing ecosystem similarity measures with new data acquired from larger reference plots to determine whether proposed revegetation measures (i.e. stem densities) are appropriate
- To develop interim closure measures for species composition and community structure for both the overstorey and understorey

Background

A range of vegetation survey methods have been used to assess reference ecosystems to serve as targets for revegetation surrounding Ranger mine. One significant body of work was conducted in the Georgetown analogue site and surrounding area where 20 x 20 m plots were used to derive similarity and stem density metrics. However, due to recent advancements in paradigms of savanna ecology, the importance of spatial scales in savanna ecosystems has been elucidated, particularly for canopy structure metrics (see Staver 2018). Importantly, this may have implications for the derivation of revegetation closure metrics at appropriate scales for restoration, and the assessment of

restoration outcomes. In order to determine the effect that plot size has on revegetation metrics, two 1 ha plots have been established within the Georgetown analogue site and surveyed using the AusPlots survey method. These data, together with additional 1-ha scale data and small-scale (20 x 20 m) plot data gathered in earlier years, will be used to quantify the extent that scale has on revegetation metrics (i.e. stem densities and Bray-Curtis similarity). Additionally, data will be cross-checked to currently proposed species composition and community structure metrics to determine whether the proposed metrics are appropriate.

Progress against plan

- Two 1 ha plots have been established within the Georgetown analogue site and the under- and overstorey surveyed using the AusPlots survey method
- Data analysis has commenced using these and complementary data (identified in 2019-20 workplan described below).

Key findings

- Nil to end of June 2018

Workplan for 2019–20

- Data from three sources will be used to determine the effect that plot size has on revegetation metrics: (i) two 1 ha plots recently established within the Georgetown analogue site (for which smaller-scale informaiton are available); (ii) additional 1-ha scale data (described in ProjectRES-2017-007) (for which smaller-scale information are also available); and (iii) small-scale (20 x 20 m) plot data collected from earlier years.
- Analyses will be performed at different spatial scales within the datasets, deriving revegetation metrics for each scale (in particular, stem densities and Bray-Curtis similarity).
- Limitations and/or advantages in metrics derived at particular spatial scales will be identified.
- Data will be cross-checked to currently proposed species composition and community structure metrics to determine whether these are appropriate.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Information on the effect spatial scale has determining revegetation components such as stem densities for species.
- Cross-checking of current planned stem densities and species composition with appropriate scale stem densities and species composition.

The outcome that this project will achieve is:

- Implications of metrics used to quantify restoration standards derived at different spatial scales

Planned communication activities

The primary communication activities for the project are:

- Report to the relevant Ecosystem Restoration 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)

Nil

Project Title	Factors affecting spatial and temporal change in savanna		
KKN Theme	Ecosystem restoration		
KKN Title	ESR1. Determining the characteristics of ecosystems in the areas surrounding the RPA.		
KKN Question	ESR1A. What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally-inundated savanna) surrounding the RPA, and how do they vary spatially and temporally?		
Project Status	Active		
Project number	RES-2017-026	**Project commencement date**	30/03/2018
Project duration (months)	12	**Estimated completion date**	30/03/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Lynda Prior, David Bowman, Grant Williamson - University of Tasmania

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

- Manuscript has been completed and submitted to journal for peer review: "Prior, LD, Whiteside, TG,Williamson, G, Bartolo, RE and Bowman, DMJS (submitted), Multi-decadal stability of woody cover in a mesic eucalypt savanna in the Australian monsoon tropics. Austral Ecology"
- Technical advice memo has been drafted and will be provided to ERA early in 2019-20.

Key findings

- No overall trend in woody cover was detected through time (see also ProjectRES-2013-002).Some variation in woody cover was related to rainfall in the previous 12 months, and there were weak effects associated with fire history in the year of image acquisition and the antecedent four years. The results suggest that at the local (or regional) scale, mesic eucalypt savannas have been resilient to short term variations in rainfall and fire activity.

Workplan for 2019–20

- Complete a Technical advice memo (August 2019).

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Identification of the drivers of woody cover, landscape change based on the correlative analysis.
- Refinement of the State and Transition Model for Ranger revegetation.
- Peer-reviewed journal publication
- Technical advice memo

The outcome that this project will achieve is:

- The statistical inference of the key drivers of historical change in woody cover which can be used to indicate potential future change and recovery after natural disturbance in savanna surrounding the rehabilitated mine site

Planned communication activities

The primary communication activities for the project are:

- 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)

Nil

Project Title	Deriving vegetation community structure measures to assess ecosystem restoration similarity		
KKN Theme	Ecosystem restoration		
KKN Title	ESR1. Determining the characteristics of terrestrial vegetation in the areas surrounding the RPA.		
KKN Question	ESR1C. What values should be prescribed to each indicator of similarity to demonstrate revegetation success?		
Project Status	Active		
Project number	RES-2019-012	**Project commencement date**	04/02/2019
Project duration (months)	29	**Estimated completion date**	30/06/2021
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	CMLR: Peter Erskine; Lorna Hernandez-Santin CSIRO: Shaun Levick

Aims

- To select and establish ecologically appropriate 1 ha reference site plots in areas of Kakadu National Park adjacent to Ranger mine site and undisturbed areas of the Ranger Project Area.
- To conduct floristic surveys of the 1 ha reference site plots.
- To develop interim closure measures for community structure (canopy, understorey and ground cover, size class distribution, stem diameter at breast height) for both the overstorey and understorey.
- To obtain data to allow development of vegetation monitoring methods with drones.

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 m^2 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 inter-annual changes and variability required for specifying a number of the relevant closure criteria for ecosystem restoration.The availability of understorey data from earlier surveys is also very limited.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 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 provide interim community structure measures that can be used in revegetation planning for rehabilitation. These data will also be used in the development of methods for monitoring revegetation at-scale with drones.

Progress against plan

- Twelve one hectare plots have been established and surveyed using the Ausplots method on suitable land units surrounding the mine, including two in the Georgetown analogue area.
- All data have been collected to populate the ecosystem restoration standard 'similarity' attributes with interim metrics
- Two intermittent flooding savanna plots have been established with surveys completed in May 2019 (DBH surveys have not yet been conducted due to logistical constraints).
- Submitted Technical Advice report on community structure.
- Presentations to Ecosystem Restoration Working Group and ARRTC undertaken with updates of recent data collected.

Key findings

- Basal area varied between plots with an average of 7.5 m^2 ha-1. However, the two most abundant eucalypt species (E. miniata and E. tetrodonta) made up over 50% of this area, indicating their significant dominance across the landscape.

- 80% of stems were less than 10 cm diameter at breast height (DBH). A large proportion of these smaller trees were *Acacia mimula* and *Eucalyptus tetrodonta*. There were few trees greater than 30 cm DBH in all plots.

