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Department of the Environment and Energy

Supervising Scientist

SUPERVISING SCIENTIST

Annual Technical Report

2015-16

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Our mission

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

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

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










Photos (from top left): UAV image of Wirnmuyurr billabong and adjacent savanna; using the Water and Sediment Quality Team's high resolution stereo microscope to photograph northern trout gudgeon fry; egg mass of freshwater snail *Amerianna cumingi*; *Hydra viridissima*; helicopter used to access remote and inaccessible water sampling points; bushfood collected as part of Gundjeihmi bushfood project; 2016 popnetting crew; collecting mussels as part of the ecotoxicology program; Supervising Scientist staff running the organisation's information stall at the 2015 Mahibilil Festival in Jabiru; water flea *Moinodaphnia macleayi*; Supervising Scientist Branch's octocopter in flight.

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EXECUTIVE SUMMARY

Over the 2015–16 reporting period the Supervising Scientist Branch completed all planned monitoring and supervision activities, and finalised a number of key research projects. The multiple lines of evidence gathered through these combined programs continue to show that the people and the environment of the Alligator Rivers Region remain protected from the effects of uranium mining, including from the Ranger uranium mine.

The Supervising Scientist Branch released a revision of the Ranger Water Quality Objectives in early 2016. The revised objectives were the accumulation of 10 years of research and monitoring data, forming a truly world leading water quality compliance framework. For the first time water quality objectives were set for Gulungul Creek and continuous monitoring and automatic sampling were included as a statutory requirement. The Northern Territory Department of Primary Industries and Resources formally issued the revised Ranger Water Quality Objectives on 7 March 2016 thereby giving them statutory force.

All statutory water quality objectives were met in both Magela and Gulungul Creeks throughout the 2015–16 wet season. The mine had negligible influence on water quality in Magela Creek. Gulungul Creek water quality continued to show the effects of shallow groundwater seepage expressing into Gulungul Creek Tributary 2, originating from the western edge of the Ranger Tailings Storage Facility. Effects on water quality were reduced in comparison to the 2014–15 wet season due to low wet season rainfall and extensive seepage interception works.

The Supervising Scientist Branch continues to take a risk and evidence-based approach to environmental monitoring. During 2015–16 the Supervising Scientist Branch reduced the inspection schedule for Jabiluka, and ceased surface water monitoring at Jabiluka and atmospheric radiological monitoring surrounding Ranger. These changes are supported by a large amount of data showing the associated environmental and human health risks to be very low. Monitoring in the Gulungul Creek catchment was significantly increased in response to observed changes in water quality, including the installation of an additional upstream monitoring station and the deployment of a number of temporary sensors throughout the catchment. The Supervising Scientist will continue to monitor any changes in mining operations through-out the Region and adjust monitoring programs accordingly.

The Supervising Scientist Branch continued an active and applied research program through 2015–16, focussed almost solely on the rehabilitation of Ranger. Of the 34 research projects underway, 11 were completed during 2015–16. The program has been expanded to 41 projects for the 2016–17 year, including significant external collaboration. The Supervising Scientist Branch's research outputs included 28 peer reviewed publications and representation at a range of domestic and international fora. The feedback from these engagements has been overwhelmingly positive and shows that the Supervising Scientist continues to produce world leading science.

Oversight and endorsement of the Supervising Scientist Branch's research program was provided by the Alligator Rivers Region Technical Committee which met three times during 2015–16.

Importantly, both a comprehensive ecological risk assessment on the rehabilitation of Ranger and a revision of the Alligator Rivers Region Technical Committee Key Knowledge Needs were completed during the reporting period. The risk assessment formed the basis for the revised Key Knowledge Needs, which in turn drive the Supervising Scientist Branch research program. In combination with a strengthened planning and prioritisation process, these key projects ensure that the research program remains clearly linked to the rehabilitation of Ranger, and focussed closely on the highest priority needs.

During 2014–15 the Supervising Scientist Branch was focussed on the assessment of expansion plans, including an extension of operations on the Ranger Project Area beyond 2021. The announcement by Energy Resources of Australia Ltd on 11 June 2015 that the Ranger 3 Deeps underground mine would not proceed significantly shifted the focus of the Supervising Scientist Branch to the imminent cessation of operations and the rehabilitation of Ranger.

The Supervising Scientist Branch continues to provide advice to Energy Resources of Australia Ltd through the Closure Criteria Working Group process. Whilst the development of closure criteria by Energy Resources of Australia Ltd is delayed, rapid progress is now being made and many criteria appear likely to be agreed during the 2016–17 year.

The Supervising Scientist Branch continued to oversee uranium mining operations in the Region through 2015–16, including conducting a range of site inspections, audits and incident investigations. Notable developments at Ranger included: the commissioning of a dredge in the Tailings Storage Facility; the installation of a significant seepage and surface water interception system to the west of the Tailings Storage Facility; and the October 2015 fire which escaped the Ranger Project Area and burnt through adjacent areas of Kakadu National Park.

Following from the re-alignment of the work program during 2015–16, and the transition of the Supervising Scientist Division to a Branch within the Science Division, significant structural changes were completed. The structure of the Branch was revised to align with the statutory functions of the Supervising Scientist and key business outputs. This included the introduction of a Public Assurance and Advice team, the amalgamation of the Supervision and Monitoring functions into a single team and a consolidation of research teams to better facilitate multi-disciplinary projects. Additional to the structural changes, the Branch planning, prioritisation and reporting processes have been significantly revised and strengthened. These changes will position the Supervising Scientist Branch well to continue to support the statutory role of the Supervising Scientist into the future.

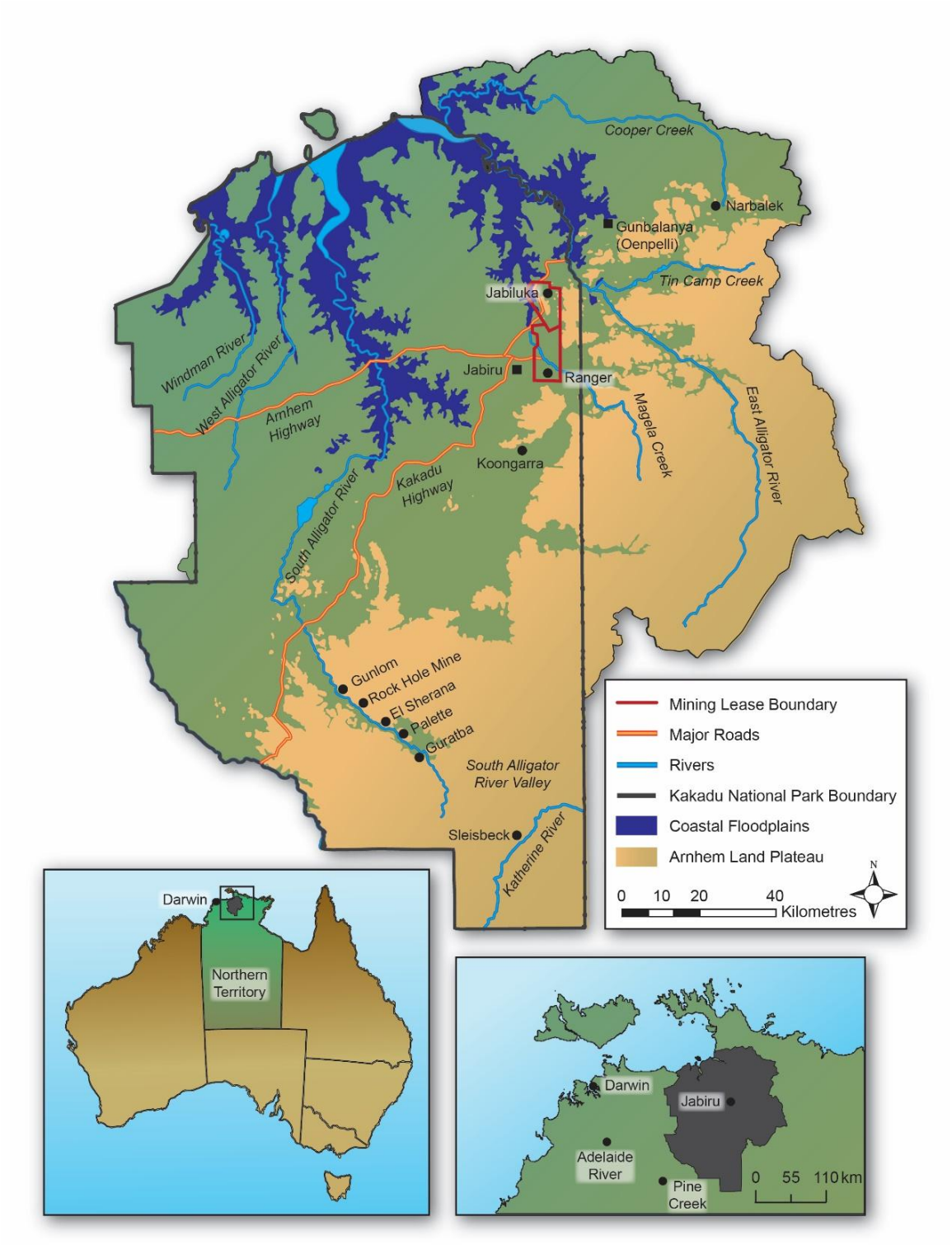

Figure 1 Alligator Rivers Region.

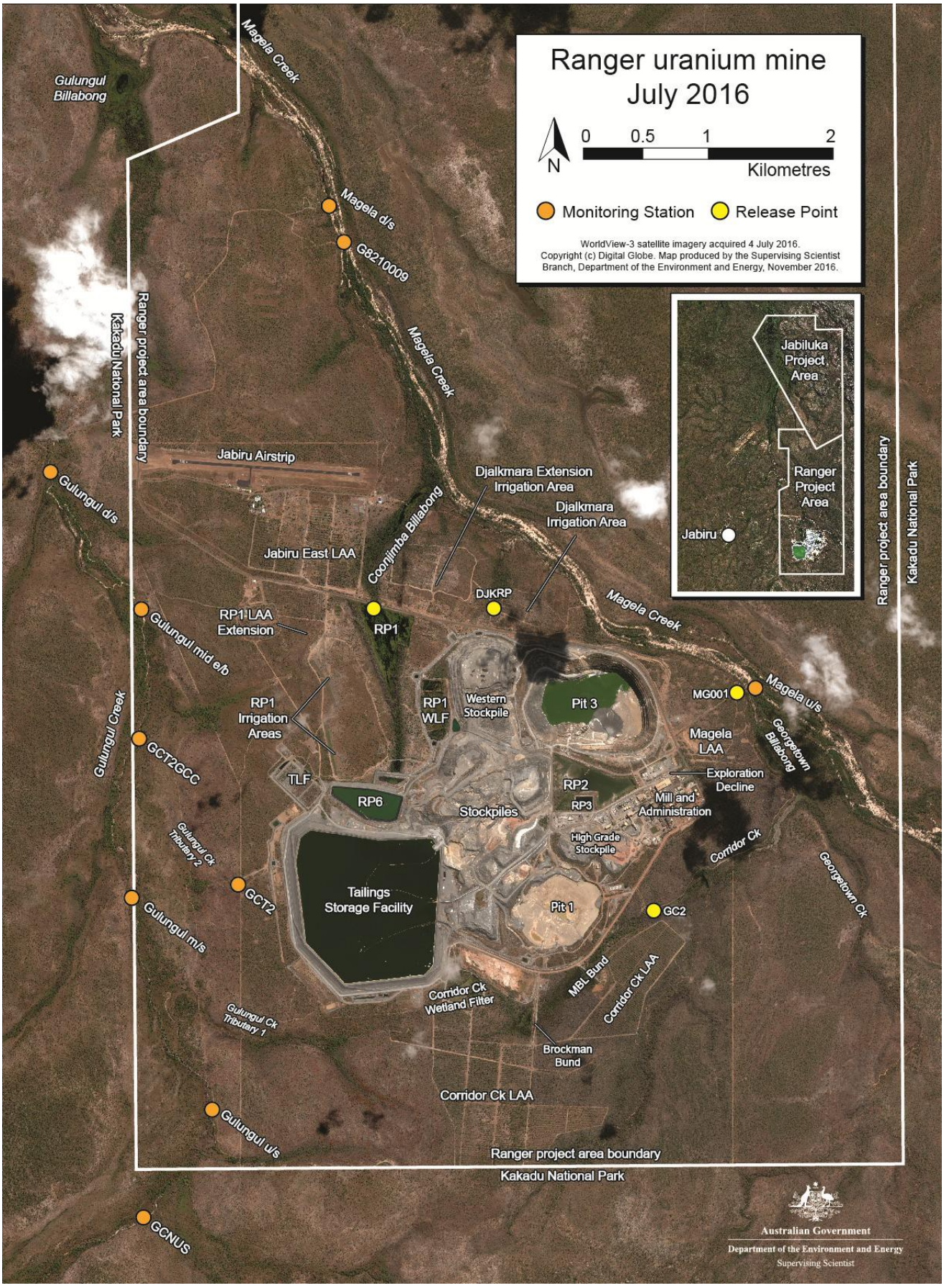

Figure 2 Ranger mine site.

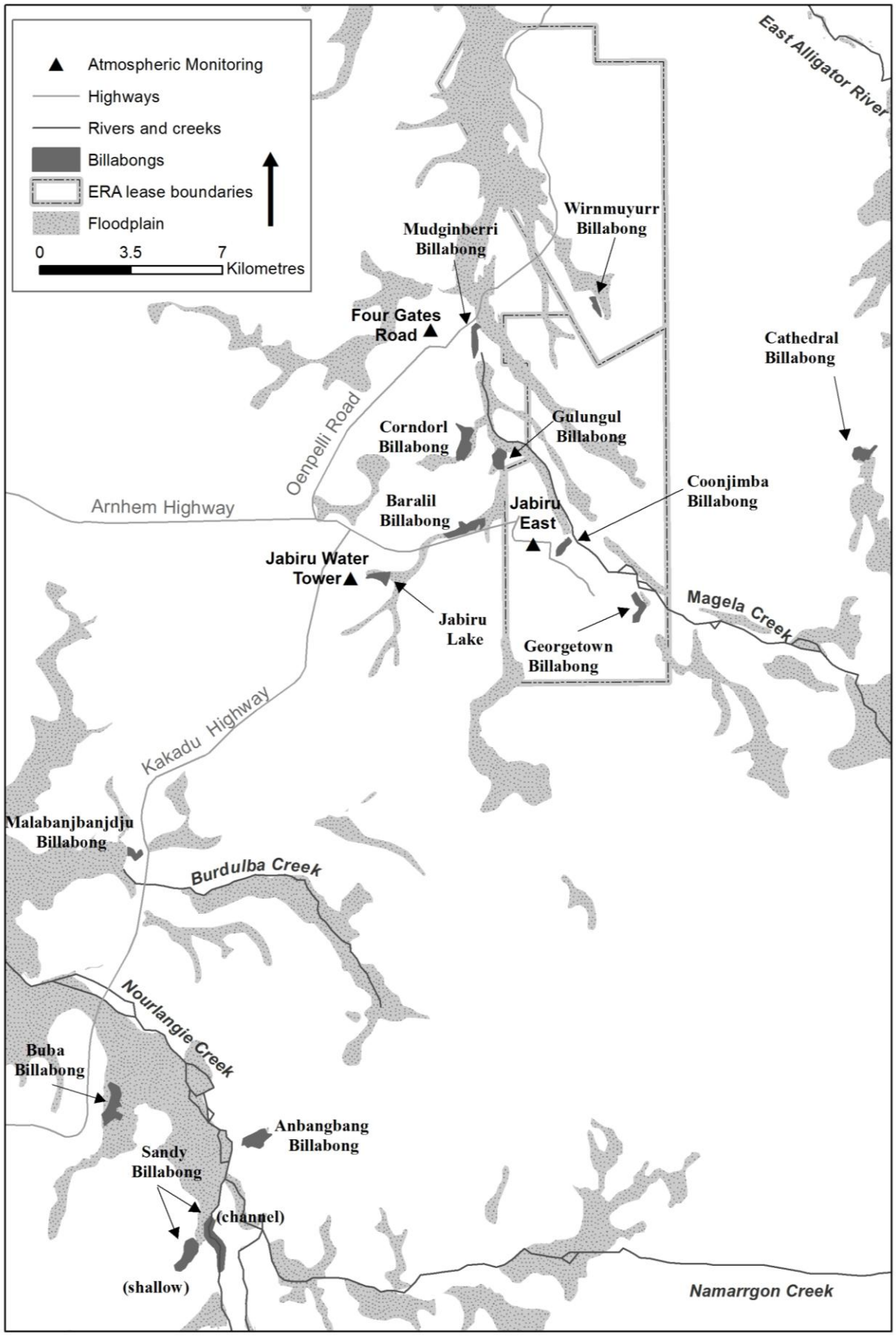

Figure 3 Location of waterbodies and atmospheric monitoring sites used until December 2015 in SSB's research and monitoring programs.