Workplan for 2019–20

- Ground scans with LiDAR instruments and drone flights in selected reference plots (August 2019).
- Write up of journal paper on scaling of ground-based LiDAR to drone-based LIDAR to measure savanna structure (September 2019).
- Technical Advice completed on using LiDAR to measure savanna ecosystem structure (October 2019).
- Surveys of any additional plots required (September and October 2019, and March 2020).
- Update ecosystem restoration standard with interim metrics

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Interim vegetation community structure measures for both overstorey and understorey at 1 ha scale that can be used in nursery planning for the rehabilitation being undertaken at Ranger. Measures include canopy cover and size class distribution.
- Development of methods and metrics for monitoring and assessing revegetation closure criteria for community structure through the linking of plot data with drone data.
- Conceptualisation of reference ecosystems for communication with stakeholders

The outcomes that this project will achieve are:

- Conceptualisation of reference ecosystems for communication with stakeholders
- Understanding of the comparison between ground-based and airborne LiDAR data collection in savanna woodland

Planned communication activities

The primary communication activities for the project are:

- 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.
- Series of Technical Advice reports submitted to ERA.

Project publications to date (if applicable)

Nil.

Project Title	Deriving species composition measures and their environmental correlates to assess ecosystem restoration similarity		
KKN Theme	Ecosystem restoration		
KKN Title	ESR1. Determining the characteristics of ecosystems in the areas surrounding the RPA.		
KKN Question	ESR1C. What values should be prescribed to each indicator of similarity to demonstrate revegetation success?		
Project Status	Active		
Project number	RES-2017-007	**Project commencement date**	01/10/2017
Project duration (months)	33	**Estimated completion date**	30/06/2020
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Centre for Mined Land Rehabilitation, The University of Queensland

Aims

- To select and establish ecologically appropriate 1 ha reference site plots in areas of Kakadu National Park adjacent to Ranger mine site and undisturbed areas of the Ranger Project Area.
- To conduct floristic surveys of the 1 ha reference site plots.
- To derive environmental correlates of vegetation species composition using existing plot data from Kakadu National Park and Georgetown studies, and from physical and chemical properties of additional soil samples.
- To assess 1 ha plot variability using the above-mentioned data.

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 m^2 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 combine for use in deriving and 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 inter-annual changes and variability required for specifying a number of the relevant closure criteria for ecosystem restoration. The availability of understorey data from earlier surveys is also very limited. 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 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 provide interim species composition measures that can be used in revegetation planning for rehabilitation. Importantly, this project will include measures of understorey and seasonal changes in vegetation (phenology). These data will also be used in the development of methods for monitoring revegetation at-scale with drones.

Progress against plan

- Twelve one-hectare plots have been established and surveyed using the Ausplots method on suitable land units surrounding the mine, including two in the Georgetown analogue area.
- All data have been collected to populate the ecosystem restoration standard 'similarity' attributes with interim metrics
- Two intermittent flooding savanna plots have been established with surveys completed in May 2019
- Soil samples for chemical analyses and metagenomics have been collected from all plots and analyses have commenced.
- First draft of a journal paper on savanna understorey diversity is available.
- Submitted Technical Advice reports on species richness and composition and functional traits.
- Presentation of the findings to the Ecosystem Restoration Working Group (and meetings with ERA)

Key findings

- Savanna woodland communities are diverse and variable across the landscape in both the understorey and overstorey. For overstorey, two open forest community types were identified, consistent with previous vegetation classifications undertaken

using smaller spatial scale (20 x 20 m) data. One of these overstorey community types (low open forest) is prominent in the Georgetown area; it appears to have an abundance of drier-adapted species which have low representation elsewhere in the surrounding KNP. Greater variability was observed in understorey composition compared to overstorey.
- Vegetation cover in both strata are dominated by a small number of species, with 9 species accounting for 70% of understorey cover and 7 species accounting for 80% of overstorey cover.

Workplan for 2019–20

- Surveys of any additional plots required (October 2019, March 2020).
- Establish two additional intermittent flooding plots (April/May 2020)
- If required, establish two plots to describe alternative "functional" end-state ecosystem (April 2020)
- Submission of savanna understorey diversity journal paper (August 2019)
- Submission of journal publication on the selection of reference sites for deriving measures of species composotion for mine site ecosystem restoration (September 2019)
- Soil sampling for measuring physical properties related to moisture availability (November 2019)
- Analyses of soil samples for physical properties (March 2020)
- Assessment of soil propertoes as environmental correlates for vegetation community assemblages.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Interim species composition data for both overstorey and understorey at 1 ha scale that can be used in nursery planning for the rehabilitation being undertaken at Ranger. Measures include stem densities.
- Interim measures for SSB's Ecosystem Restoration Standard for sub-attributes of species composition
- Journal publication on savanna understorey diversity
- Journal publication on the method undertaken for reference site selection..
- Technical Advice reports on species composition and plant functional traits.
- Conference presentations on savanna woodland diversity and alignment with the SSB Ecosystem Restoration Standard

The outcomes that this project will achieve are:

- Information informing revegetation planning, closure criteria and assessment of whether the rehabilitated site will be similar to surrounds.
- Conceptualisation of reference ecosystems for communication with stakeholders

Planned communication activities

The primary communication activities for the project are:

- 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.
- Series of Technical Advice reports submitted to ERA.

Project publications to date (if applicable)

No journal publications to date.

Supervising Scientist 2019. Species richness and composition indicator values for assessing ecosystem similarity for savanna woodland. Technical Advice #006. Supervising Scientist, Darwin.

Project Title	Recommendations for faunal standards for the rehabilitation of Ranger uranium mine (NESP)		
KKN Theme	Ecosystem restoration		
KKN Title	ESR2. Determining the requirements to support a terrestrial faunal community similar to areas surrounding the RPA.		
KKN Question	ESR2A. What faunal community structure (composition, relative abundance, functional groups) is present in the areas surrounding the RPA?		
Project Status	Completed		
Project number	RES-2018-001	**Project commencement date**	08/01/2018
Project duration (months)	15	**Estimated completion date**	31/03/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Alan Andersen and Stefanie Oberprieler (Charles Darwin University) Luke Einoder, Brydie Hill and Alaric Fisher (Northern Territory Government)

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 referece sites in the surrounding Kakadu National Park.
- To determine suitable vertebtrate 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

- Presentations provided to ARRTC and stakeholder groups including GAC.
- Final reports have been received.

Key findings

- Recommended faunal standards for potential inclusion in the Supervising Scientist Branch's Ecosystem Restoration Standard have been developed that cover:
  1) Vertebrate and invertebrate taxa to be targeted for assessment;
  2) Attributes of the target taxa that could be used in deriving indicator values;
  3) Appropriate reference condition for faunal assemblages;
  4) Measures for assessing similarity to reference condition for faunal assemblages; and
  5) Sampling methodology for monitoring and assessment of vertebrate fauna.
- Fifty vertebrate species have been recommended for use in ecosystem restoration assessment, comprising 34 bird, 11 reptile and five mammal species. Two threatened species are included – the Partridge Pigeon and Black-footed Tree-rat. For invertebrate assessment, ants are recommended as the target taxon.
- Suggested attributes of target taxa that may be used in deriving indicator values include: species diversity (richness and evenness); species composition; function-group representation; and species occupancy for vertebrates.
- With respect to the appropriate reference condition for faunal assemblages, the reference ecosystem identified by the Supervising Scientist Branch was determined to be appropriate. Therefore the faunal assemblages of the lowland savanna woodland in this reference ecosystem can be used as the reference condition for faunal standards.
- The proposed measures for assessing similarity are either: at least 60% of rehabilitation sites achieve at least 80% of the reference metric; or at least 80% of

rehabilitation sites achieve at least 60% of the reference metric. Proposed measures have also been recommended for introduced (exotic) species.
- The protocol described in the Northern Territory Top End National Parks Ecological Monitoring Program is recommended to be adopted for monitoring and assessment of vertebrate fauna.
- Further work is required to ensure culturally important species have been accounted for in the current species proposed for assessment, and if any of these species are missing they should be considered for inclusion.

Workplan for 2019–20

- Project completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A series of reports on target vertebrate species and monitoring methods, assessment of invertebrates (ants) on the Ranger trial landform compared with the reference ecosystem, and recommended faunal standards for assessing ecosystem restoration at Ranger uranium mine.
- Presentation at the Ecological Society of Australia Conference 2019.

The outcome that this project will achieve is:

- Recommended target fauna species (vertebrates and invertebrates) and proposed measures for their monitoring and assessment to inform the Supervising Scientist's Ecosystem Restoration Standard.

Planned communication activities

The primary communication activities for the project are:

- 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)

Andersen AN. 2019. Recommended faunal standards for the rehabilitation of Ranger Uranium Mine. Charles Darwin University, Darwin.

Einoder LD, Hill B & Fisher A. 2019. Rehabilitation of vertebrate assemblages at Ranger Uranium Mine: assessment standards and monitoring methodology. Department of Environment and Natural Resources, Northern Territory Government, Darwin.

Andersen AN & Oberprieler SK. 2019. Invertebrate assemblages at Ranger Uranium Mine's trial revegetation sites compared with natural reference sites. Technical Report by Charles Darwin University to Northern AustraliaEnvironmental Resources Hub, National Environmental Science Programme.

Project Title	Developing restoration trajectories to predict when the restored site will move to a sustainable ecosystem		
KKN Theme	Ecosystem restoration		
KKN Title	ESR5. Develop a restoration trajectory for Ranger mine		
KKN Question	ESR5B. How can we develop restoration trajectories (flora and fauna) to predict when the rehabilitated site will move to a sustainable ecosystem without further management intervention (e.g. different fire and weed scenarios)?		
Project Status	Active		
Project number	RES-2019-017	**Project commencement date**	21/01/2019
Project duration (months)	6	**Estimated completion date**	31/12/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	External	**Supporting team(s)**	CSIRO- Anna Richards and Amy Warnick

Aims

- To develop ecosystem restoration trajectories for Ranger mine site using a state and transition modeling approach by:
  a) Interpreting and synthesizing the considerable body of scientific research that has been undertaken for the site and region;
  b) Documenting competing or alternative viewpoints on rehabilitation trajectories and end states; and
  c) Undertaking uncertainty analysis.
- To identify knowledge gaps and inform future experimental design.

Background

Ranger uranium mine is scheduled to close in 2026. Close-out of the site will be achieved once environmental requirements set out in the Australian Government's environmental protection conditions (Environmental Requirements) have been met (or are on a trajectory to being met). The key environmental requirements for ecosystem restoration of the mine site are "to establish an environment with habitats and erosion characteristics similar to adjacent areas of Kakadu National Park and stable radiological conditions that comply with national requirements and are as low as reasonably achievable"

The Supervising Scientist's Ecosystem Restoration Standard specifies a trajectory-based approach to closure assessment. Full ecosystem restoration of the Ranger mine site will take many decades. To account for this long time scale, restoration success can be assessed against modelled restoration trajectories. The trajectories represent multiple possible restoration outcomes based on factors that may influence the progress of restoration over time, such as fire and weeds. Ongoing monitoring will be required to: assess where the ecosystem has developed relative to the possible trajectories over time; inform management activities; and validate and assess confidence in the model. The trajectory model can then be used to determine the point at which the ecosystem is likely to progress to successful restoration without further management input. Previous research (see project RES-2016-015 "Review of revegetation outcomes arising from historic mine sites in the Alligator Rivers Region") has resulted in a preliminary state and transition model for Ranger mine site based on existing research and trajectories of mines in the Alligator Rivers Region and near surrounds.

This project will build further on the preliminary state and and transition model and aims to address Key Knowledge Need ERS5B: "What are possible/agreed restoration trajectories (flora and fauna) that would ensure the rehabilitated site will move to a sustainable ecosystem without further management intervention which is significantly different from that of the surrounding natural ecosystems?".

Progress against plan

- An expert elicitation workshop (30 attendees) was held in April 2019. A number of end states were presented and described by workshop participants, along with deviated states and management actions.
- A survey was provided to workshop attendees post-workshop to quantify likelihood, consequence and uncertainty for the components of the state and transition model.
- A report has been drafted for further review by SSB and ERA.

Key findings

- A state and transition model describing desirable and undesirable transitions (and associated states) along a trajectory to closure was developed by workshop participants.
- Three potential end-states were described: 1) Similar to surrounds (assuming a plausible climate change scenario 100 years from present day; 2) Extreme climate drying (assuming an extreme climate change scenario from present day); and 3) Functional understorey (assuming a dry-adapted overstorey and midstroey species mix).
- A further 9 establishment states and 12 intermediate states were identified and described.
- Threats that drive undesirable transitions, together with management interventions applied to reverse the transitions resulting from these threats, were identified.
- A list of undesirable transitions, their drivers, timeframe for the transitions to occur, and any pre-conditions necessary for transition, was developed.