1 INTRODUCTION

1.1 Role and function of the Supervising Scientist

The position of the Supervising Scientist was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* in response to a recommendation of the final Fox Commission report in May 1977. The role of the Supervising Scientist is held by the First Assistant Secretary of the Science Division in the Department of the Environment and Energy. The Supervising Scientist Branch (SSB) is situated within the Science Division.

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

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

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 Region includes the catchments of the West Alligator, South Alligator and East Alligator Rivers, and extends into western Arnhem Land. The World Heritage listed Kakadu National Park lies entirely within the ARR.

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

Ranger is currently the only operational uranium mine in the ARR. Mining at Ranger ceased in 2012, however processing of stockpiled ore is continuing. Mining ceased at Jabiluka in 1999 and the site

remains under long-term care and maintenance. Operations at Nabarlek ceased in 1988 and the site has been substantially decommissioned and is subject to ongoing rehabilitation. There are also a number of former uranium mine sites in the South Alligator River Valley that operated during the 1950s and 1960s. The Australian Government funded the rehabilitation of these sites, which was completed in 2009.

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

2 PUBLIC ASSURANCE AND ADVICE

The outcomes of the supervision, research and monitoring activities undertaken by Supervising Scientist Branch (SSB) are communicated to various stakeholders by way of a range of consultative activities. These activities provide SSB with the opportunity to identify, understand and address the broad range of stakeholder concerns that accompany the sensitive issue of uranium mining.

2.1 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (ARRAC) provides a valuable forum for community liaison and exchange of views and information regarding protection of the Alligator Rivers Region (ARR) from the effects of uranium mining.

ARRAC comprises an independent Chairperson and representatives from various stakeholder organisations. ARRAC meeting minutes are available from the ARRAC website at: environment.gov.au/science/supervising-scientist/communication/committees/arrac

At the 46th meeting of ARRAC in Jabiru in September 2016, the committee discussed a range of matters related to SSB's role in relation to Ranger mine, including the process and progress of minesite rehabilitation, changes to SS's atmospheric monitoring program, and the functionality of an interception trench installed at the mine site.

2.2 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) plays an important role in ensuring the adequacy and appropriateness of the scientific research conducted by SSB. ARRTC also reviews the quality and adequacy of the science used for the regulatory assessment and approval of uranium mining related applications and proposals in the ARR.

ARRTC comprises a Chairperson and a number of independent scientific members.

In September 2015, ARRTC convened in Canberra for a one-day special meeting to review a synthesis report detailing the outcomes of an ecological risk assessment undertaken by SSB. The risk assessment was used to identify key risks to the environment associated with mine closure and the meeting focussed on identifying future Key Knowledge Needs based on these risks. The process was revisited during the 35th ARRTC meeting, which was held in Darwin on 23–26 November 2015.

The proposed 2016–17 research program for SSB was presented to members at the 36th ARRTC meeting, which was held in Darwin on 10–11 August 2016. The meeting focussed on the progression of rehabilitation at Ranger mine, including the successful revision of the ARRTC Key Knowledge Needs and the clarity this provided with regards to the links between the research of SSB and Ranger mine rehabilitation.

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

2.3 Communication with other stakeholders

During 2015–16 SSB communication activities have been focussed on advising stakeholders and the general public about the rehabilitation progress at Ranger mine and the contributions made by SSB. The organisation's scientific publications are made available publicly on the Department's website. A list of publications in the reporting period, is at Appendix 1. Scientific communication activities included the presentation of a number of key research outcomes to the wider national and international scientific community (Table 1).

TABLE 1 PRESENTATIONS AT KEY INTERNATIONAL CONFERENCES DURING 2015–16

Conference	Place/date (no. Papers)
Uranium Mining Remediation Exchange Group	Schlema, Germany 31 August 2015 (1 Presentation)
UAS4RS Conference	Brisbane, 17–18 February 2016 (2 presentations, 1 poster)
Aquatic Toxicology Symposium	Bar Harbour, Maine, USA, 7–9 June 2016 (1 presentation)
International Conference on Environmental Quality Standards for the Protection of the Aquatic Environment	Hong Kong, 18–20 June 2016 (1 presentation)

A number of community outreach activities have occurred during the reporting period, including the 2015 Mahbilil festival in Jabiru, at which SSB had an information stall displaying scientific posters and offering hands-on science activities. Presence at local events is an important opportunity to share information and have a two way conversation with local people. SSB's Mahbilil festival stall always attracts plenty of people to learn about the work of SSB in protecting the ARR.

SSB recently produced an online movie on mine closure and rehabilitation. The information is presented in the Kunwinjku language with English subtitles. Kunwinjku is the main dialect spoken in Aboriginal communities in the ARR. This is the third in a series of movies in the Kunwinjku language and all have received a very positive reception. All the movies can be accessed through the Department of the Environment and Energy's website.

Through local employment arrangements, SSB staff regularly work alongside Indigenous landowners, enabling sharing of knowledge and gaining of insight into cultural values. In May 2016, staff from SSB undertook the biannual aquatic sampling ('pop netting') program in billabongs around the mine (see section 4.1.3). The activity involved the deployment of a large temporary labour force which included team members from Gundjeihmi Aboriginal Corporation, Departmental staff from Canberra, students from Charles Darwin University and a volunteer from Jabiru (Figure 4).

Figure 4 Science Division and Gundjeihmi Aboriginal Corporation staff undertaking 2016 popnetting program

3 SUPERVISION

SSB provides regulatory oversight of mining and exploration activities in the ARR. The primary mechanism for SSB's participation in the regulatory processes of the Northern Territory Government is through assessment of applications made by Energy Resources of Australia Ltd (ERA) under the Authorisations for Ranger and Jabiluka, which are issued under the Northern Territory *Mining Management Act 2008*.

In addition to undertaking assessments, SSB also carries out routine periodic site inspections (RPIs) and audits, and integrates these processes with the results obtained from a comprehensive suite of environmental monitoring programs. Minesite Technical Committees (MTCs) have been established for Ranger, Jabiluka and Nabarlek to enable key stakeholders to discuss issues in relation to the assessment of applications, the findings of the site inspections and the outcomes of the monitoring programs.

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 and is adjacent to Magela Creek, a tributary of the East Alligator River. Ranger is an open cut mine and commercial production of uranium concentrate (U_3O_8) has been under way since 1981. Orebody No 1 was exhausted in late 1994 and excavation of Orebody No 3 began in 1997. Mining in Pit 3 at Ranger ceased in 2012 and the pit has been backfilled and engineered provide a long-term repository for tailings and other wastes. In accordance with the Ranger Authority processing of stockpiled ore can continue until January 2021.

The majority of data presented in this section is 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 Water Management Plan, which is updated annually and subject to assessment by the MTC before approval. The plan describes the systems for routine and contingency management of the three water classes on site which are classified based on quality, as shown in Table 2.

TABLE 2 WATER CLASSES AT RANGER MINE

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

As shown in Figure 5, the rainfall in the 2015–16 wet season was a well below average, with a total of 921 mm recorded at Jabiru Airport compared to the average annual rainfall of 1550 mm (since 1971).

Process water

Process water has been in direct contact with uranium ore during processing and it must be retained on site due to its very poor quality. Process water is currently stored in the above ground Tailings Storage Facility (TSF), Pit 3 and parts of the Pit 1 catchment area. As part of the strategy to manage and reduce the process water inventory on site, ERA constructed a brine concentrator in 2013 to treat process water for off-site release. Details of water treatment using the brine concentrator are shown in Table 3.

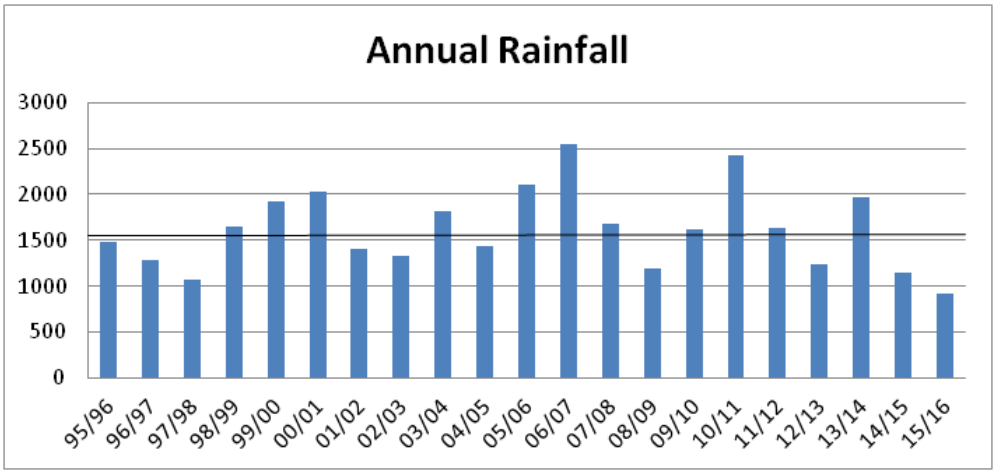

Figure 5 Annual rainfall Jabiru Airport 1995–96 to 2015–16

TABLE 3 ANNUAL PROCESS WATER TREATMENT VOLUMES

Date	Annual operating period (days)	Distillate produced (ML)
2013–14	181	470
2014–15	328	1031
2015–16*	138	523

* Data from September 2015 to February 2016.

Brine concentraor distillate is of a very high quality and it is discharged at various locations around the site, ultimately reporting to Magela Creek during the wet season or being irrigated on Land Application Areas (LAAs) during the dry season. The brine concentrator has a nominal capacity to treat 1830 ML of process water per year and forms an integral part of ERA's rehabilitation strategy.

Pond water

The pond water has been in contact with stockpiled mineralised material and operational areas of the site other than those contained within the process water system. Pond water is stored in Retention Pond 2 (RP2), Retention Pond 3 (RP3), Retention Pond 6 (RP6) and parts of the Pit 1 catchment area. ERA has previously committed that pond water will not be released without prior treatment. Pond water is currently treated via three microfiltration/reverse osmosis water treatment plants (WTP), with WTP1 and WTP2 each having a 7 ML/day capacity and WTP3 an 11 ML/day capacity. Table 4 shows the annual volume of water treated and permeate produced.

TABLE 4 ANNUAL POND WATER TREATMENT VOLUMES

Date	Volume treated (ML)	Permeate produced (ML)
2011–12	7097	4873
2012–13	842	589
2013–14	4782	3311
2014–15	3028	2025
2015–16	N/A*	620

* Awaiting data from ERA.

Treated permeate is discharged at various locations around the site, ultimately reporting to Magela Creek during the wet season or being irrigated on LAAs during the dry season.

Release water

Rainfall runoff from certain locations of the Ranger site discharges passively during the wet season. Major release pathways include the Coonjimba Creek system and the Corridor Creek system (Figure 2). Relatively small volumes of water were released passively during the 2015–16 wet season due to the very low rainfall. Table 5 shows the total volume of water released from the site since 2013.

TABLE 5 ANNUAL WATER RELEASE VOLUMES

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

3.1.1.2 Tailings and waste management

Table 6 summarises the management of tailings over time. The Tailings and Brine Management (TBM) project is now focussed on the final deposition of tailings into the mined out pits. Tailings deposition in Pit 1 has been completed and the pit is now capped and awaiting final backfill. Tailings deposition in Pit 3 commenced in 2015 and it is now receiving tailings from both the processing mill and from the TSF.

TABLE 6 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 from processing to Pit 3 commences	2015
Tailings transfer from TSF to Pit 3 commences	2016

The primary mechanisms for disposal of controlled wastes include disposal in the mine pits, incineration via turbo burning and offsite recycling. Non-hazardous wastes are disposed of either through disposal to landfill or offsite recycling. In 2016 an application to instate a new temporary controlled waste disposal site adjacent to Pit 3 was approved. This new site replaces the waste disposal site in the North West section of Pit 1.

3.1.2 Rehabilition

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

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

These announcements required a significant re-focus for SSB, from the assessment of the expansion proposal to rehabilitation and eventual site closure.

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

In order to progress the development of relevant closure criteria and provide a forum for reaching consensus between stakeholders on closure objectives, the Ranger MTC established a Closure Criteria Working Group (CCWG) in 2008. The CCWG comprises representatives from the Supervising Scientist, the NT Department of Primary Industry and Resources (DPIR), the Northern Land Council and the Gundjeihmi Aboriginal Corporation (representing Traditional Owner interests) and is chaired by ERA. The CCWG has established six Technical Working Groups (TWG) covering the Landform, Radiation, Water and Sediment, Flora and Fauna, Soils, and Cultural themes. Figure 6 provides an overview of how these working groups and the MTC will be utilised to develop closure criteria for ministerial approval.

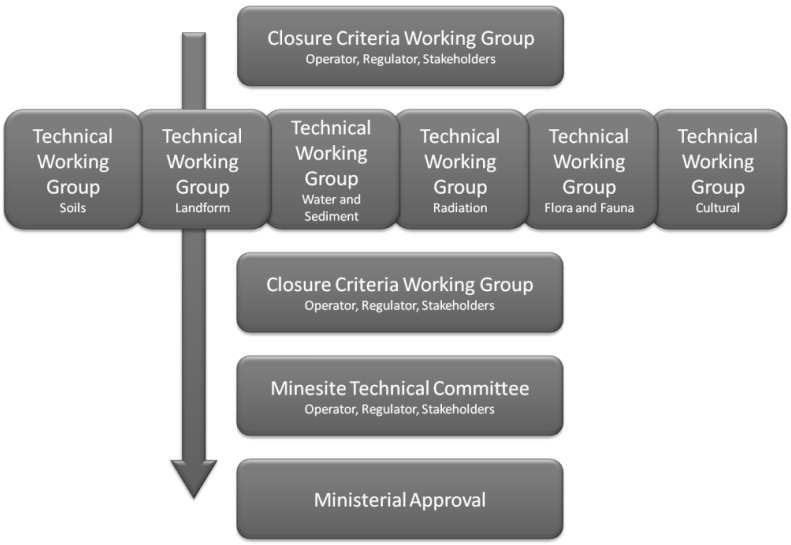

Figure 6 The closure criteria development process for Ranger mine.

The CCWG and the TWGs met frequently throughout 2015–16 and there has been significant progress in the development of closure criteria. In August 2016, SSB commenced the development of rehabilitation standards for Ranger, which draw upon years of research undertaken by the Branch to quantify the rehabilitation objectives set out in the Ranger Environmental Requirements.

The Environmental Requirements for the Ranger uranium mine set out the Commonwealth's environmental protection conditions for the Authority issued under Section 41 of the *Atomic Energy Act 1953*. Section 11.2 of the Environmental Requirements requires that by the end of operations all tailings must be placed in the mined out pits. Major rehabilitation works in relation to this requirement are summarised in Table 7 and described in the sections below.

TABLE 7 REHABILITATION WORKS

Activity	Year
Pit 1	
Preload capping with waste rock	2014
Laterite cover - conversion to pond water catchment	2016
Pit 3	
Waste rock backfill to -100 mRL	2014
Under bed drainage and brine injection infrastructure	2014
Deposition of mill tailings	2015
Deposition of TSF tailings	2016
TSF	
Tailings dredging	2016

3.1.2.1 Pit 1

Mining in Pit 1 ceased in 1995 and tailings transfer to the pit commenced in 1996 and was completed in 2008. During 2014, a 2.5 m thick layer of waste rock was placed over the tailings within Pit 1 to activate 7,499 wicks and accelerate the dewatering of the tailings. The placement of a laterite cap on top of the waste rock was completed in 2016. This enabled conversion of the Pit 1 footprint from the process water catchment to the pond water catchment. Incident rainfall and runoff from surrounding areas that report to the laterite capped section of Pit 1 is managed as pond water, provided the electrical conductivity (EC) remains below a management threshold of 4,000 μS/cm. ERA will continue to manage water in the Pit 1 catchment area until the final placement of wasterock and subsequent revegetation of this area.