Workplan for 2019–20

- Anaysis of workshop participant survey results to examine uncertainty and to identify those transitions that present the most risk to diverting ecosystem restoration into an undesirable state.
- Finalisation of report through formal review of the project and outputs in collaboration with ERA to ensure the resulting state and transition model is useful for informing operational management of ecosystem restoration at Ranger mine site.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Project report documenting the restoration trajectories to assess the achievement of closure criteria that are expected to be reached after a period of time after the initial establishment, and defined end state(s) for up to 50-100 years after initial establishment.
- Conference presentation at the Ecological Society of Australia Conference in November 2019.

The outcomes that this project will achieve are:

- Agreed ecosystem restoration trajectories that ensure the rehabilitated site will move to a sustainable ecosystem without further management intervention significantly different from that of the surrounding natural ecosystems.
- Address the requirements for an ecosystem restoration trajectory approach as outlined in the Supervising Scientist Ecosystem Restoration Standard.

Planned communication activities

The primary communication activities for the project are:

- Presentations to ARRTC.
- Presentations to stakeholders including the Ecosystem Restoration Working Group.
- Conference presentation at the Ecological Society of Australia Conference 2019.
- Technical Advice.

Project publications to date (if applicable)

Nil

Project Title	Review of revegetation outcomes arising from historic mine sites in the Alligator Rivers Region		
KKN Theme	Ecosystem restoration		
KKN Title	ESR5. Develop a restoration trajectory for Ranger mine		
KKN Question	ESR5B. How can we develop restoration trajectories (flora and fauna) to predict when the rehabilitated site will move to a sustainable ecosystem without further management intervention (e.g. different fire and weed scenarios)?		
Project Status	Completed		
Project number	RES-2016-015	**Project commencement date**	28/11/2016
Project duration (months)	31	**Estimated completion date**	12/06/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Centre for Mined Land Rehabilitation

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 contain 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 submitted.

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 River 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 native fauna has recolonised the rehabilitated area, and is able to use this 'new' habitat as it would the surrounding environment.

Workplan for 2019–20

- Project completed.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Preliminary State and Transition Model for revegetation.
- Identification of further research to be undertaken to inform understanding site trajectories.
- Journal publication submitted titled: "A review of revegetation mine sites in the Alligator Rivers Region, Northern Territory, and the development of a state and transition model for ecological restoration at Ranger uranium mine".

The outcome that this project will achieve is:

- Clear expectations of the pathway (viz modelled trajectories) to successful revegetation of the Ranger final landform.

Planned communication activities

The primary communication activities for the project are:

- Submit journal paper.

Project publications to date (if applicable)

Nil

Project Title	Long-term viability of the ecosystem established on the trial landform		
KKN Theme	Ecosystem restoration		
KKN Title	ESR5. Develop a restoration trajectory for Ranger mine		
KKN Question	ESR5B. How can we develop restoration trajectories (flora and fauna) to predict when the rehabilitated site will move to a sustainable ecosystem without further management intervention (e.g. different fire and weed scenarios)?		
Project Status	Active		
Project number	RES-2017-009	**Project commencement date**	01/07/2018
Project duration (months)	12	**Estimated completion date**	30/06/2019
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

- To use remote sensing and field-based methods to undertake a quantitative assessment over a number of years of the long-term sustainability of the ecosystem established on the trial landform, including the monitoring of vegetation health, survival and recruitment, and soil development and evolution of nutrient cycling.

Background

Revegetation of the trial landform (TLF) commenced 10 years ago with the planting of overstorey species (trees). Most other research on waste rock ecosystem establishment at Ranger has been undertaken on much shorter time frames and many of these areas have since either been cleared or covered in stockpiles. Therefore, the TLF provides a valuable 'baseline' for the assessment of revegetation efforts on waste rock over a long term period (10-15 years). This project will use quantitative methods to assess the long term sustainability of the ecosystem that has been established on waste rock. Analysis of the fate of the waste rock system as it further matures (including dynamics in plant phenology, recruitment, mortality, species preferencing, understory establishment, soil development and litter decomposition etc.) will contribute to informing whether closure criteria for the rehabilitated landform are likely to be met.

Progress against plan

- The GPS location of all woody plants has been recorded for three out of the four plots on the TLF.

Key findings

- Nil to report

Workplan for 2019–20

- Use the overstorey species data to determine its similarity to vegetation communities from the surrounding natural landscape, and thereby assist in the development of metrics for similarity and assessment methods for determining revegetation success
- Complete the recording of the GPS location of all trees.
- Undertake a UAV flight to capture multispectral data over the TLF post-burning.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A quantitative assessment of key indicators of the similarity and sustainability of the plant community on the trial landform post 10 years establishment.
- Refinement of the State and Transition Models to be developed for revegetation.

The outcome that this project will achieve is:

- Information that can be used to assess the long term sustainability of the ecosystem that has been established on Ranger waste rock.

Planned communication activities

The primary communication activities for the project are:

- Research papers published in international and peer-reviewed scientific journals describing methods and validation, and findings, including comparisons to analogue sites.
- 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)

Whiteside T, Bartolo, R & Boyden J 2017. Application of multi-source UAV data to assess revegetation efforts on waste rock, In: UAS4RS 2017 Conference, 24-25 May 2017, Hobart.

Project Title	Ecohydrology and sensitivity of riparian flora (NESP project)		
KKN Theme	Ecosystem restoration		
KKN Title	ESR6. Understanding the impact of contaminants on vegetation establishment and sustainability		
KKN Question	ESR6A. What concentrations of contaminants from the rehabilitated site may be available for uptake by terrestrial plants?		
Project Status	Active		
Project number	RES-2017-022	**Project commencement date**	01/03/2018
Project duration (months)	31	**Estimated completion date**	01/09/2020
Lead team	ERL	**Date required**	01/05/2022
In-house or outsourced	Collaboration	**Supporting team(s)**	Charles Darwin University: Lindsay Hutley; Clement Duvert; Michael Brand; Sam Setterfield

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 toleerances of key riparian species.

Background

Current understanding of ecohydrological properties of Northern Australian 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 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 $MgSO_4$)
- Preliminary pot trials have been completed at the University of Western Australia.
- Definitive experiments have commenced at Charles Darwin University with 4 species.

Key findings

- The preliminary pot trials have optimised the conditions under which the pot trials will be conducted
- Preliminary studies showed that *Melaleuca* sp. were very tolerant to magnesium sulfate exposure but *Alphitonia* sp. were of intermediate tolerance

Workplan for 2019–20

- Field campaign – mid-dry season sampling (soil, twigs, groundwater, tritium sampling), processing (July-August 2019)
- Field campaign - late dry season sampling (soil, twigs, groundwater) sample processing (September 2019)
- Isotope data collation, manuscript preparation (January-February 2020)
- Pot trial - operation, application of treatments, ongoing measures of growth, plant stress Block 2 (November-December 2019)
- Pot trial – Harvest, sample processing, data summation (December 2019-January 2020)
- Pot trial – Data analysis, manuscript preparation and publication submission (January-March 2020)
- Seed collection of target species Kakadu NP, germination of seedlings (January-March 2020)

- Synthesis and collation of data and reports, and communication activities (March-December 2020)

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Assessment of the risks to riparian vegetation of groundwater solute expressing to Magela and Gulungul Creeks, and determine the ($MgSO_4$) tolerances of key riparian species.