On 17 March 2016 ERA submitted an application for a final tailings level in Pit 1. This application was supported by tailings consolidation and solute egress modelling reports. This application and supporting information is currently under review by SSB.

3.1.2.2 Pit 3

A number of projects are underway to transfer tailings into Pit 3, including diversion of mill tailings from the TSF to Pit 3 and transfer of TSF tailings to Pit 3. To increase potential for process water treatment in the future, it is intended that brines produced from the Brine Concentration will be stored in the waste rock under-fill in Pit 3.

Mining in Pit 3 was completed in November 2012 and preparation of Pit 3 to receive tailings was completed on 23 December 2014. This included backfilling the pit with 31.2 million tonnes of waste rock, establishing a network of brine injection bores in the waste rock backfill and constructing a water relief drainage system on top of the waste rock backfill, which will enable removal and treatment of waste water produced during and after tailings consolidation. Brine injection trials are currently underway.

3.1.2.3 Tailings Storage Facility

As indicated above, the tailings currently stored in the above ground TSF will be transferred to the mined out Pit 3 using a custom-built dredge. Assembly of all dredge components, including a support vessel and pontoon was completed in early 2015 and the dredge was successfully launched on the TSF in August 2015. As of 30 June 2016, 1,050,238 m^3 of tailings has been transferred from the TSF to Pit 3.

During 2015–16 a significant amount of work was undertaken to characterise and delineate groundwater contamination around the TSF, including the installation of a number of additional monitoring bores. In November 2014, ERA installed a 300 m long seepage interception trench adjacent to the north-western wall of the TSF. The trench was excavated to competent rock and is of varying depth, down to approximately 4 m. Water collected in the trench is recovered via two wells and pumped to the adjacent Tailings West Wall Sump (TWWS) and from there transferred to the pond water system. Further groundwater investigations are planned, including the development of 3D groundwater models for the region to the south-east of the TSF.

3.1.3 Assessment Activities

3.1.3.1 Assessments and approvals

SSB assessed and provided feedback to the regulatory authorities on the numerous periodic reports produced by ERA according to the requirements in the Authorisation. A number of technical scientific reports were also reviewed.

The Ranger MTC met six times during 2015–16. Significant agenda items discussed at the meetings included updates from ERA on site activities including, management and monitoring strategies for high EC events in Gulungul Creek, TSF tailings dredging, process safety developments, Pit 3 tailings deposition and Pit 1 preload.

3.1.3.2 Audits and inspecitons

The 2015 environmental audit of Ranger mine was conducted from 15 to 19 June 2015 with criteria focusing on the evaluation of critical controls associated with the TSF, bulk diesel, and ammonia storage facilities. The audit identified two Category 2 Non-Conformances and three Conditional findings. As of July 2016, these identified deficiencies had been satisfactorily addressed.

The 2016 environmental audit was conducted from 14 to 17 June 2016. Seventy-five commitments were drawn from environmental commitments and actions contained within the approved Ranger Mining Management Plan and supporting Environmental Management Plans. The audit identified two Category 2 Non-Conformances and fourteen Conditional findings. SSB and other stakeholders will continue to follow up on all identified issues and ensure the close-out of corrective actions.

Routine Periodic Inspections (RPIs) were carried out for each month of the 2015–16 reporting year with the exception of June 2016 when the annual environmental audit was conducted. Table 8 shows the focus areas for the RPIs.

TABLE 8 RANGER ROUTINE PERIODIC INSPECTIONS DURING 2015–16

Month	Primary focus
July 2015	Dredge assembly, ADU slurry incident at calciner, brine concentrator, Pit 3 tailings deposition, southern boundary track
August	Annual TSF statutory inspection
September	Pond water pipe leak NW of RP6, Pit 1 hazardous waste alternative disposal site, CV21 process water spill (21/08/2015), Diesel spill at TWWS (4/9/2015)
October	Presentations by ERA, stakeholder discussion and site inspection related to the Fire Incident of 01 October 2015
November	Pit 3 tailings deposition, pond water discharge line at SED2B, GCT2 cut-off trench installation, TSF and dredge
December	Pit 1, GCT2 cut-off trench installation
January 2016	TSF dredge, GCT2 cut-off trench, Pit 1 earthworks including Pit 1 tip head, Pit 3 status update
February	Proposed hazardous waste disposal site, Pit 3 tailings disposal update, Pit 1 post earthworks inspection, GC2 weir
March	GCT2, processing CCD knife gates, RPA external gate damage
April	TSF 6 monthly inspection
May	Pit 3 wall slip, TLF burn, power station diesel spill, exposed tailings in TSF, WTP brines squeezing trials.

Following discussion at the Ranger MTC on 27 May 2016, all stakeholders agreed that the RPI process should be reviewed to ensure that it remains effective and appropriate. This review was undertaken in July 2016 by SSB in consultation with DPIR and the outcomes are currently being implemented. Ongoing improvement of the RPI process will continue throughout 2016-17.

3.1.3.3 Environmental incidents

A number of environmental incidents were reported to stakeholders throughout 2015-16. These incidents are summarised in the section below. All incidents were investigated by SSB through the RPI process and were deemed to be resolved satisfactorily.

During 2015–16, 16 environmental incidents were reported. Of note, reporting of minor process water spills has increased and reporting of hydrocarbon spills has decreased. The reduction in the number of hydrocarbon spills reported was in part attributed to the realignment of incident reporting requirements with DPIR guidelines. Table 9 summarises the 2015–16 breakdown of environmental incident types and locations with Figure 7a) showing the distribution by location and Figure 7b) showing the distribution by incident type.

TABLE 9 2015–16 ENVIRONMENTAL INCIDENTS AT RANGER MINE

	Uranium product spill (ADU)	Hydrocarbon spill	Process water	Fire	Other	Total
Off RPA	-	-	1	1	-	**2**
Operational Mine site	1	-	-	-	-	**1**
Processing	-	-	9	-	1	**10**
RPA	-	2	-	1	-	**3**
Total	**1**	**2**	**10**	**2**	**1**	**16**

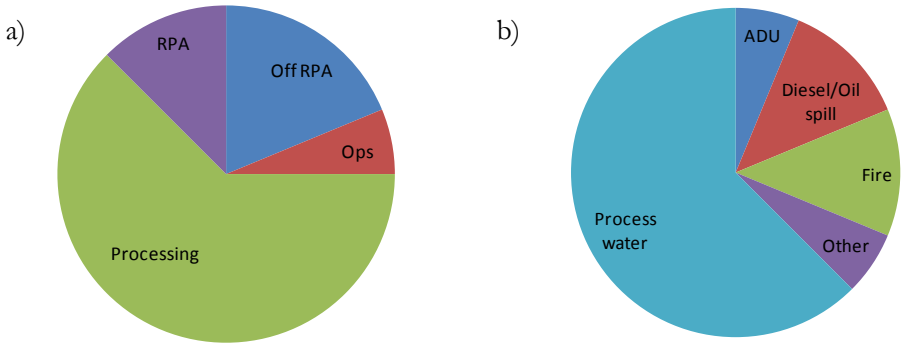

Figure 7 2015 – 2016 Incidents at Ranger mine a) by location and b) by type

An annual comparison of incidents reported each year for the last 5 years is shown in Figure 8, demonstrating a consistent downward trend in the number of environmental incidents reported each year since 2009.

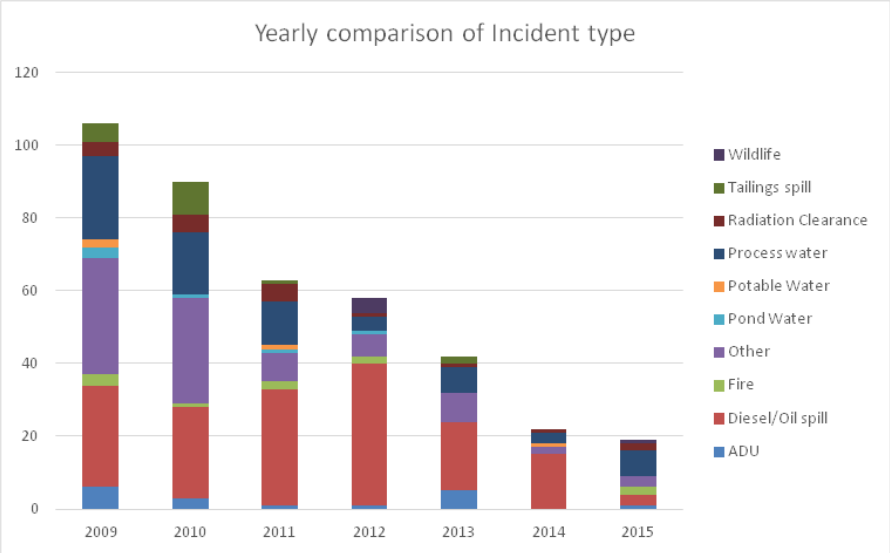

Figure 8 Ranger incidents by year

3.1.3.4 Notable incidents

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

Uncontrolled fire in Kakadu National Park

On 1 October 2015 a fire associated with weed management burning adjacent to RP1 within the Ranger Project Area escaped into Kakadu National Park. The multi-front fire burnt into culturally and environmentally sensitive areas within Kakadu's floodplain and stone country. Following aerial water bombing and ground based back burning all the fires were extinguished by 8 October 2015. SSB estimated the extent of the fire affected area from a Landsat 8 image was 147 km^2.

The Department's Compliance and Enforcement Branch determined that the action of starting the fire that burnt into Kakadu National Park between 1 and 9 October 2015 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.

A separate investigation, conducted jointly with SSB and DPIR, identified deficiencies in ERA's fire management system. The 2016 Ranger Annual Environmental Audit included a formal assessment of the current Ranger fire management practices and an assessment of the implementation status of corrective actions identified by ERA as part of their internal investigation into this incident.

Product Packing Stack emissions

In November 2014 the Supervising Scientist was notified that uranium emissions from the product packing stack at Ranger mine during July 2014 had exceeded the authorised value of 1.5 kg/day of uranium, as detailed in Schedule 4.2.5 of the Ranger Authorisation. Preliminary investigation findings suggested technical issues with the product packing scrubber system were responsible for the exceedance.

In September 2015 ERA presented updated findings in relation to this incident, indicating that there was a data entry error for the reporting period, which incorrectly inflated the stack emission value. Their investigation concluded the limit was not exceeded. SSB and DPIR are satisfied with this conclusion.

Leach Tank incident

In December 2013 Leach Tank No. 1 at the Ranger uranium mine collapsed, spilling approximately 1,400 m^3 of slurry containing ground uranium ore, water and sulphuric acid into the processing area. SSB determined that there were no adverse impacts to human health or the surrounding environment arising from this incident. The findings of the Supervising Scientist's investigation have been published in SSR207.

In February 2016, DPIR finalised their investigation and concluded they would not be proceeding to prosecution. DPIR has retained Noetic Solutions Ltd to monitor the implementation of recommendations related to process safety via a series of quarterly inspections

3.2 Jabiluka

The ERA owned Jabiluka Mineral Lease abuts the northern boundary of the Ranger Project Area. The Jabiluka mine site is situated 20 km north of the Ranger mine site. It is in the catchment of the East Alligator River, adjacent to Ngarradj (Swift Creek), which drains north to the Magela floodplain. 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, an agreement was reached between the parties that resulted in Jabiluka being placed in long-term care and maintenance.

3.2.1 Rehabilitation

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

3.2.1.1 Revegetation

Revegetation of the remaining disturbed parts of the Jabiluka Lease utilises local native plant species in similar density and abundance to that existing in undisturbed, adjacent areas. In late 2013 3,600 tube stock were planted at the site, with approximately 4,000 additional plantings conducted during November and

December 2014. ERA advised that the six-month revegetation survival was 48% for the planting conducted in late 2013.

ERA has an active program of weed management within the Jabiluika lease, which includes application of broad-scale herbicide glyphosate as the primary control mechanism.

Fire will be excluded from revegetated areas for approximately three years to allow framework species to develop sufficiently to withstand a cool burn. The revegetation at the former Djarr Djarr camp site has historically been detrimentally affected by wild fires, which come from the bush areas surrounding Djarr Djarr including the adjacent Kakadu National Park. ERA undertakes annual burning of the area around Djarr Djarr to reduce the chance of wildfires affecting the revegetation.

3.2.1.2 Water management

Water management at Jabiluka was transitioned from an active to a passive system in 2013 with the removal of the IWMP infrastructure, and is currently managed and monitored in accordance with the Authorisation. ERA has installed a number of sediment traps to reduce the transport of fine material in surface run off and resulting turbidity in the creek. ERA monitors continuous water quality upstream and downstream of Jabiluka, and in both the northern and central tributaries of Ngarradj Creek. Given the low environmental risk posed by the Jabiluka site SSB did not undertake water quality monitoring at Jabiluka during the 2015–16 wet season.

3.2.2 Assessment activities

SSB assessed and provided feedback to DPIR on the numerous periodic reports produced by ERA according to the requirements in the Authorisation. The Jabiluka MTC met on six occasions throughout 2015–16. Discussions focussed on the ongoing progress of revegetation.

Two RPIs have been undertaken at Jabiluka with the second being the 2016 pre-wet season inspection, which is scheduled for November 2016.

The 2015 annual Jabiluka environmental audit was conducted from 18 to 19 June 2015, with commitments taken from the 2013–14 Wet Season Report and the Interpretative Report. No non-compliances were identified, however the audit team made a number of observations to assist in ongoing development of these annual plans for Jabiluka.

Following a review of the audit program by SSB in consultation with DPIR and noting that Jabiluka has now entered a long-term revegetation phase of rehabilitation, the annual audit of Jabiluka has been suspended indefinitely. Pre and post-wet season RPIs will continue to be undertaken to assess any emerging issues with the site revegetation progression.

A single incident was recorded at the Jabiluka site, involving an uncontrolled fire originating off lease and impacting on the Djarr Djarr rehabilitation area.

3.3 Nabarlek

The former Nabarlek mine is located approximately 280 km east of Darwin. Queensland Mines Ltd undertook mining at Nabarlek during the dry season of 1979 and milling of the ore continued until 1988. Some 10,857 tonne of uranium concentrate (U_3O_8) was produced. Decommissioning of the mine was completed in 1995 and the performance of the rehabilitation and revegetation program continues to be monitored by SSB. In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd thereby acquiring the Nabarlek lease. Since then UEL has undertaken further exploration on the lease as well as a range of weed control, revegetation and other rehabilitation works.

3.3.1 Rehabilitation

UEL has undertaken significant works to clean up several areas of the site including the old Nabarlek Village and re-contouring the waste rock dump runoff pond. Further revegetation works are planned by UEL, including additional planting and ongoing fire and weed management activities.

3.3.1.1 Water management and monitoring

Statutory monitoring of the site is conducted by DPIR and the operator, UEL. DPIR carries out surface and groundwater monitoring on and off site, including surface water monitoring downstream of the mine in Kadjirrikamarnda and Cooper Creeks, and reports the results of this monitoring in the six-monthly *Northern Territory Supervising Authorities Environmental Surveillance Monitoring in the ARR* reports.

3.3.1.2 The Radiologically Anomalous Area

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

In August 2015, UEL undertook a shallow program of drilling involving 25 x 5 m drill holes within the RAA to better understand the area's radioactivity profile. Analysis of 1 m composites from this program suggests the majority of the elevated radioactivity is located in a discrete near surface section of the RAA. This information will assist in refining the work program required to rehabilitate this area.

3.3.2 Assessment activities

A Mining Management Plan for the 2016 dry season exploration works was submitted to DPIR in June 2016. SSB provided comments on this proposed program on 26 July 2016. The 2015 Nabarlek MTC was held on 10 December 2015 with the 2016 MTC yet to be scheduled.