The outcome that this project will achieve is:

- The $MgSO_4$ concentrations that will be "safe" for riparian vegetation, which will inform the risk to off-site environment and ALARA process for the on-site rehabiliation.

Planned communication activities

The primary communication activities for the project are:

- 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)

Nil

Project Title	A review of compaction layers in mining landforms and possible implications for Ranger uranium mine.		
KKN Theme	Ecosystem restoration		
KKN Title	ESR7. Understanding the effect of waste rock properties on ecosystem establishment and sustainability		
KKN Question	ESR7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?		
Project Status	Completed		
Project number	RES-2017-018	**Project commencement date**	31/10/2017
Project duration (months)	16	**Estimated completion date**	22/02/2019
Lead team	ERL	**Date required**	30/06/2018
In-house or outsourced	In-house	**Supporting team(s)**	

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 lead to a review of the advantages and disadvantages of compaction layers in mining landforms.

Progress against plan

- A literature search was undertaken with over 150 references sourced from peer-reviewed journals, conference proceedings and ERA-commissioned work.

- Technical Advice #003 'Potential risks associated with compaction layers' was provided to ERA on 02/02/2019.

Key findings

- The purpose of the Technical Advice was to highlight the potential risks to restoration associated with compaction arising from reconstruction of the Ranger final landform. Compaction may result from either the backfilling techniques proposed in the Ranger Mine Closure Plan (ERA 2018), covered "paleo"-features (haul roads, benches, platforms and ramp horizons) or mine-induced compaction of the underlying Koolpinyah surface.
- The summary of advice was: SSB finds little literature support indicating optimization of PAW from engineered compaction during landform construction, however, nor is there evidence that these strategies will unequivocally be detrimental to ecosystem restoration. Moreover, compaction from historic and landform construction activities are either inevitable or difficult to mitigate and given there is no compelling evidence of detriment, a different construction method is not recommended. Instead, SSB recommends accurate identification of all areas of the rehabilitated site that may be subject to past, current or potential (including cumulative) compaction so the internal characteristics of the final landform are known. In particular, compaction should be measured for the remaining backfilling of Pit 1 so that it may be correlated with other data that will be collected from the Pit 1 progressive rehabilitation monitoring. This will inform ecosystem restoration efforts by allowing monitored outcomes to be linked to causative agents, including location and degree of compaction.

Workplan for 2019–20

- Nil

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Literature review on compaction layers in mining landforms with particular reference to implications at Ranger.
- Listed advantages and disadvantages of compaction layers for ecosystem restoration and function
- Technical Advice #003 Potential risks associated with compaction layers was provided to ERA on 02/02/2019.

The outcome that this project will achieve is:

- Improved knowledge of potential effects of compaction on rehabilitated landform outcomes at Ranger.

Planned communication activities

The primary communication activities for the project are:

- Technical Advice #003 Potential risks associated with compaction layers was provided to ERA on 02/02/2019.

Project publications to date (if applicable)

Supervising Scientist 2019. Potential risks associated with compaction layers. Technical Advice #003. Supervising Scientist, Darwin.

Project Title	Hydrology on the trial landform to inform water balance		
KKN Theme	Ecosystem restoration		
KKN Title	ESR7. Understanding the effect of waste rock properties on ecosystem establishment and sustainability		
KKN Question	ESR7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?		
Project Status	Active		
Project number	RES-2010-024	**Project commencement date**	01/12/2009
Project duration (months)	193	**Estimated completion date**	01/01/2026
Lead team	ERL	**Date required**	01/01/2026
In-house or outsourced	In-house	**Supporting team(s)**	

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 recommended that monitoring of hydrology viz wet season measurements of rainfall, runoff and infiltration, continue on the trial landform to inform plant available water (PAW) studies. A below average wet season followed by a long dry season could mean that the PAW has declined well before the end of the dry season, impacting on the health of vegetation.

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 2017–2018.

- Data were collected during the 2018-2019 wet season and are currently being quality checked using a new, mostly automated process.

Key findings

- Average annual Runoff coefficients determined for the four erosion plots on the trial landform (TLF) range from 6.1 to 28.2, suggesting that more than 70% of rainfall is lost/removed by processes other than runoff, including infiltration. Infiltration measurements using a Disc Permeameter showed that water flows into the waste rock at rapid rates, supporting the high runoff coefficients.

Workplan for 2019–20

- Confirm that the automated data checking process works effectively, check and archive 18-19 wet season data.
- Clean out inlet pipes for the stilling well to remove sediment.
- Check that the primary stage indicators are functioning (shaft encoders), and remove the pressure transducers (secondary stage height) as they are no longer providing accurate data.
- Collect 2019-2020 wet season data and store in Hydstra database.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- The outputs for this project are:
- Rainfall and runoff data from four erosion plots on the trial landform.
- Summary data sets that can be used to inform PAW and other rainfall and runoff information.

The outcome that this project will achieve is:

- Rainfall, runoff, and infiltration relationships to inform long term sustainability of the revegetated landform specifically related to PAW

Planned communication activities

The primary communication activities for the project are:

- 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)

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 2019. Technical Advice #002 - Runoff coefficients relevant to the Ranger waste rock landforms, Supervising Scientist Branch.

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.

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 Title	Developing monitoring methods for revegation using RPAS: Jabiluka revegetation		
KKN Theme	Ecosystem restoration		
KKN Title	ESR9. Developing best-practice monitoring methods for ecosystem restoration.		
KKN Question	ESR9A. How do we optimise methods to measure revegetation and faunal community structure and sustainability on the rehabilitated site, at a range of spatial/temporal scales and relative to the areas surrounding the RPA?		
Project Status	Completed		
Project number	RES-2014-003	**Project commencement date**	01/07/2014
Project duration (months)	48	**Estimated completion date**	1/10/2018
Lead team	ERL	**Date required**	01/04/2020
In-house or outsourced	In-house	**Supporting team(s)**	

Aims

- To test and develop 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 needs to be measured and modelled. To assess 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 paper detailing the method of data capture, processing and analysis has been published in the *International Journal for Applied Earth Observation and Geo-information.*

Key findings

- The technique was tested on three data sets that covered three different dates (23rd December 2014, 10th July 2015 and 1st June 2016), two different sensors, (Sony NEX-5 cameras providing Red, Green, Blue and near-infrared data, and multispectral data obtained using a MicaSense RedEdge sensor) and two different processing methods.
- Using an object-based image analysis approach, proportional woody cover per planting area and per 10m x 10m cell were quantified.
- Overall woody cover detection accuracies from each data set were over 95%. Proportional woody cover derived from the technique showed strong linear relationships with manually estimated cover ($r > 0.88$).
- This study shows that the technique is robust, works with a range of RPAS data sets and enables at-scale analysis of woody cover change between dates.
- This method will be an important component of ongoing monitoring of revegetation efforts at Ranger mine site and will inform State-and-Transition models of ecosystem restoration for the site by providing measures of canopy cover. Additionally, such monitoring will inform adaptive management (e.g. infill planting) by providing timely data on mortality and recruitment.
- Further work will focus on applying fate metrics to these data over the 10 datasets acquired at Jabiluka to test the use of landscape ecology metrics for assessing revegetation efforts

Workplan for 2019–20

- Nil.

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 that this project will achieve are:

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

Planned communication activities

The primary communication activities for the project are:

- Conference presentations.
- 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 Title	Radiation monitoring at the El Sherana containment facility		
KKN Theme	n/a		
KKN Title	n/a		
KKN Question	k/n		
Project Status	Active		
Project number	MON-2013-006	**Project commencement date**	1/7/2012
Project duration (months)	n/a	**Estimated completion date**	n/a
Lead team	ENRAD	**Date required**	n/a
In-house or outsourced	In-house	**Supporting team(s)**	

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 located in the South Alligator Valley. 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 which were 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 routinely measured. The Supervising Scientist currently undertakes radon exhalation and gamma dose rate monitoring at the containment every two years.

Progress against plan

- Baseline radon exhalation and gamma dose rate measurements conducted in 2007.

- Routine radon exhalation and gamma dose rate measurements made at the containment in 2010, 2012, 2013, 2015, 2017 and 2019.
- Internal report with results of the 2019 measurements drafted.
- The next set of measurements will be conducted in 2020-21.

Key findings

- No change in gamma dose rates at the El Sherana containment facility compared to baseline values for the site.
- Radon-222 exhalation flux densities have typically been higher than baseline values and variable between years, but this is likely to be a consequence of the time of year when measurements were made rather than performance issues with the facility.
- Gamma and radon levels measured in May 2019 were consistent with baseline values.
- Radiation dose to members of the public from the containment is presently negligible.

Workplan for 2019–20

n/a

Planned project outputs and associated outcomes

The primary output for the project is:

- A long-term dataset of radon exhalation and gamma dose rate measurements for the El Sherana containment facility.

The outcome that this project will achieve is:

- Public and regulator assurance that there is no unacceptable radiation risk arising from the El Sherana containment facility.

Planned communication activities

The primary communication activities for the project are:

- Internal reports.
- Presentations to stakeholders on request

Project publications to date (if applicable)

Bollhöfer A & Doering C 2013. Radiological assessment of the El Sherana containment. In eriss research summary 2011–2012, Supervising Scientist Report 204, Supervising Scientist, Darwin, 182–187.

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.

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, Medley P & Da Costa L 2014. Radiological monitoring and assessment at the El Sherana airstrip containment. In eriss research summary 2012–2013, Supervising Scientist Report 205, Supervising Scientist, Darwin, 229–234.

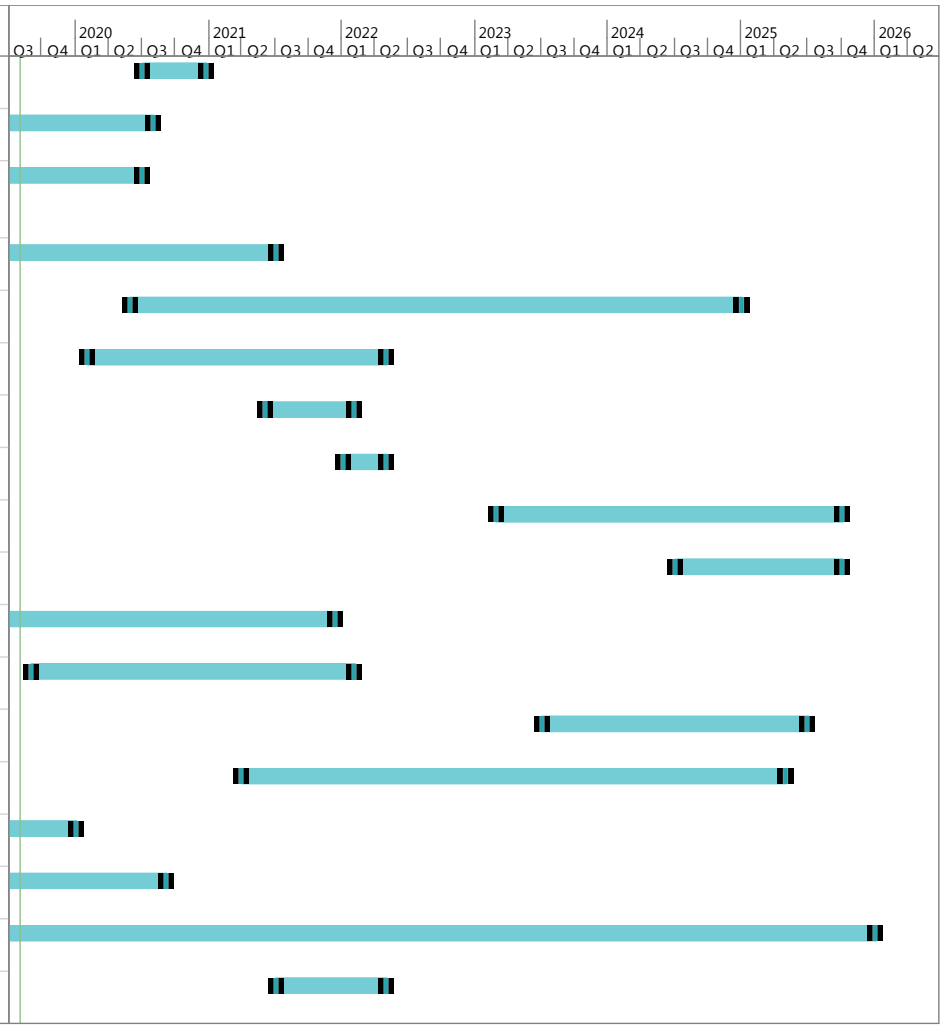
Doering C, Bollhöfer A, Ryan B, Sellwood J, Fox T & Pfitzner J 2011. Baseline and post-construction radiological conditions at El Sherana airstrip containment, South Alligator River valley, Australia. Internal Report 592, June, Supervising Scientist, Darwin.