The 2015 audit of Nabarlek was undertaken on 3 November 2015 with the audit criteria being assessment of compliance to the approved 2015 Nabarlek MMP. Four conditional findings were determined, relating to hazardous substance storage and fire management.

3.4 Other activities in the Alligator Rivers Region

3.4.1 Rehabilitaiton projects

3.4.1.1 South Alligator Valley uranium mines

During the 1950s and 1960s a number of small uranium mines and milling facilities operated in the South Alligator River Valley, in the southern part of Kakadu National Park. The majority of these sites are now the responsibility of the Australian Government Director of National Parks and 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 numerous sites throughout the South Alligator River Valley. Further background on the remediation of historic uranium mining sites in the South Alligator Valley has been provided in the 2008–09 Supervising Scientist Annual Report.

SSB staff carried out the annual inspection of the containment facility on 26 June 2015. Bushfires had been through the area in September 2014 impacting on vegetation regrowth however monitoring equipment was not damaged by these fires. An audit of the facility was conducted by ARPANSA on 10 September 2015.

3.4.1.2 Koongarra

The Koongarra deposit is about 25 km southwest of Ranger, in the South Alligator River catchment. The Koongarra lease was owned by Koongarra Pty Ltd, a subsidiary of AREVA Australia Pty Ltd. In 2011, the Koongarra Project Area was added to the Kakadu World Heritage Area by the World Heritage Committee with the support of the Australian Government. The lease area was incorporated into Kakadu National Park in 2013.

SSB will assist Parks with technical advice on the removal of remnant infrastructure and any remediation of the site which may be required.

3.4.2 Exploration Projects

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

The 2015 audit of Cameco Arnhem Project and Wellington Range – King River Joint Venture Projects was undertaken from 1 to 2 October 2015. The audit identified two conditional findings. The audit also provided a number of observations based upon the audit criteria. All non-conforming issues raised in the 2014 audit have been closed out.

3.4.2.2 Alligator Energy Arnhem Project

The 2015 audit of Alligator Energy Arnhem Project was undertaken from 30 September to 1 October 2015. The audit identified two conditional findings. The audit also provided a number of observations based upon the audit criteria. All non-conforming issues raised in the 2014 audits have been closed out.

3.4.2.3 UEL West Arnhem Joint Venture

The 2015 audit of UEL West Arnhem Joint Venture was undertaken in conjunction with the Nabarlek audit on 3 November 2015. The focus of the audit was compliance with the approved Mining Management Plan. Four conditional findings were determined, relating to hazardous substance storage and fire management.

3.4.2.4 UXA Resources Nabarlek Group Project

As no exploration activity was being undertaken an audit of UXA Nabarlek Group Project was not undertaken in 2015.

4 MONITORING

4.1 Environmental monitoring

In order to ensure protection of the environment and the people of the ARR, ERA is required to achieve specific water quality objectives for both Magela and Gulungul creeks (Figure 2). These objectives are largely based on site-specific biological effects data and as such, their achievement gives confidence that the environment has been protected. The water quality objectives for Magela Creek were reviewed and updated by SSB in 2016, and issued by DPIR on 7 March 2016. Key amendments include:

- Objectives for Gulungul Creek;
- Mandated continuous monitoring and event-based sampling;
- A chronic exposure Limit for Mg;
- A pulse exposure framework for deriving event-specific Mg guideline values;
- A revised Limit for uranium – reduced from 6 to 2.8 μg/L;
- A revised Limit for 226Ra – reduced from 10 mBq/L to 3 mBq/L;
- Revised turbidity trigger values based on continuous monitoring; and
- Removal of statutory requirement to measure pH for regulatory purposes.

Supervising Scientist Internal Report 638 details the review process, providing scientific justification for each of the amendments as well as guidance on their implementation. This report can be found on the Supervising Scientist Branch website.

In addition to ERA's statutory monitoring program, SSB conducts an independent surface water quality monitoring program that uses a multiple lines of evidence approach for undertaking environmental impact assessment. This includes measurement and assessment of key chemical, physical and biological indicators. All monitoring undertaken by SSB during 2015–16 indicated that there was no environmental impact from operations at Ranger mine, and that the Ranger Water Quality Objectives were met in both Magela and Gulungul Creeks.

SSB uses two broad approaches to assessment of the effects of mine water inputs to receiving waters during the wet season: (1) early detection throughout the wet season, and (2) assessment of long-term ecosystem-level responses at the end of the wet season.

Early detection methods include continuous monitoring of chemical and physical indicators as well as in situ toxicity monitoring using freshwater snail reproduction.

For long-term ecosystem-level responses, benthic macroinvertebrate and fish community data from late wet season sampling in Magela and Gulungul Creek sites are compared with historical data and data from control sites in streams unaffected by contemporary mining. The dates for flow commencement and cessation since the 2009–10 wet season are listed in Table 10.

The monitoring results provided below show that the people and the environment of the ARR continue to remain protected from the effects of uranium mining.

4.1.1 Early detection monitoring in Magela Creek

Magela Creek runs to the north west of the Ranger mine site and receives water from RP1, the former Djalkmara Billabong and Georgetown Creek (Figure 2). The electrical conductivity data measured in Magela Creek upstream and downstream of these mine inputs are shown in Figure 9.

There were no significant electrical conductivity events (i.e. no exceedances above the compliance value) in Magela Creek during the 2015–16 wet season. A number of samples were collected as part of the routine quality control program and the concentrations of all key analytes were well within those measured historically. All water quality objectives were met, including that set for ^{226}Ra which was revised from 10 mBq/L to 3 mBq/L. Figure 10 shows the ^{226}Ra measurements for the 2015–16 wet season along with historical results.

TABLE 10 SEASONAL 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 June 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

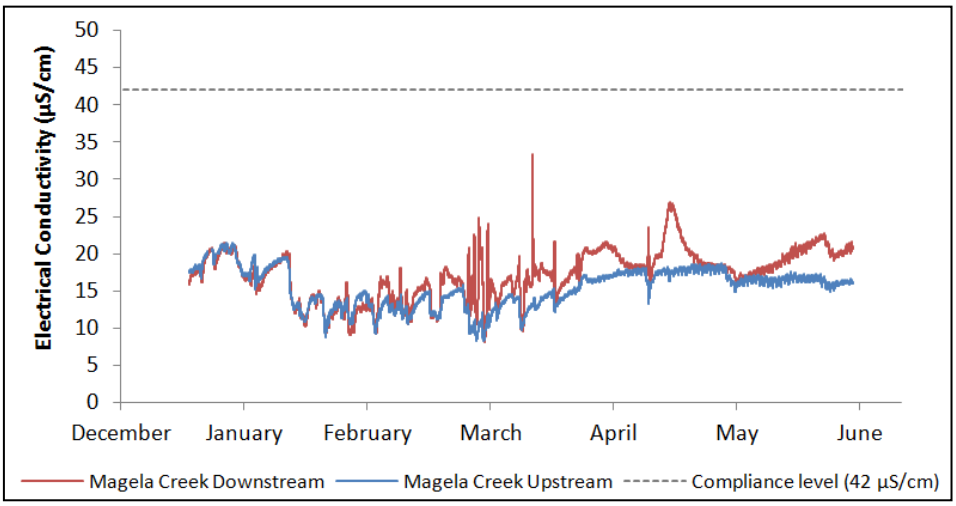

Figure 9 Magela Creek electrical conductivity (EC) data measured during the 2015–16 wet season.

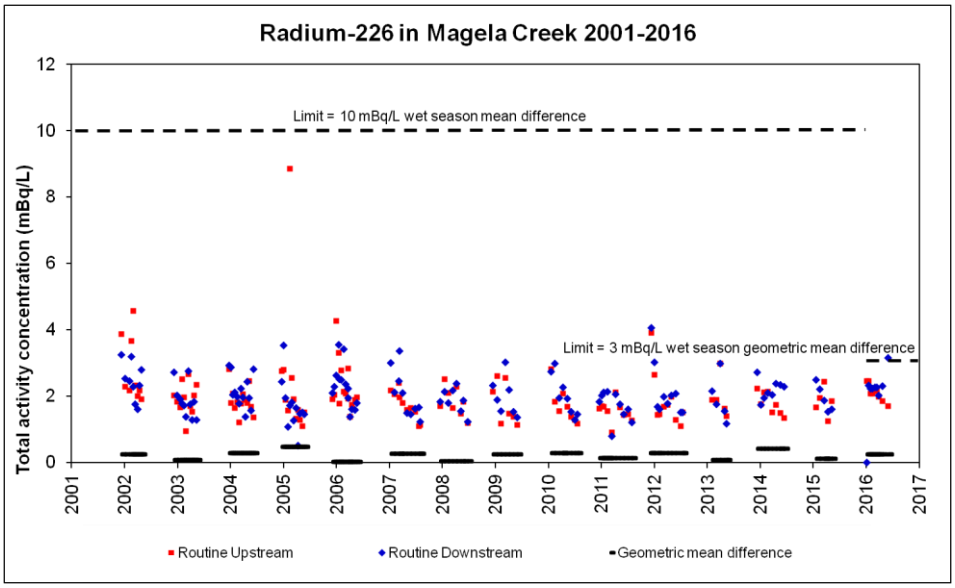

Figure 10 Magela Creek ^{226}Ra data.

Seven in situ toxicity monitoring tests were conducted in Magela Creek, spanning the period 04 January 2016 to 21 March 2016 (Figure 11). Very high concordance in mean upstream and downstream snail egg production and difference values for the tests was observed (mean egg number upstream, 200.3; downstream, 201.6; difference value, -1.3), reflecting similar high concordance in water quality observed between the two sites. Results showed no significant difference between the 2015–16 wet season results and those from all previous wet seasons conducted in Magela Creek.

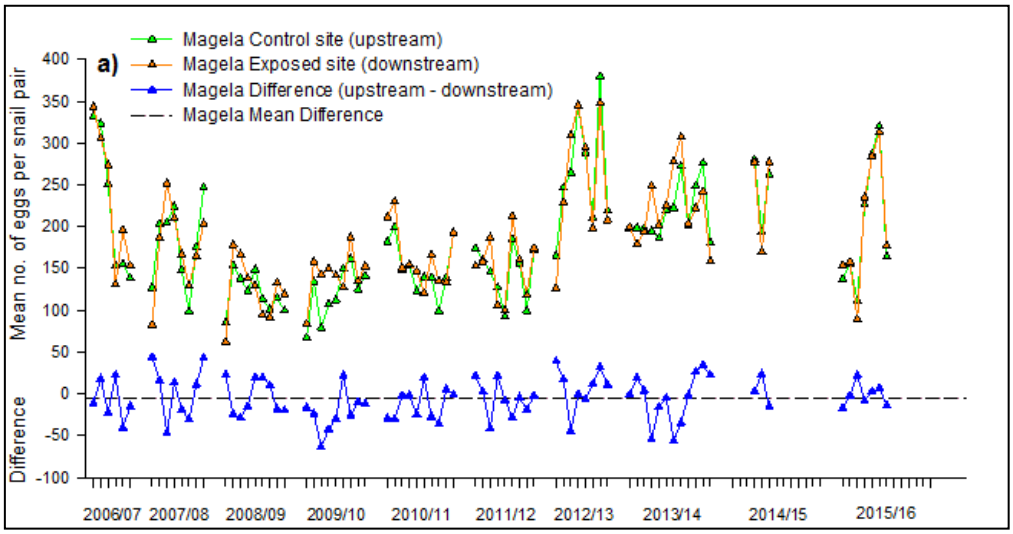

Figure 11 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Magela Creek since 2006.

4.1.2 Early detection monitoring in Gulungul Creek

Gulungul Creek runs along the western boundary of the Ranger project area (Figure 2). ERA does not release any mine water into the Gulungul Creek catchment other than surface runoff. A number of water collection and diversion systems are installed on the mine site in an attempt to limit the volume of poor quality mine derived water that enters Gulungul Creek.

The electrical conductivity data measured in Gulungul Creek upstream and downstream of the mine are shown in Figure 12. There were five notable EC events in Gulungul Creek during the 2015–16 wet season, which are summarised in Table 11.

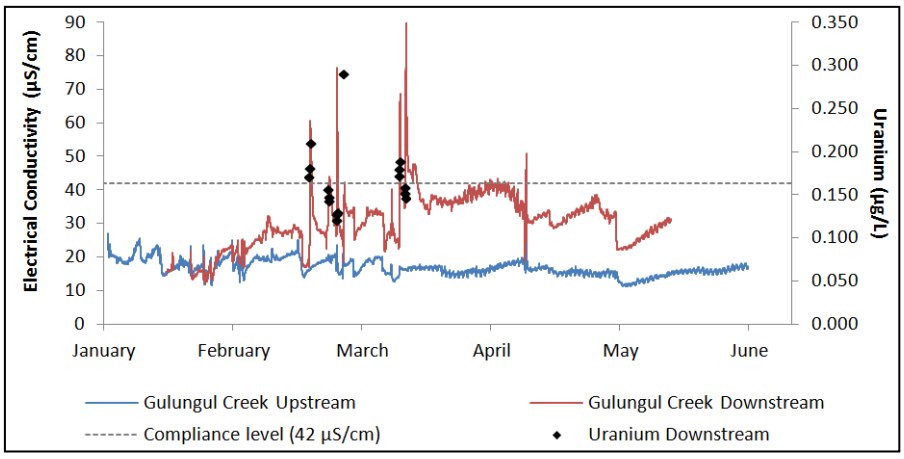

Figure 12 Gulungul Creek electrical conductivity (EC) data measured during the 2015–16 wet season.

TABLE 11 2015–16 GULUNGUL CREEK EC EVENTS

Date	Duration[1] (hour)	Maximum EC (µS/cm)	Maximum concentrations (Limit/Guideline values)				
			Mg (3) mg/L	U (2.8) µg/L	Mn (75) µg/L	SO4 (N/A) mg/L	^{226}Ra (N/A) mBq/L
28 Feb 2016	6	60.7	3.7	0.21	29.9	13.1	14.6
5 March 2016	6	76.4	4.5	0.13	5.9	16.7	
19–20 March 2016	6.5	68.6	4.8	0.19	31.8	15.8	
21–23 March 2016	67.5	95.8	6.9	0.16	23.1	26.8	13.8
18 April[2] 2016[2]	2	50.7	-	-	-	-	-

[1] Above 42 µS/cm at downstream site

[2] Data supplemented from ERA site GCLB

Whilst a number of these events exceeded 42 µS/cm, they did not exceed 72 hours in duration and therefore did not constitute a breach of the water quality objectives.

Since the 2013–14 wet season there has been an increase in the frequency of high EC events in Gulungul Creek. Previous investigations carried out by SSB indicated that the elevated EC in Gulungul Creek was caused by input of high EC water originating from the north-western perimeter of the TSF. Investigations to date, conducted by ERA, have indicated that the contamination is generally confined to the shallow aquifer system which expresses along the reach of Gulungul Creek Tributary 2 (GCT2), which is shown in Figure 2.

To reduce solute delivery to Gulungul Creek, ERA installed a surface/shallow ground water interception system, comprising an interception trench adjacent to the west wall of the TSF and seven dewatering bores installed down gradient along the GCT2 alignment. Approximately 72 ML of water was extracted from the interception system during the 2015–16 wet season. Electrical conductivity of the water varied between approximately 3,000 µS/cm and 7,000 µS/cm.

^{226}Ra readings were below the geometric mean limit at Gulungul Creek for the 2015–16 wet season. Figure 13 displays the historical ^{226}Ra readings. Note that the revised limit of 3 mBq/L was in effect for the 2015–16 wet season.

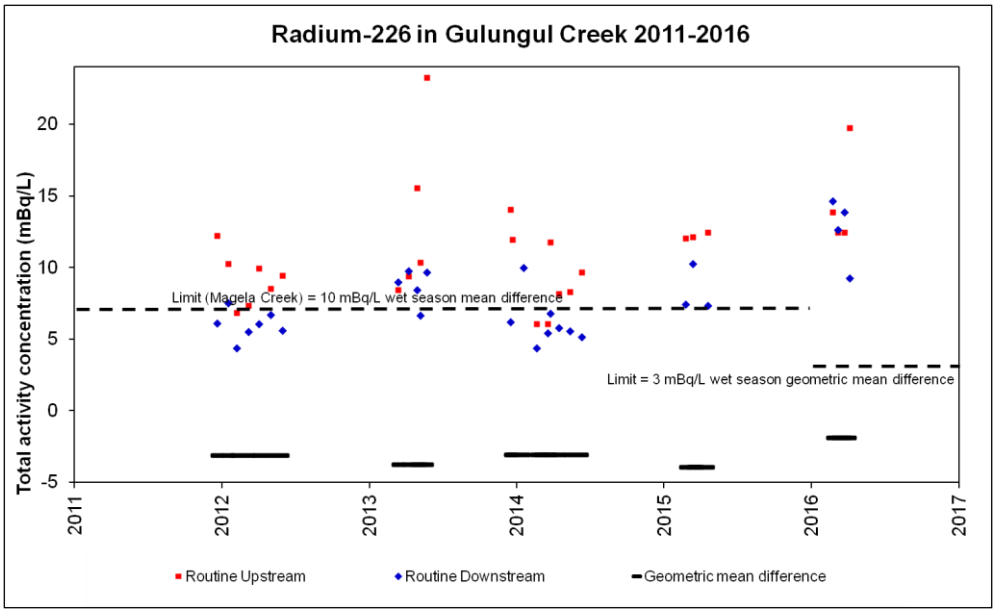

Figure 13 Gulungul Creek ^{226}Ra historical data.

Four toxicity monitoring tests were conducted in Gulungul Creek, spanning the period 4 February 2016 to 28 March 2016 (Figure 14). Results showed no significant difference between the 2015–16 wet season results and those from all previous wet seasons conducted in Gulungul Creek. This includes the reproductive responses of snails exposed to elevated EC downstream of GCT2, at the Gulungul lease boundary site (referred to as midstream in Figure 14). Egg production was generally higher at the downstream site compared to the upstream site, which has been observed in previous years.

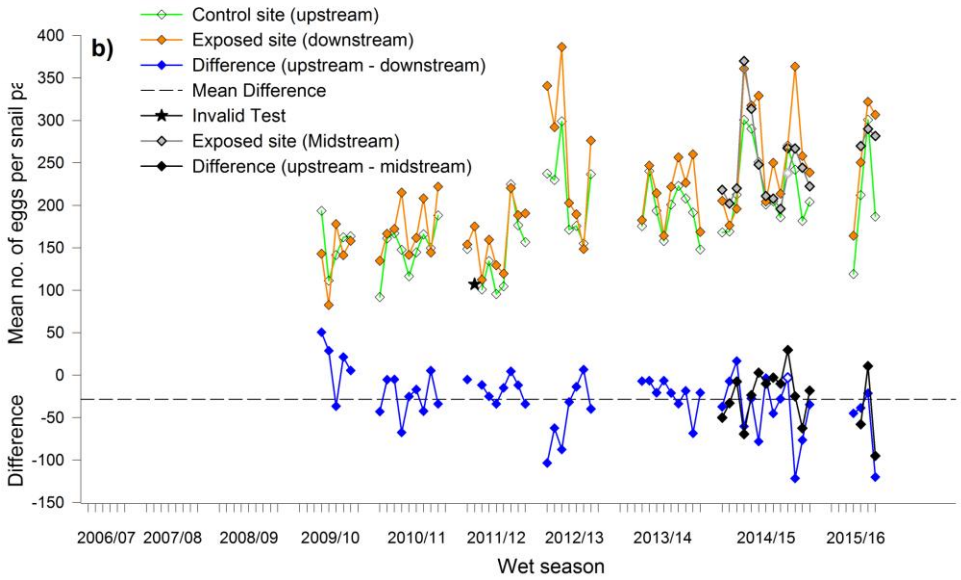

Figure 14 Time series of in situ snail egg production data from toxicity monitoring tests conducted in Gulungul Creek since 2009.

4.1.3 Ecosystem monitoring

4.1.3.1 Macroinvertebrate communities

During the recessional flow period of the 2015–16 wet season macroinvertebrate communities were sampled from upstream and downstream sites on Gulungul and Magela creeks ('exposed' sites) and from Burdulba and Nourlangie creeks (control sites).

Compilation of the full macroinvertebrate dataset from 1988 to 2016 has been completed, with results shown in Figure 15. This figure plots the paired-site dissimilarity values using family-level (log-transformed) data, for the two 'exposed' streams and the two 'control' streams. For the past two seasons, a third Gulungul Creek site has also been sampled (GCT2GCC). This site was also paired with the current year's Gulungul Creek upstream site to derive an additional dissimilarity value (Figure 15). Disturbed sites may be associated with significantly higher dissimilarity values compared to undisturbed sites. Dissimilarity values for 2016 data were comparable to those from previous years, indicating no significant alteration of macroinvertebrate communities at the downstream exposed sites.

The ANOVA completed on the original sites (i.e. without GCT2GCC) showed no significant change from the before (pre 2015–16) to after (2015–16) periods in the magnitude of upstream-downstream dissimilarity across both 'exposed' streams, and this was consistent between both streams (BA and BA*Stream interaction not significant respectively). This result is unsurprising given that the dissimilarity values for both creeks for 2016 plot at similar values to those recorded in most previous years (Figure 15).

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. Data points associated with the 2016 Gulungul and Magela Creek downstream sites are generally interspersed amongst the points representing the control sites (Figure 16), indicating that these 'exposed' sites have macroinvertebrate communities that are similar to the communities occurring at the control sites. This was confirmed by PERMANOVA (PERmutational Multivariate Analysis of Variance) testing on the individual sites (cf paired site

dissimilarity for the above ANOVA) of the exposed streams (Magela and Gulungul sites, excluding GCT2GCC). This showed no significant difference between the downstream data from 2016 with downstream data from previous years, and no significant difference between the upstream data from 2016 with upstream data from previous years.

GCT2GCC site replicates, exposed to higher EC waters than Gulungul and Magela Creek downstream replicates for both 2015 and 2016, are also generally interspersed within control sites. However, the dissimilarity for GCT2GCC vs upstream Gulungul Creek is greater than that for the paired upstream and downstream sites (Figure 15). This distinction deserves further investigation. Despite exposure in Gulungul Creek to mine wastewaters at solute concentration in excess of those experienced in previous seasons, no apparent impairment to macroinvertebrate community was observed at the downstream site over the last two wet seasons. This result was consistent with the results of toxicity monitoring studies reported in section 4.1.2.

These collective results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2016 have not adversely affected macroinvertebrate communities.

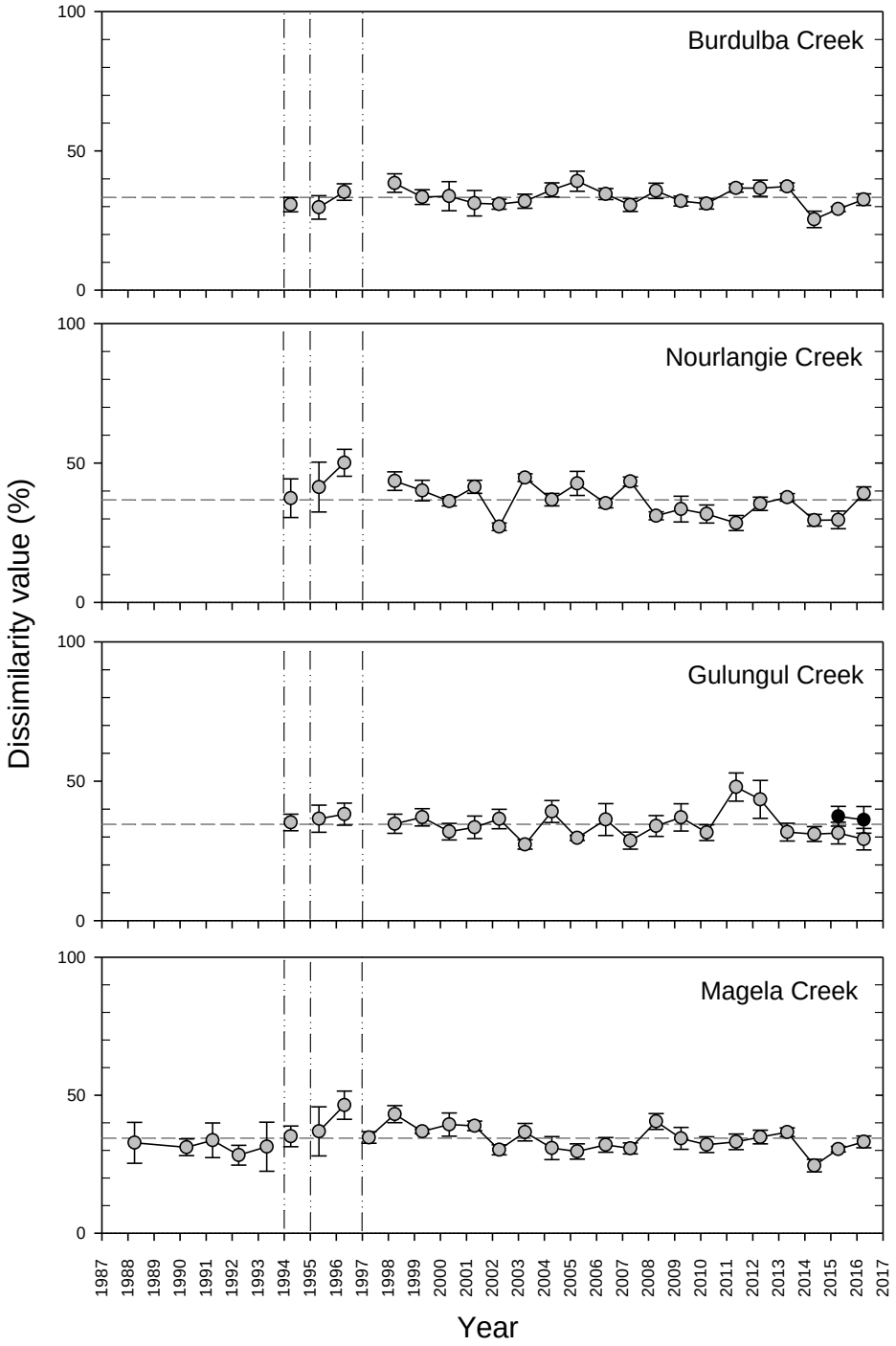

Figure 15 Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger mine for the period 1988 to 2016. The black symbol on the Gulungul Creek dissimilarity graph represents the Upstream-GCT2GCC stream pairwise comparison. The dashed vertical lines delineate periods for which a different sampling and/or sample processing method was used. Dashed horizontal lines indicate mean dissimilarity across years. Dissimilarity values represent means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of upstream-downstream replicate samples within each stream.

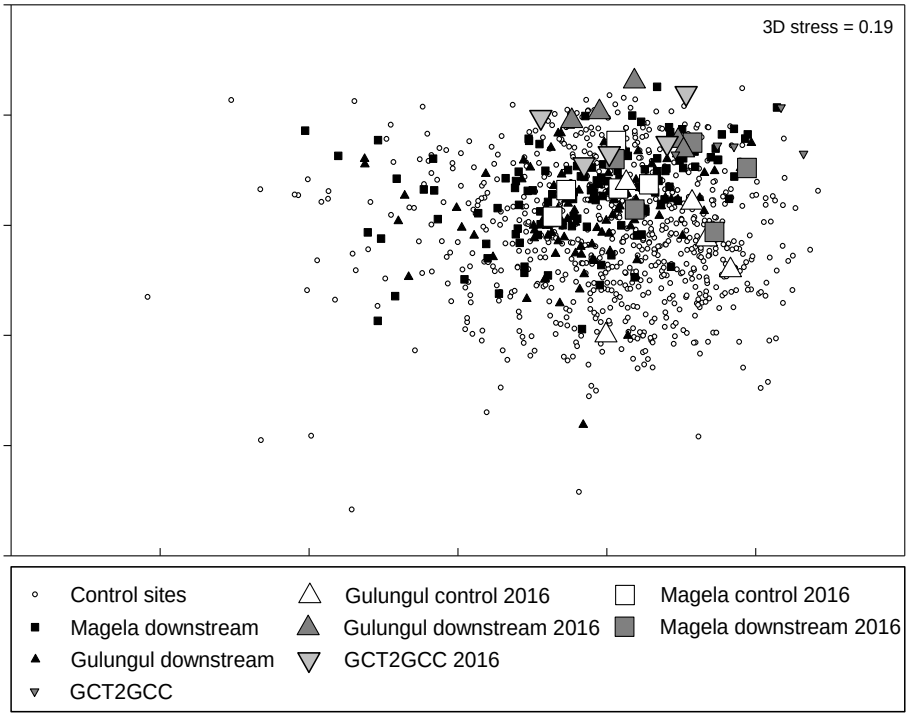

Figure 16 Ordination plot (axis 1 and 2) of macroinvertebrate community structure data from sites sampled in several streams in the vicinity of Ranger mine for the period 1988 to 2016. Data from Magela and Gulungul Creeks for 2016 are indicated by the enlarged symbols.

4.1.3.2 Fish communities

Fish communities in deep channel billabongs are assessed every year, and in shallow lowland billabongs are assessed every two years.

Monitoring of fish communities is conducted in six shallow lowland billabongs, comprising three 'control' versus 'exposed' billabong pairs. Multivariate dissimilarity indices are used to compare fish communities in shallow billabongs downstream of Ranger mine on Magela Creek (Georgetown, Coonjimba and Gulungul billabongs) with communities in control billabongs (Sandy Shallow and Buba billabongs on Nourlangie Creek and Wirnmuyurr Billabong – a Magela floodplain tributary) (see Figure 4). For all billabongs, and billabong pairs, there was no significant change in fish communities in 2016 compared to all previous years.

Paired-site dissimilarity values are displayed in Figure 17 and they show that fish communities in each of the billabongs comprising a site-pair are quite different from one another (between 40 and 60%). The particularly high dissimilarity value observed for the Gulungul versus Wirnmuyurr site-pair for 2016 is likely to be caused by significant plant growth in one of the five plots in Gulungul Billabong. Plant growth is known to physically prevent fish residency.

The results of fish community monitoring to date indicate that changes to water quality downstream of Ranger mine has not adversely affected fish communities in shallow lowland billabongs.

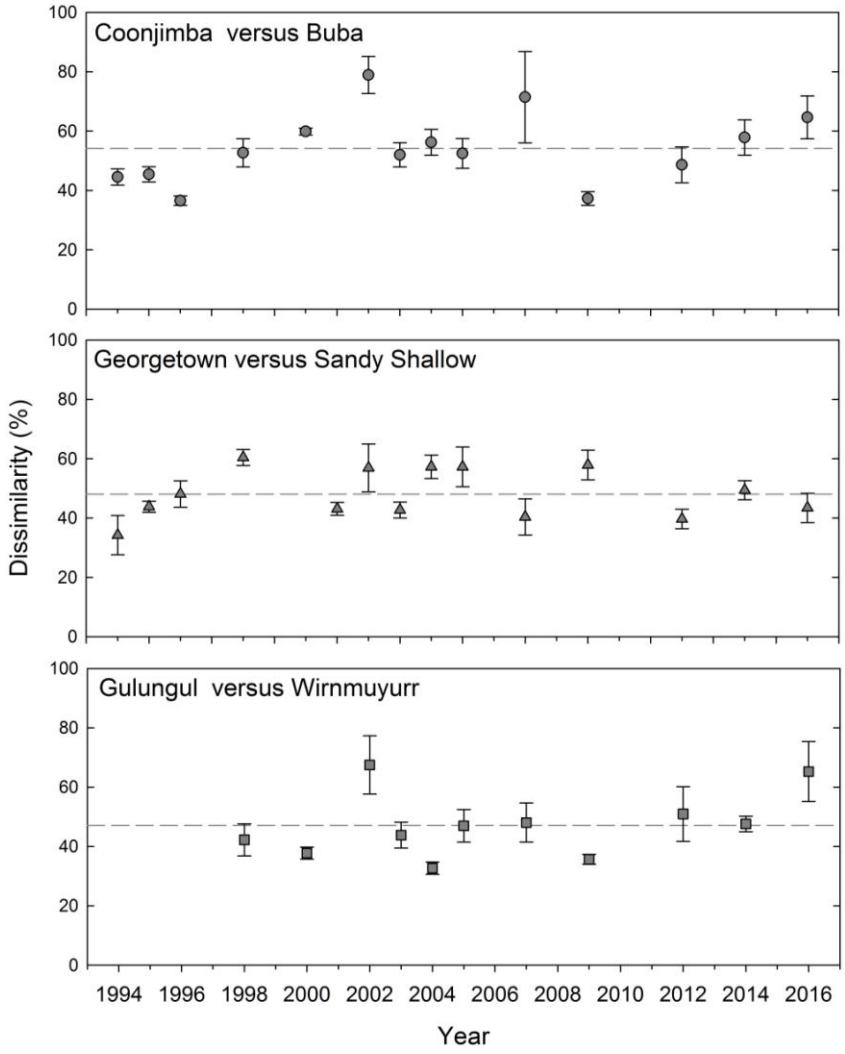

Figure 17 Paired control-exposed site dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in 'exposed' Magela and 'control' Nourlangie and Magela Billabongs in the vicinity of Ranger mine over time. Values are means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of average trap enclosure data between the pairwise billabong comparisons, Coonjimba-Buba, Gulungul-Wirnmuyurr and Georgetown-Sandy shallow billabongs.