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, 2019-2026

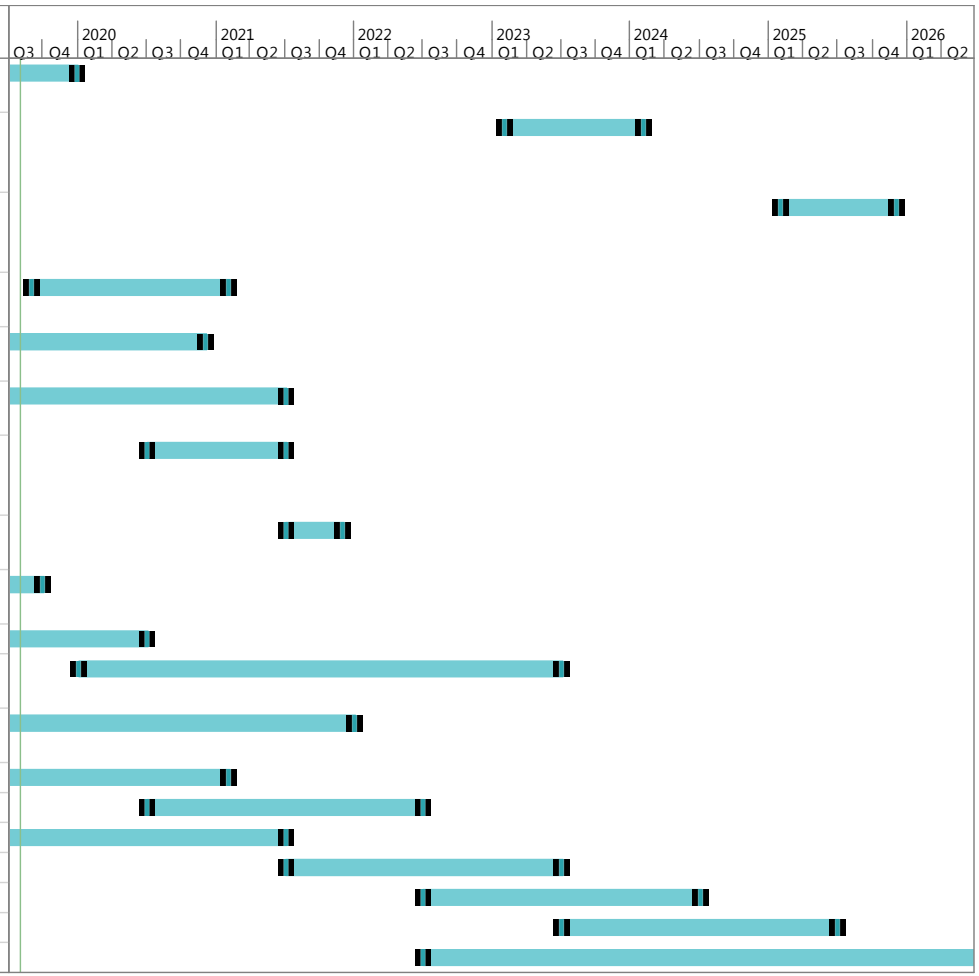
Projects against Ecosystem Restoration (ESR) Key Knowledge Needs

Project Title	KKN No.
Quantifying spatial and temporal change in seasonally-inundated savanna	ESR1A
Using hyperspectral drone data for deriving species composition	ESR1A
Deriving species composition measures and their environmental correlates to assess ecosystem restoration similarity	ESR1C
Deriving vegetation community structure measures to assess ecosystem restoration similarity	ESR1C
Deriving similarity metrics for ecosystem restoration at the scale of the Ranger rehabilitation	ESR1C
Applying patch metrics to characterise 'natural' distribution of vegetation	ESR1C
Habitat features that influence the colonisation of fauna on the landform	ESR2B
Risk assessment for feral animals impacting faunal colonisation of the landform	ESR2C
Improved understanding of sources and magnitude of sources of weeds off site using remote sensing	ESR4A
Assess the occurrence and density of feral animal species in the adjacent off-site environment	ESR4A
Assessing long-term viability of revegetation on waste rock at Nabarlek.	ESR5A
Determining the key terrestrial ecological processes required for ecosystem restoration	ESR5A
Develop monitoring program to evaluate impacts of disturbance on revegetation trajectory	ESR5B
Monitoring and assessment of ecosystem establishment and long-term viability on Pit 1 waste rock to inform	ESR5B
Developing restoration trajectories to predict when the restored site will move to a sustainable ecosystem	ESR5B
Ecohydrology and sensitivity of riparian flora (NESP)	ESR6A
Hydrology on the trial landform to inform water balance	ESR7B
Acute and chronic toxicity of CoPCs to soil fauna	ESR7D



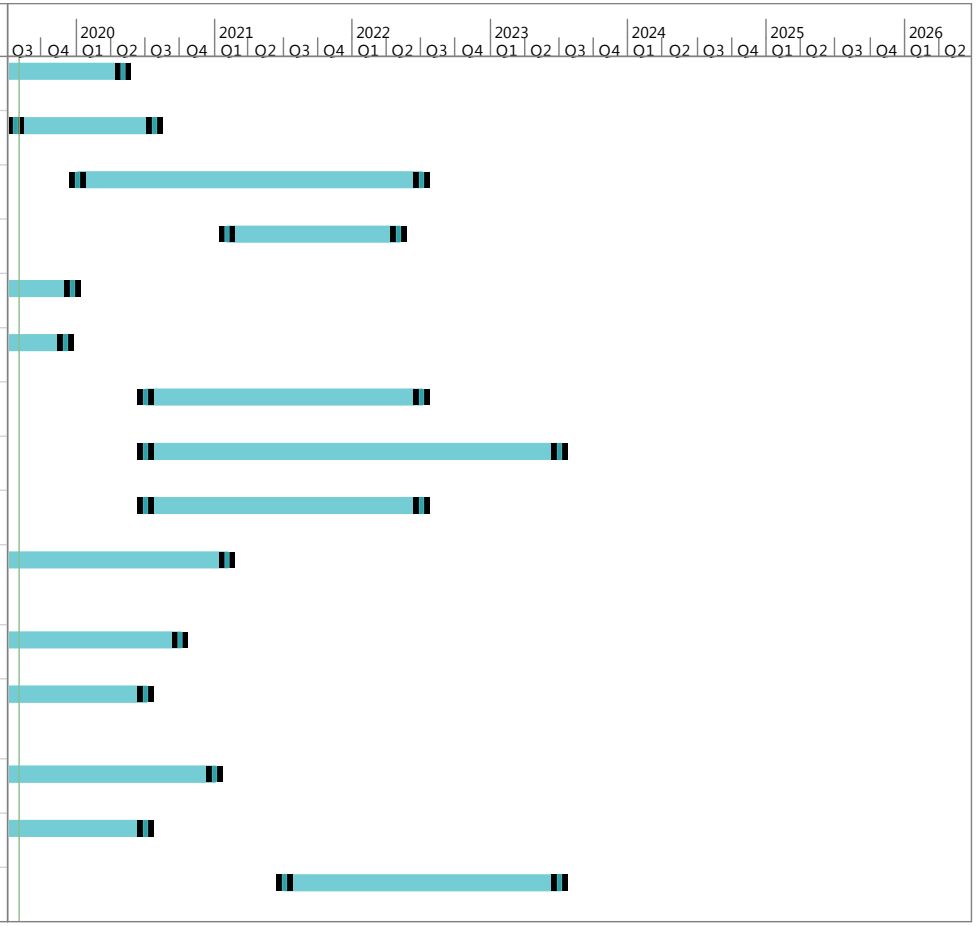
Projects against Cross-theme (CT), Landform (LAN) and Health Impacts of Radiation and Contaminants (RAD) Key Knowledge Needs