4.2 Radiological monitoring

4.2.1 Background

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 the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) are:

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

Designated workers are those who may be expected to receive a significant occupational radiation dose, nominally above 5 mSv per year. These workers are monitored more intensely than the non-designated workers. It is ERA's responsibility to ensure that the level of exposure to ionising radiation received by workers and the general public are as low as reasonably achievable.

Dose constraints for the Ranger operation are revised annually and detailed in the *Annual Radiation and Atmospheric Monitoring Report*. The current dose constraints for Ranger mine are listed in Table 12.

TABLE 12 ANNUAL RADIATION DOSE CONSTRAINTS FOR RANGER MINE (MSV)

Proposed Operational Area/Work Group	Existing Work Group	Annual Dose Constraint (mSv)
Ranger Operations	Processing Production	6.0
	Processing Maintenance	
Non-Designated Workers	Non-Designated Workers	5.0
Workers under the age of 18	Under 18	6.0
Members of the public	Members of the Public	0.3

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

Following a review of 16 years of atmospheric radiation monitoring data SSB identified that the mine-derived radiation dose from airborne radon progeny and radioactive dust from Ranger uranium mine do not currently pose a public health risk (typically contributing less than 5 per cent of the public dose limit). In 2016 changes were made to SSB environmental monitoring program including the cessation of atmospheric radiation monitoring.

ERA undertakes a program of atmospheric radiation monitoring which overlaps with the program previously undertaken by SSB, and SSB will continue to review monitoring data from ERA to ensure that there is no radiological risk to people and the environment from the Ranger uranium mine.

4.2.2 Radiological exposure of the public

The two main pathways of potential radiation exposure to the public during the operational phase of Ranger mine and the care and maintenance phase at Jabiluka mine are inhalation and ingestion. The inhalation pathway results from radionuclides released to the air from the mine site, while the ingestion pathway is caused by the uptake of radionuclides into bush foods from the Magela Creek system downstream of the mine (Figure 2).

4.2.2.1 Inhalation pathway

SSB measured concentrations of radon progeny and dust-bound long-lived alpha activity (LLAA) radionuclides in air at Jabiru town and near the Mudginberri community at Four Gates Road radon station until the end of 2015 (Figure 3). Jabiru town and Mudginberri community are the main areas of permanent habitation in the vicinity of the Ranger mine and Jabiluka.

Figure 18 and Figure 19 show hourly and quarterly average radon progeny potential alpha energy concentration (PAEC) monitoring data from Jabiru town and near Mudginberri community, respectively, for the 2015 calendar year. Coverage was 80 per cent of the year for Jabiru town and 66 percent for Four Gates Road. Gaps in the data for both stations are due to instrument maintenance and data quality issues. In addition, the Four Gates Road station was vandalised in November 2015, preventing further data collection for the year.

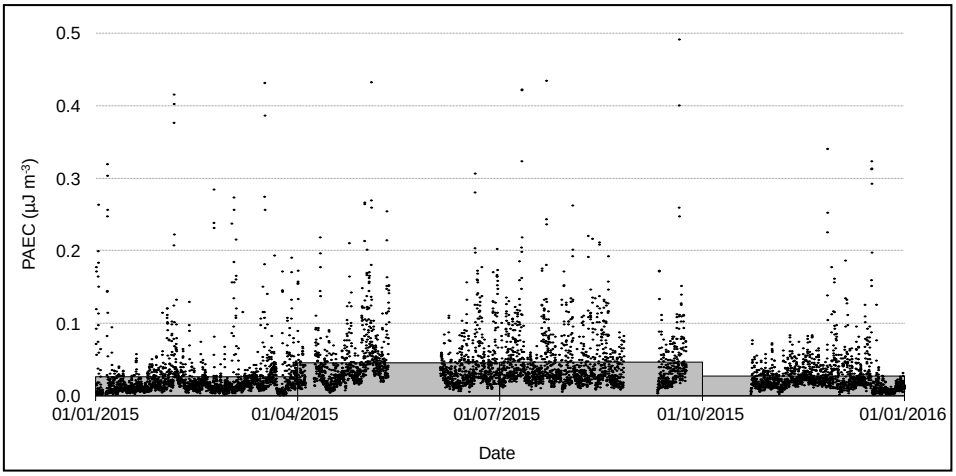

Figure 18 Hourly (black diamonds) and quarterly average (grey columns) radon progeny PAEC in air at Jabiru town in 2015.

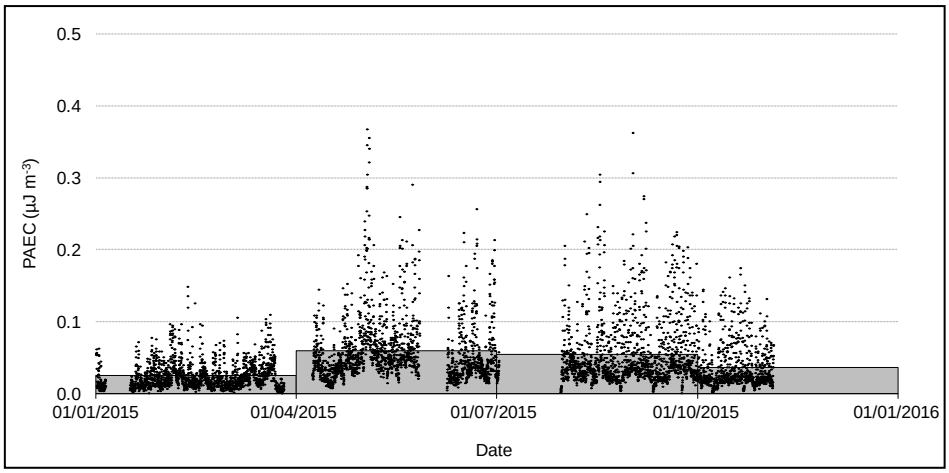

Figure 19 Hourly (black diamonds) and quarterly average (grey columns) radon progeny PAEC in air at Four Gates Road radon station near Mudginberri community in 2015.

The quarterly average PAEC results show the typical wet-dry seasonal trend, with higher concentrations occurring in the second and third quarter of the year (dry season) and lower concentrations occurring in the first and fourth quarter of the year (wet season).

Table 13 provides a summary of annual average radon progeny PAEC in air and estimated doses to the public. The total annual effective dose from radon progeny in air, which is largely due to the contribution from natural background, has been estimated to be 0.339 mSv at Jabiru town and 0.428 mSv at Mudginberri.

TABLE 13 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI DURING 2015

	Jabiru town	Mudginberri
Annual average PAEC [µJ m^{-3}]	0.035	0.044
Total annual dose [mSv]	0.339	0.428
Mine-derived dose* [mSv]	0.038	0.001

* The radon progeny PAEC difference used in SSB mine-derived dose calculation was 0.018 µJ/m^3 for Jabiru town and 0.006 µJ m^{-3} for Mudginberri.

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

The mine-derived annual dose from radon progeny in air has been estimated to be 0.038 mSv at Jabiru town and 0.001 mSv at Mudginberri, much less than the public dose limit of 1 mSv in a year. This dose is dependent on wind direction and has been estimated from the difference in average radon progeny PAEC in air when the wind was from the direction of the mine and when the wind was from directions other than the mine. Hourly wind direction data for 2015 were obtained from the Bureau of Meteorology weather station at Jabiru Airport. Analysis of these data suggests that the wind was from the direction of the mine for 1,970 hours during the year at Jabiru town (90–110 degree sector) and 198 hours during the year at Mudginberri (140–160 degree sector).

Figure 20 and Figure 21 show measured and quarterly average concentrations of dust-bound LLAA radionuclides in air at Jabiru town and near Mudginberri community, respectively, for 2015. Gaps in the data are due to instrument maintenance and data quality issues, as well as vandalism of the Four Gates Road radon station in November 2015.

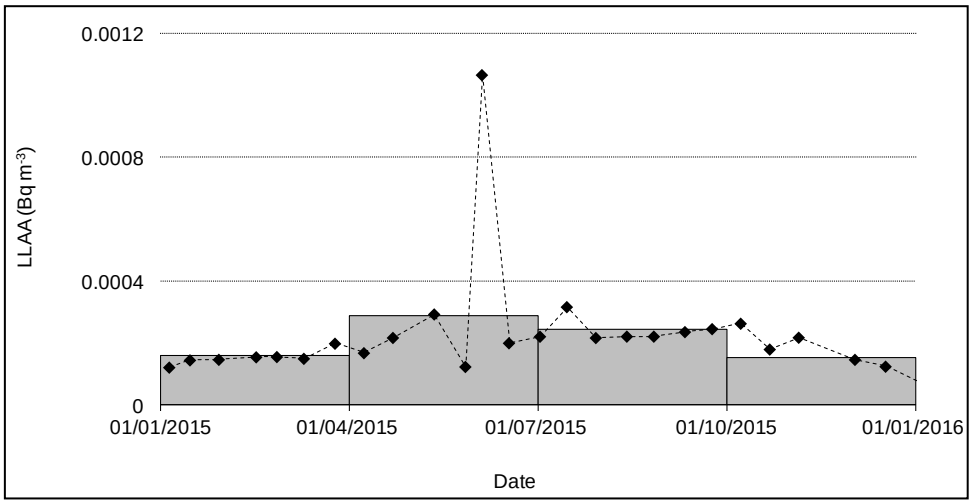

Figure 20 Measured (black diamonds) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Jabiru town in 2015.

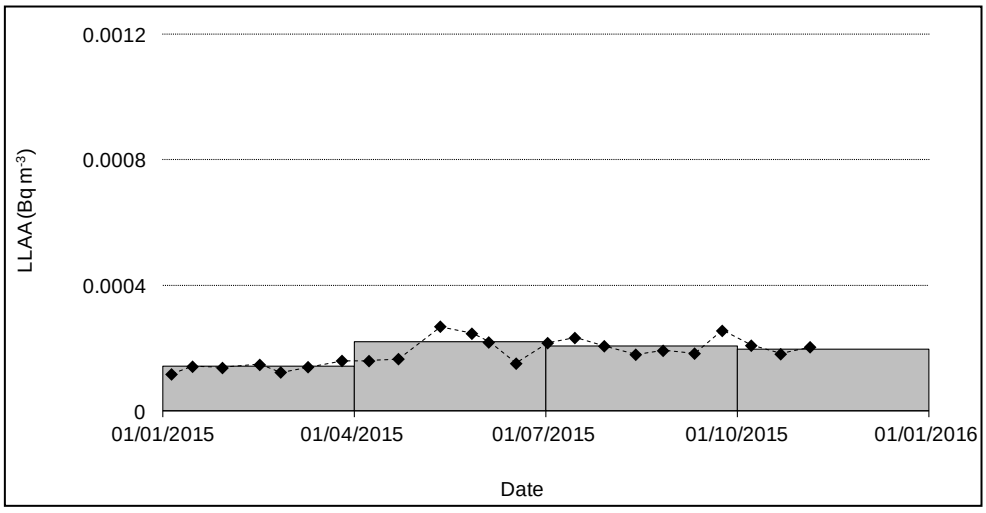

Figure 21 Measured (black diamonds) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Four Gates Road radon station near the Mudginberri community in 2015.

Table 14 provides a summary of annual average LLAA radionuclide concentration and estimated total and mine-related doses to the public. The total annual effective dose from dust-bound LLAA radionuclides, which includes contribution from natural background, has been estimated to be 0.008 mSv at Jabiru town and 0.008 mSv at Mudginberri. This total annual dose has been estimated by calculating the time weighted annual average LLAA concentration from the individual samples and then multiplying

with a dose conversion factor of 0.0061 mSv Bqα^{-1}, breathing rate of 0.75 m^3 h^{-1} and assumed full year occupancy of 8,760 hours.

TABLE 14 LLAA RADIONUCLIDE CONCENTRATIONS IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI IN 2013

	Jabiru town	Mudginberri
Annual average PAEC [µJ m^{-3}]	2.1×10^{-4}	1.9×10^{-4}
Total annual dose [mSv]	0.008	0.008
Mine-related dose* [mSv]	9×10^{-4}	2×10^{-5}

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

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

4.2.2.2 Ingestion pathway

The uptake of ^{226}Ra by freshwater mussels has been previously identified as the most important food source contributing to radiation dose from traditional diet. Mussels are collected annually from Mudginberri Billabong (potentially impacted site) and triennially from Sandy Billabong (un-impacted site) for measurement of ^{226}Ra (Fig 3).

In 2015, mussels were collected in both Mudginberri Billabong and Sandy Billabong. Figure 22 shows ^{226}Ra activity concentrations in mussels collected from Mudginberri and Sandy Billabongs in 2015 and compares them with average activity concentrations measured previously. ^{226}Ra activity concentrations in aged mussels from Sandy Billabong were lower than from Mudginberri Billabong in 2015, as with previous years, and activity concentrations measured in 2015 were no different compared with average values from previous collections.

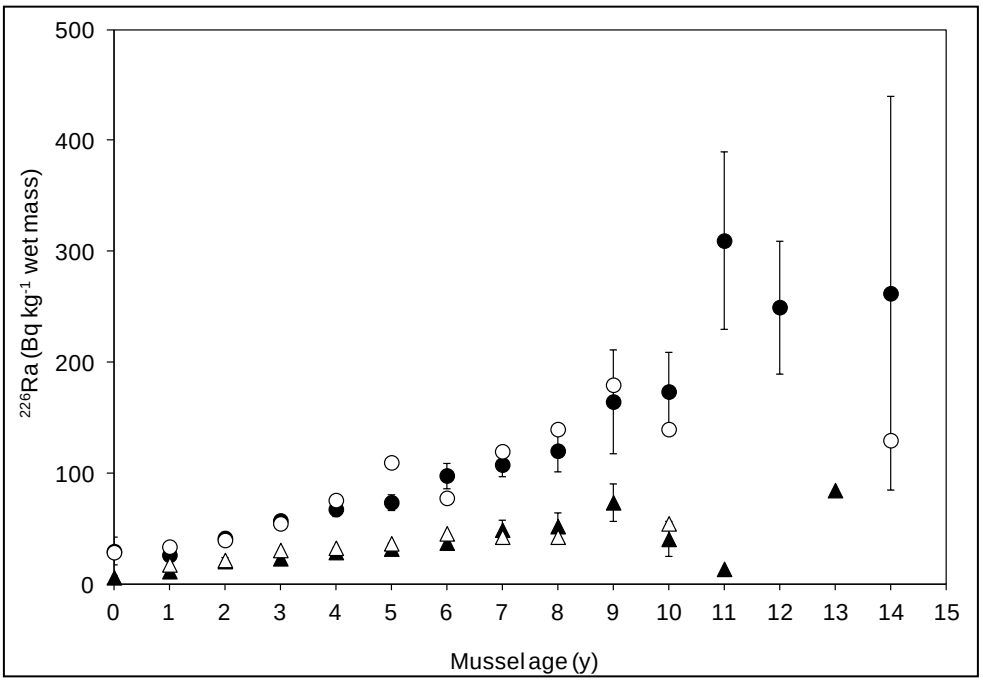

Figure 22 ^{226}Ra activity concentrations measured in mussel flesh (wet mass) from Mudginberri Billabong (circles) and Sandy Billabong (triangles). The average of previous end of dry season collections (2000–2013) is shown as solid symbols, open symbols show the results from the 2015 collections.