Project Title	KKN No.
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 2 (aquatic pathways)	CT1A
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Periodic review and update (2024)	CT1A
Cumulative risk assessment for Ranger mine site rehabilitation and closure- Periodic review and update (2026)	CT1A
Determine baseline extent, size and rate movement of gullies in undisturbed areas surrounding the mine site	LAN1A
Determine natural bedload movements in Magela and Gulungul Creeks	LAN1B
Assessment of sedimentation risk to on-site and off-site billabongs	LAN1B
Mapping and characterisation of geomorphology of on-site creeks in and adjacent to the mine site, including historical change	LAN1B
Identify landscape-scale processes that could adversely affect the stability of the rehabilitated landform	LAN2B
Assessing the geomorphic stability of the Ranger trial landform: calibrating model outputs	LAN3C
Ranger trial landform erosion research	LAN3C
Assessing the stability of the constructed Pit 1 Landform using modelling	LAN3D
Radon exhalation from waste rock on the Ranger trial landform	RAD3A
Environmental fate and transport of Ac-227 and Pa-231	RAD5A
Radionuclide uptake in small proliferators	RAD6B
Radionuclide uptake in terrestrial vegetation	RAD6B
Radionuclide uptake in terrestrial invertebrates	RAD6B
Radionuclide uptake in terrestrial birds	RAD6B
Radionuclide uptake in amphibians	RAD6B
Radiation dose-effect relationships for non-human biota	RAD6D



Projects against Water and Sediment (WS) Key Knowledge Needs

Project Title	KKN No.
Assess the ecological risks of mine water contaminants in the dry season, subsurface waters of Magela sand channel	WS4A
Identification and mapping of Groundwater Dependent Ecosystems (GDEs)	WS4A
Impact of acid sulfate soils on aquatic ecosystems	WS5A
Assessment of physico-chemical (modifying) factors that affect metal bioavailability and toxicity in sediments	WS5B
Assessing the toxicity of mine water mixtures for operational and closure scenarios	WS7A
Weight of evidence assessment to derive a water quality standard for magnesium in surface waters	WS7A
Assessing the impacts of COPC mixtures and exposure scenarios through multiple lines of evidence	WS7A
Investigating the effects of pulse scenarios for metals and multiple Mg pulses	WS7A
The development of salt tolerance in aquatic organisms	WS7A
Hazard and risk assessments for potential / emerging water quality contaminants and toxicity modifying factors: Phase 1 desktop hazard assessment	WS7B
'Seasonal sensitivity' (to Mg) profile for organisms in the Magela creek channel	WS7C
Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity (NESP fish migration)	WS7F
Assess the effects of turbidity on aquatic ecosystems using field effects information	WS8A
The direct effects of suspended sediment on tropical freshwater biota (currently suspended)	WS8A
Impact of suspended sediment-associated contaminants	WS8A



Appendix 4 Technical Advice memoranda

To improve collaborative working relationships between SSB and ERA, the timely communication of KKN research outcomes and sharing of information between respective research groups are critical. This is particularly important given the increasing number of Applications ERA is preparing and for informing or meeting closure objectives and criteria. The need for such knowledge sharing was also recognised at the November 2018 ARRTC meeting (ARRTC 41). To facilitate and expedite this process into the future, SSB has initiated the writing of technical advice memoranda to provide to key ERA staff as research outcomes are completed or as significant information arises throughout SSB's review processes. The intent is to provide short, concise and clear information and advice which can be used to inform ERA planning in a timely manner.

Five technical advice memoranda have been prepared and provided to ERA in the period between 2 January and 24 May 2019. The subject titles are:

1. Technical Advice #001: Feedback on INTERA numerical groundwater model presentations at ARRTC 41
2. Technical Advice #002: Runoff coefficients relevant to the Ranger waste rock landforms
3. Technical Advice #003: Potential risks associated with compaction layers
4. Technical Advice #004: Initial assessment of the FLV6.2 landform
5. Technical Advice #005: Waste rock particle size on the Trial landform
6. Technical Advice #006: Species richness and composition indicator values for assessing ecosystem similarity for savanna woodland

Glossary of terms, abbreviations and acronyms

ANOVA	Analysis of Variance testing
application	A document stating how the mining operator proposes to change the conditions set out in the mining Authorisation. These changes need to be approved by all MTC stakeholders.
AREVA	AREVA, France – (formerly - Afmeco Mining and Exploration Pty Ltd)
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARR	Alligator Rivers Region
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
authorisation	For mining activities authorisation is required under the Northern Territory *Mining Management Act 2008* (MMA*)* for activities that will result in substantial disturbance of the ground. It details the authorised operations of a mine, based on the submitted mining management plan and any other conditions that the Northern Territory Minister considers appropriate.
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 '*a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation*' for assessing site remediation options.
DPIR	Northern Territory Department of Primary Industry and Energy (formerly Northern Territory Department of Mines and Energy)
early detection	Measurable early warning biological, physical or chemical response in relation to a particular stress, prior to significant adverse effects occurring on the system of interest.
EC (electrical conductivity)	A measure of the total concentration of salts dissolved in water.
EC50	The concentration of a toxicant that reduces a group of organisms' sub-lethal health measurements (e.g. growth or reproduction) by 50% relative to that of a control group of organisms (i.e. a group of organisms not exposed to the toxicant).
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' and identifies tests been conducted in the creeks in the vicinity of the mine-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 toxicant 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 toxicant).
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	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.
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).
toxicity testing	The use of a standardised protocol, in the laboratory or the field, to determine the effects of a toxicant on an organism.
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.
WTP	Water Treatment Plant