Based on the activity concentrations of ^{226}Ra in mussel flesh and the age distribution of mussels collected, the average annual committed effective dose can be calculated for a 10-year-old child who eats 2 kg (wet mass) of mussel flesh from Mudginberri Billabong. The average of all collections from 2000 to 2013 is 0.11 mSv. In 2015, the committed effective dose was also 0.11 mSv.

This dose is almost exclusively from natural background contributions 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 mine is very small; and (2) the findings from previously reported research show that mussel radionuclide activity loads in Mudginberri Billabong are due to natural catchment rather than mining influences.

5 RESEARCH

5.1 Introduction

The Environmental Research Institute of the Supervising Scientist (ERISS) provides specialist technical advice to the Supervising Scientist on the protection of the environment and people of the Alligator Rivers Region (ARR) from the effects of uranium mining. Its major function is to conduct research into developing environmental standards and leading practice methodologies for monitoring and assessing the environmental impact of uranium (U) mining in the ARR. The research spans the operational, decommissioning and post-rehabilitation phases of mining. This chapter summarises the status of the research program of ERISS for the period 2015–16 and the first half of 2016–17. It captures projects proposed, active and completed across this period.

5.2 Planning and the Key Knowledge Needs

SSB undertakes a comprehensive planning and prioritisation process to ensure that its work is appropriately targeted to the highest priority issues (Appendix 2). The process considers the following aspects:

1. Relevance to ensuring environmental protection from both operations and rehabilitation;
2. Timeframe for when the knowledge is needed; and
3. Project duration.

For the ERISS research program, this process is underpinned by the Key Knowledge Needs (KKNs), which are developed through consultation between ARRTC, the Supervising Scientist, ERA and other stakeholders. The KKNs articulate the relevant knowledge and tools required, to ensure:

- the environment and people of the Alligator Rivers Region (ARR) are protected from the impacts of uranium mining; and
- upon reaching end-of-life, uranium mines in the ARR are rehabilitated to the standard required by the Australian Government and community.

The KKNs were revised in 2015–16, following completion of an ecological risk assessment for the decommissioning and post-decommissioning phases at Ranger (see below for further details of the risk assessment). Final amendments to the revised KKNs were being made at the time of completion of the present report. The highest priority areas within the KKNs relate to (i) the continued need to ensure environmental protection during mine operations at Ranger, and (ii) the development of robust closure criteria by ERA, to assess the success of rehabilitation at Ranger. The current research planning process also adheres to two general guiding principles: (i) the size of the overall work program should be commensurate with the available staff and financial resources; and (ii) wherever possible, existing projects should be completed before new projects commence.

SSB has strengthened research prioritisation and planning processes to ensure that available resources are applied to their greatest effect, and that the highest priority work is undertaken. Moreover, not all of the KKN research areas are able to be covered by ERISS, since not all of the required disciplines are available within the Institute. To address these particular gaps, collaborative projects are conducted between ERISS and researchers from other organisations, and consultants are commissioned by ERISS and others to undertake specific pieces of work.

5.3 Status of research program

The ERISS has been focusing almost solely on Ranger rehabilitation-related research for well over 5 years, in accordance with the KKNs. The revision of the KKNs in 2015–16 resulted in a re-alignment of the research program towards four key Ranger closure themes, namely, Water

and sediment, Landform, Radiation and Flora and fauna, and a focus on the various closure criteria that will need to be developed for each of these. Associated with this, in September 2016, the ERISS research program was re-structured from five teams to three teams, Water and Sediment Quality, Radiation and Revegetation and Landform. Importantly, however, there was no reduction in the breadth of disciplines covered by ERISS. Although the responsibility for developing closure criteria for Ranger rests with ERA, much of the science to inform the criteria has been, and is being, undertaken by ERISS. As a result, in August 2016, SSB commenced the development of rehabilitation standards for Ranger, which will provide quantitative measures against which the regulatory authorities can judge the achievement of the rehabilitation objectives provided in the Ranger Environmental Requirements. These standards, being developed in accordance with s5c of the *Environment Protection Alligator Rivers Region Act 1978,* will provide the basis for the advice of the Supervising Scientist to the Minister for Resources and Northern Australia as required under clause 9 of the Environmental Requirements. This significant work effort has involved many ERISS staff.

Research projects proposed, active or completed during 2015–16 and for 2016–17 are listed in Table 16, and described in Appendix 3, where they are listed in order of the mine phase. Rehabilitation-related projects are listed according to the closure themes (i.e. *Water and sediment*, *Radiation*, *Landform*, *Flora and fauna*) and, within these, according to the three key categories, *Developing closure criteria*, *Demonstrating achievement of closure criteria* and *Monitoring of closure criteria*. In numerous cases, projects will be applicable to more than one mine phase or closure criteria category, although they will only appear once, typically wherever they are needed most urgently.

Of the 41 projects on this list, 11 were completed during the reporting period (see Table 15). The remainder are either currently active or expected to commence before the end of 2016–17. The ERISS research program for 2015–16 comprised 34 research projects and was endorsed by ARRTC at its 34th meeting in May 2015. The ERISS research program for 2016–17 comprised 33 research projects, and was endorsed by ARRTC at its 36th meeting in August 2016. All of the 41 projects are relevant to Ranger uranium mine, with some, most notably method development projects, also being relevant to other sites. A breakdown of the research program in relation to the relevance of the 41 projects to the key aspects of Ranger's current operations and rehabilitation is provided in Figure 23. Although not evident from this figure, it is worth re-emphasising that the outcomes of numerous projects are relevant to both current operations and rehabilitation. For example, research on ammonia toxicity to aquatic biota will inform both operational water quality limits as well as closure criteria.

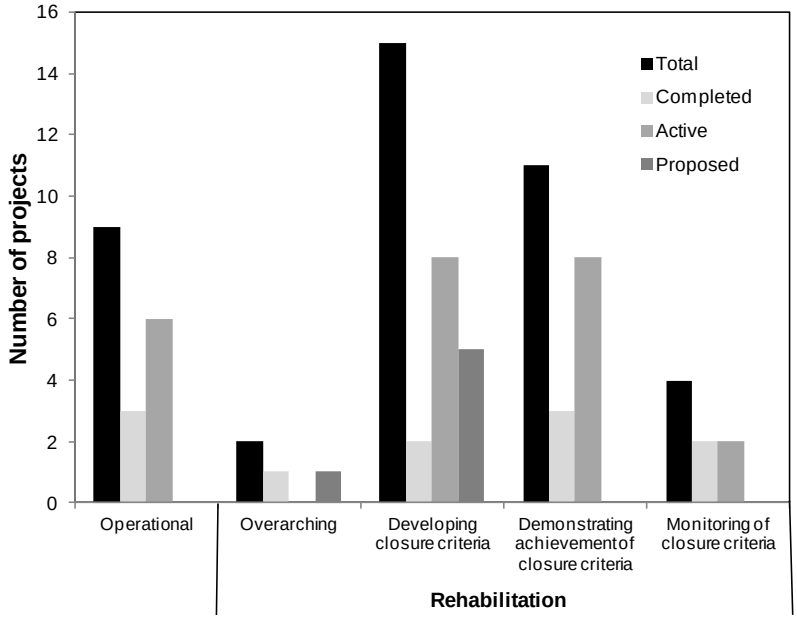

Figure 23 Breakdown of the ERISS research program during 2015–16 and 2016–17 according to the phase of operations and closure themes at Ranger uranium mine.

TABLE 15 SUPERVISING SCIENTIST BRANCH RESEARCH PROJECTS COMPLETED, ACTIVE OR PROPOSED DURING 2015–16 AND FOR 2016–17.

Project	Status
Operational phase	
Refining the toxicity test protocol for *Chlorella* sp	Completed
Refining the toxicity test protocol for the duckweed *Lemna aequinoctialis*	Completed
Development of a model for radium-226 uptake in *Velesunio angasi* (freshwater mussel)	Completed
Developing a short-term chronic toxicity test for the fish, *Mogurnda mogurnda*	Active
Desktop assessment of historical WET data to evaluate multiple single toxicant water quality Limits	Active
Evaluating the appropriateness of the water quality limit for Mg	Active
Toxicity of ammonia to freshwater mussels	Active
Developing videography-based methods for monitoring fish	Active
Genomics-based identification of macroinvertebrates to species level	Active
Rehabilitation	
Overarching	
Critical Groundwater Research Needs for Ranger Mine and the Alligator Rivers Region	Completed
Cumulative risk assessment for Ranger rehabilitation and closure - includes literature review of quantitative risk assessment methods	Proposed
Water and sediment	
Toxicity of ammonia to freshwater biota and derivation of a site-specific water quality guideline value	Completed
Aquatic ecosystem knowledge assessment and evaluation	Completed
Monitoring billabong turbidity using a Remotely Piloted Aircraft System (RPAS)	Completed
Billabong macroinvertebrates responses to mine-derived solutes	Active
The toxicity of U to sediment biota of Gulungul Billabong	Active
Effects of pH on ammonia toxicity to local species	Active
Literature and data review of seasonal utility of Magela channel for connectivity processes	Active
Developing a rehabilitation standard for sulfate (acid sulfate soils)	Active

Project	Status
A review of the risks associated with nutrient inputs from the rehabilitated mine site	Proposed
Re-analysis of magnesium toxicity mesocosm study data	Proposed
Scope and undertake a pilot study to inform design of detailed study for chemical and biological characterisation of Magela sand channel	Proposed
Landform	
Analysis of historical unpublished erosion studies in the ARR	Active
Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to a rehabilitated ranger mine - Gulungul Creek scale	Active
Model geomorphic stability of pre-mine landform for up to 10,000 years	Active
Trial Landform Research	Active
Development of enhanced vegetation component for the CAESAR model	Active
Impact of rip lines on runoff and erosion	Active
Model the geomorphic stability of the landform for up to 10,000 years	Active
Determine natural bedload movements (non-mine impacted) in Magela and Gulungul Creeks.	Active
Establishing updated/new site specific relationships between suspended sediment and turbidity to enable use of turbidity as a surrogate for suspended sediment	Proposed
Radiation	
Radionuclide uptake in traditional Aboriginal foods	Completed
Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine	Completed
Atmospheric dispersion of radon and radon daughters from the rehabilitated landform	Active
Dose rates to non-human biota	Active
Environmental fate and transport of Ac-227 and Pa-231	Active
Flora and fauna	
Evaluation of aquatic vegetation data	Completed
Preliminary mapping of groundwater dependent ecosystems (GDEs) on the Ranger Lease.	Completed
Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria	Active
Vegetation analogue review	Active
Development of a low cost method for continuous monitoring of water stress in eucalypt vegetation on a rehabilitated mine site.	Active

As with previous years, and in order to focus on higher priorities, a number of projects remained suspended due to competing priorities. At the time of publication of this report, 12 projects were suspended (Table 16), including nine projects suspended during the reporting period. As always, assessing priorities and ways of achieving efficiencies are ongoing activities. As part of this, emphasis continues to be placed on working with external consultants and collaborators to achieve research outcomes. Eight (24%) of the 33 research projects in 2016–17 are being or will be done as external contracts, while another eight (24%) involve significant external collaboration with other research organisations. We continue to look for such collaborative opportunities where they align with our strategic research priorities and timelines.

TABLE 16 LIST OF SUSPENDED RESEARCH PROJECTS AS OF NOVEMBER 2016.

Project No.	Project title
RES-2010-007	Assessing the geomorphic stability of the Ranger trial landform
RES-2014-006	East Alligator Slackwater deposits.
RES-2009-003	Turbidity closure criteria for off-site billabongs and streams
RES-2012-014	Optimisation of cladoceran diet for toxicity testing
RES-2008-006	The direct effects of suspended sediment on tropical freshwater biota
To be advised	Potential biological impacts due to acidification of Coonjimba Billabong: Responses of macroinvertebrate communities to acid event in January 2016
RES-2005-003	Use of analogue plant communities as a guide to revegetation and associated monitoring of the post-mine landform at Ranger
RES-2008-002	Development and implementation of a remote sensing framework for environmental monitoring within the Alligator Rivers Region (focus on the Magela Floodplain)
RES-2009-009	Geological province of fine suspended sediment within the Magela Creek catchment
RES-2013-009	Radionuclide fluxes from the trial landform
RES-2013-012	Demonstrating the utility of unmanned aerial vehicles (UAVs) for monitoring rehabilitation and revegetation of the Ranger mine site
RES-2014-009	Spectral investigation of Ranger salts
RES-2015-015	Characterising and mapping salt effloresences using remotely sensed data

With timelines imminent for the development of various closure criteria, it is critical to track overall progress of relevant research projects in the context of these timelines. Appendix 4 presents graphs showing the timelines for all the projects currently identified for the *Water and sediment*, *Landform*, *Radiation* and *Flora and fauna* closure criteria themes in the context of key closure criteria milestone dates.

The project summaries (Appendix 3) have not been formally linked to the relevant KKNs at this stage, because the KKNs were still being finalised following feedback from ARRTC37 in August. Once finalised, the relevant linkages between KKNs and their associated projects will be made.

Key projects to be undertaken during the reporting period include (but are not limited to):

- *Toxicity of ammonia to freshwater species* – Toxicity data for six local species have been used to derive a matrix of water quality guideline values for ammonia based on pH and temperature ranges of local creeks. This work has now been extended in a new project to test the validity of existing quantitative relationships between ammonia toxicity and pH for local species and conditions;
- *Development of an enhanced vegetation component for the CAESAR landform evolution model* – Remote sensing data for local vegetation establishment and dynamics are being used to calibrate vegetation parameters used in the CAESAR-Lisflood landform evolution model, which will be used to assess the evolution and long-term stability of the final rehabilitated landform at Ranger;
- *Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria* – An historical aerial photographic record extending back to 1950 is being analysed to characterise temporal variability and

associated patterns in undisturbed woodlands. The results will inform closure criteria for rehabilitation at Ranger, including understanding potential vegetation trajectories following disturbances;

- *Radionuclide uptake in traditional Aboriginal foods* – Measurements of radionuclide activity concentrations in bush foods over the past 30 years have been brought together in a database that can be used to calculate bush food concentration ratios and facilitate more rigorous radiological dose assessments for the ingestion pathway;
- *Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine* – Intra- and inter-seasonal radon-222 exhalation flux densities from different depths of waste rock were measured in large experimental columns as well as on a trial rehabilitated landform. The data are being used to inform radiological dose assessments for the post-rehabilitated landform; and
- *Developing water quality closure criteria for solutes in billabongs* – Field data have been used to identify magnesium / electrical conductivity thresholds at or below which aquatic communities are not impacted. The results support existing laboratory and mesocosm toxicity data for magnesium, with thresholds typically occurring at concentrations of 3 mg/L. The data from the different lines of evidence are currently being brought together in a formal weight of evidence assessment to finalise a water quality guideline for magnesium.
- *Screening level ecological risk assessment for the decommissioning and post-decommissioning phases at Ranger uranium mine* – The risks of the Ranger rehabilitation to (i) the protection of the off-site ecosystems and (ii) the success of the rehabilitation itself, were assessed based on a multiple stakeholder evaluation approach. Causal conceptual models were constructed and, based on these, approximately 150 stressor-pathway combinations were assessed. The results from the stakeholder workshops were analysed using Bayesian networks to determine critical, high, moderate and low risk stressor-pathway combinations. The critical and high risks were subsequently subjected to further assessment to identify knowledge needs, from which the revised KKNs (see above) were developed. The study was completed with final publication of the results expected in early 2017.

Research for other sites within the Supervising Scientist's remit has been scaled back to focus on the research needs for the rehabilitation of Ranger. The project developing UAS-based monitoring methods for the Ranger rehabilitation is using the Jabiluka rehabilitated area and, to a lesser extent, the El Sherana radiological containment site in the South Alligator River Valley, as study sites. At present, no research is being undertaken at Nabarlek. This is recognised as a critical gap, and a Nabarlek knowledge needs workshop has been proposed for February 2017.

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

Researchers at ERISS continue to publish their work externally. In 2015–16, approximately 25 peer-reviewed journal publications and three peer-reviewed Supervising Scientist Reports were produced from the research program (see Appendix 1). The 2016–17 publications will be reported in the 2016-17 Annual Technical Report.

APPENDIX 1 SUPERVISING SCIENTIST PUBLICATIONS FOR THE PERIOD JULY 2015 TO JUNE 2016

Bollhöfer A & Doering C 2016. Long-term temporal variability of the radon-222 exhalation flux from a landform covered by low uranium grade waste rock. *Journal of Environmental Radioactivity* (published online DOI: 10.1016/j.jenvrad.2015.06.005).

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

Dafforn KA, Johnston EL, Ferguson A, Humphrey C, Monk W, Nichols SJ, Simpson SL, Tulbure MG & Baird DJ 2015. Big data opportunities and challenges for assessing multiple stressors across scales in aquatic ecosystems. *Marine and Freshwater Research* 67, 393–413.

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

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

Erskine W 2016. River Reaches, Historical Channel Changes and Recommended Methods to Improve Macquarie Perch Habitat on Hughes Creek, Victoria, June 2015. Supervising Scientist Report 208, Supervising Scientist, Darwin.

Erskine WD & MJ Saynor 2016. Changes in Distribution and loading of Large Wood in Sand-Bed Channels Flanked by A Monsoonal Vine Forest in Kakadu National Park, Australia, Following Cyclone Monica in 2006 *11th International Symposium on Ecohydraulics*, Melbourne, Australia, The University of Melbourne.

Hancock GR, Coulthard TJ & Lowry JBC 2016. Predicting uncertainty in sediment transport and landscape evolution – the influence of initial surface conditions. *Computers and Geosciences* 90, 117–130.

Hancock GR, Coulthard TJ & Lowry JBC 2015. Predicting uncertainty in sediment transport and landscape evolution – the influence of initial surface conditions. *Computers and Geosciences*. Published online 16 September 2015 doi:10.1016/j.cageo.2015.08.014

Hancock GR & Lowry JBC 2015. Hillslope erosion measurement – a simple approach to a complex process. *Hydrological Processes*. Published online DOI: 10.1002/hyp.10608

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, 121–132.

Hancock GR, Lowry JBC, Dever C & Braggins M 2015. Do introduced fauna influence soil erosion? A field and modelling assessment. *Science of the Total Environment*. Published online Mar 7;518–519C:189–200. doi: 10.1016/j.scitotenv.2015.02.086.

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

Harford AJ, Mooney TJ, Trenfield MA & van Dam RA 2015. Manganese (Mn) toxicity to tropical freshwater species in low hardness water. *Environmental Toxicology and Chemistry* (published online DOI: 10.1002/etc.3135).

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

Medley P & Bollhöfer A 2016. Influence of group II metals on Radium-226 concentration ratios in the native Green Plum (Buchanania obovata) from the Alligator Rivers Region, Northern Territory, Australia. *Journal of Environmental Radioactivity*. 151, 522–529

Pease C, Trenfield M, Cheng K, Harford A, Hogan A, Costello C, Mooney T, & van Dam R, 2016. Refinement of the reference toxicity test protocol for the tropical duckweed *Lemna aequinoctialis*. Internal Report 644, June, Supervising Scientist, Darwin.

Prouse AE, Hogan AC, Harford AJ, van Dam RA & Nugegoda D 2015. Hydra viridissima (Green hydra) rapidly recover from multiple magnesium pulse exposures, *Environmental Toxicology and Chemistry* (published online DOI: 10.1002/etc.2966).

Saynor MJ & WD Erskine 2016. Morphodynamic changes caused by Cyclone Monica April 2006 on Ngarradj Creek, Northern Territory. *11th International Symposium on Ecohydraulics*, Melbourne, Australia, The University of Melbourne.

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* Vol 98(2), 169–181.

Saynor MJ, Erskine WD & Sinclair 2016 Soils and surficial materials of the Ranger Leach Tank Incident Site. Internal Report 634, March 2016 Supervising Scientist, Darwin.

Saynor MJ, Boyden JM & Erskine WD 2016 Ranger Trial Landform: Hydrology –Rainfall & runoff data for Erosion Plot 2: 2009 – 2014. Internal Report 632, April Supervising Scientist, Darwin.

Suradi M, Fourie AB & Saynor MJ 2015. An experimental and numerical study of a landslide triggered by an extreme rainfall event in northern Australia. *Landslides: 1–14*. DOI 10.1007/s10346-015-0606-1

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Pease C, Mooney T, Trenfield M, Costello C & Harford A, 2016. Updated procedure for the 72 hour algal growth inhibition toxicity test using *Chlorella* sp. Internal Report 645, June, Supervising Scientist, Darwin.

APPENDIX 2 SUMMARY OF SSB WORK PLANNING AND PRIORITISATION PROCESS FOR 2016–17

The 2016-17 planning process is described below and depicted in Figure 1.

Three workshops were held:

1. *SSB project identification workshop (February 2016)* – SSB staff identified projects that would be needed to address each of the new KKNs. A coarse prioritisation process was undertaken, using the scheme that was applied at ARRTC35 for the KKN identification workshops. It was recognised that not all project requirements could be identified at the time, while KKNs that were viewed to be primarily the responsibility ERA were typically skipped. Thus, the list is not exhaustive. Discussions still need to be held with ERA to populate the remaining KKNs with projects. In a few instances, follow-up mini-workshops/meetings were held to further discuss and agree project requirements.
2. *SSB closure criteria workshop (April 2016)* – Given impending deadlines for numerous closure criteria, a separate workshop was held with the primary aim of refining the SSB's view on closure criteria and associated information. This included views on proposed criteria, their scientific basis, gaps in knowledge, ability to undertake additional work within existing timeframes, etc. Additional projects that were identified were added to the overall projects list.
3. *SSB project prioritisation and 2016-17 work planning workshop (May 2016)* – Given the large number of projects identified through the first two workshops, there was a need to undertake a more detailed assessment of priorities. From this, and considering timelines and resourcing, a proposed work program for 2016-17 was then determined. A finer resolution prioritisation process was developed as an extension to the process used at the first workshop and for the ARRTC35 KKN workshops (**Attachment A**). The process also captured elements of the project prioritisation that was undertaken when planning the 2015-16 work program (see ARRTC34 report), and included consideration of the following:
   - Relevance to ensuring environmental protection from both operations and rehabilitation;
   - Timeframe for when the knowledge is needed; and
   - Project duration.

The process enabled the identification of the most important projects that could still be completed within the required timeframes, with these projects forming the basis of the 2016-17 workplan. Other projects, with less imminent timeframes, have been sequenced to commence after 2016-17. The process also helped identify projects that could be outsourced, either through collaboration or consultancy.

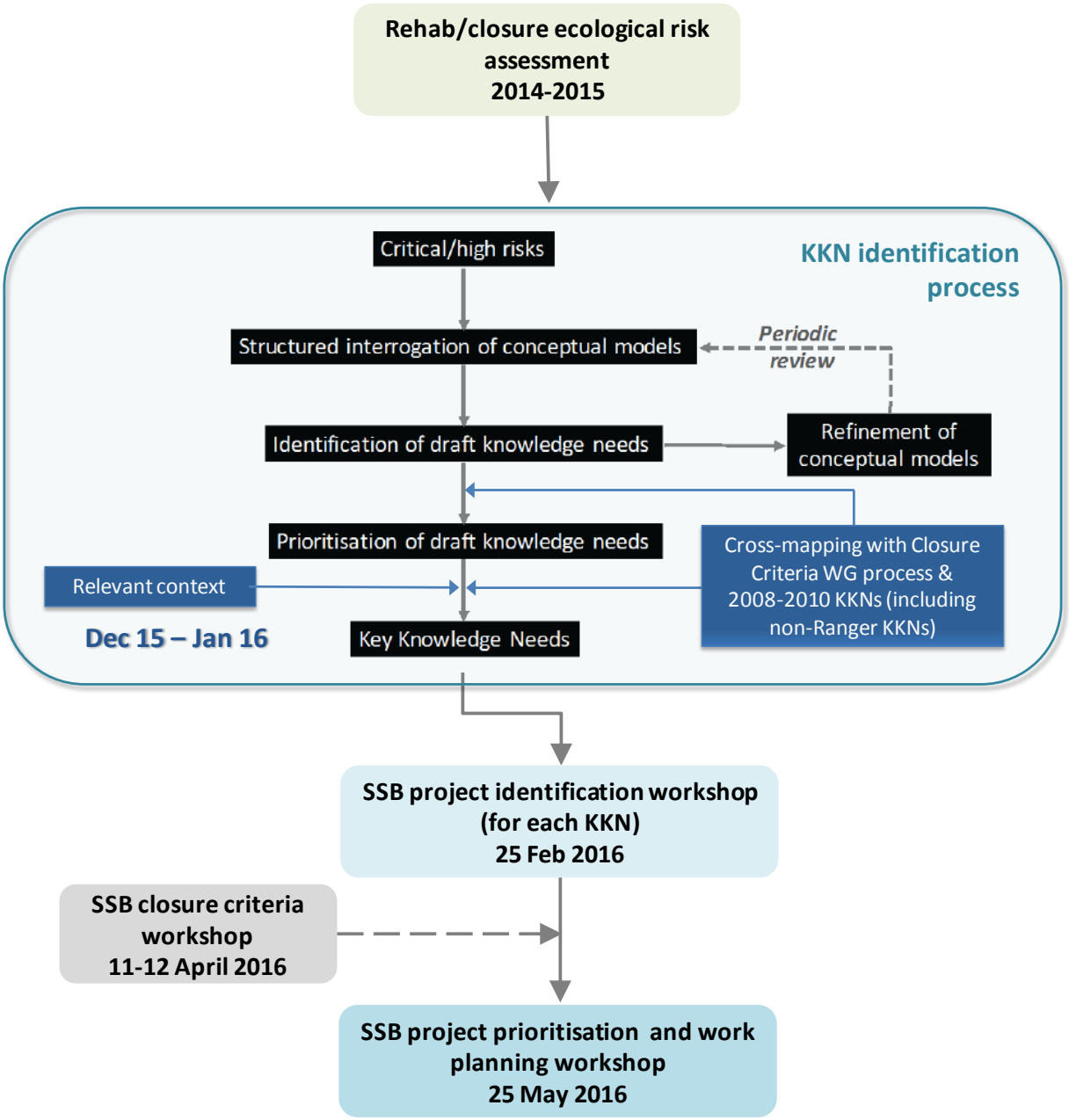


Figure 1 Summary of SSB work planning process for 2016-17, flowing from the Ranger rehabilitation risk assessment and subsequent Key Knowledge Need review.

Attachment A Project prioritisation process

There are three factors to consider for project prioritisation: 1. project relevance; 2. when the results are needed (i.e. timeframe); and 3. the time it will take to complete the project (i.e. project duration). These elements have been combined into a three step process, as follows:

1. *Project importance matrix* - combines project relevance and timeframe (see below). The higher the relevance and the shorter the timeframe, the higher the importance and priority. Timeframe is to be determined mostly by the revised closure criteria schedule (which will be provided);

2. *Time buffer estimate* - subtracts the time required to complete the project from the timeframe (see below). A small time buffer means there is only a small time window to start a project in order to achieve the results in time for when they're required; and

3. *Assessment of project priority* - the combination of project importance and the time buffer determines its relative priority, and should assist with project scheduling / work planning for each Research Program (see example below).

1. Project Importance Matrix

(Relevance v imminence)

Relevance	Score	Timeframe: Needed in <1 year (1)	Needed in 1-3 years (2)	Needed in >3 years (3)
1. Directly related to: (a) closure criteria development or monitoring (b) monitoring and research critical for environmental protection (c) Ranger assessments and inspections (d) Ministerial advice (e) WHS, governance and corporate requirements (f) Statutory committees	1	1	2	3
2. Directly related to: (a) assessing whether closure criteria can be achieved (b) Public assurance and general communications (c) Jabiluka assessments and inspections (d) method development for improving the safety, cost-effectiveness or quality of our work	2	2	2	3
3. (a) Provides information that will **inform** (1) or (2) but is not essential (b) Nabarlek assessments and inspections	3	3	3	4
4. (a) Provides information that is not related to (i) closure criteria and/or (ii) operational standards (b) method development that does not improve the safety, cost-effectiveness or quality of our work (c) Exploration related assessments and inspections (d) External work not related to the SD priorities	4	4	4	4

2. Time buffer estimate

How long until project must start to meet date required.
(when the results are needed minus time required for completion)

A	0-6 months
B	6-12 months
C	12-18 months
D	>18 months

3. Assessment of project priority

Example

Program X

Unordered

	Importance	*Time buffer*
Project a	3	A
Project b	2	B
Project c	1	A
Project d	1	B
Project e	3	D
Project f	4	A

Ordered

	Importance	*Time buffer*	*Priority order*
Project c	1	A	1
Project d	1	B	2
Project b	2	B	3
Project a	3	A	4
Project e	3	D	5
Project f	4	A	6

APPENDIX 3 SUMMARIES OF RESEARCH PROJECTS PROPOSED, ACTIVE OR COMPLETED IN 2015–16 AND 2016–17

Ranger–Operational phase (and decommissioning)

Research (9 projects)

Monitoring (1 project)

Rehabilitation

Overarching (2 projects)

Water and sediment (11 projects)

Landform (9 projects)

Radiation (5 projects)

Flora and fauna (5 projects)

Other sites

Research (0 projects)

Monitoring (0 projects)

Ranger - Operational phase (and decommissioning)

Research projects (9 projects)

Project details					
Project title	Refining the toxicity test protocol for the duckweed *Lemna aequinoctialis*				
SSB function	Research	**Site**	All		
Project category	Operational phase	**Project status**	Completed		
What business need does this project inform?	This project will improve the confidence in the toxicity estimates produced for the duckweed species *Lemna aequinoctialis*				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 1	**Timeframe** 1	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	RES-2012-014	**Project commencement date**		1/7/2011	
		Estimated completion date		1/3/2013	
Project duration (months)	68	**Date required**			
In-house or outsourced	Collaboration	**Actual completion date**		20/9/2016	
Lead team	Ecotox	**Reason for project delay (where applicable)**		Additional test features that required optimisation	
Supporting team(s)	N/A				
Project manager	Pease, Ceiwen	**Project total estimated internal resources (person weeks)**		8	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

To refine the toxicity test protocol for the duckweed species *Lemna aequinoctialis* to incorporate an additional, more accurate endpoint (surface area) and to optimise the nutrient concentrations used in the test.

Background

There was a need to develop a more suitable test medium for *L. aequinoctialis* which would promote healthy growth of the plants but also have a more environmentally relevant nutrient concentration. The nutrient concentrations used previously were excessive and potentially interfering with the assessment of metal toxicity.

There was also a need to use a more accurate and sensitive endpoint than the current endpoint based on frond number.

Progress against plan

- Completion of new method occurred in early 2016.
- An Internal Report was published in June/July 2016.

Key findings

- The most suitable test medium for *L. aequinoctialis* reference toxicity testing was synthetic soft water with the addition of 1 mg L^{-1} of NO^{3-} and 0.1 mg L^{-1} PO_{4-}.
- A successful method was developed using surface area as an endpoint which will now be used as a secondary endpoint (in addition to frond number) for all toxicity tests with *L. aequinoctialis*.

Workplan for 2016–17

This project is completed

Planned project outputs and associated outcomes

Results were communicated in the form of an Internal Report (644).

Planned communication activities

Published as an Internal Report.

Project publications to date (if applicable)

Pease C, Trenfield M, Cheng K, Harford A, Hogan A, Costello C, Mooney T & van Dam R 2016. Refinement of the reference toxicity test protocol for the tropical duckweed *Lemna aequinoctialis*. Internal Report 644, June, Supervising Scientist, Darwin.

Project details			
Project title	Refining the toxicity test protocol for *Chlorella sp*		
SSB function	Research	**Site**	All
Project category	Operational phase	**Project status**	Completed
What business need does this project inform?	The refinement of this method will result in a more sensitive algal toxicity test		
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 1 **Timeframe** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	COR-2003-001	**Project commencement date**	6/10/2014
		Estimated completion date	10/7/2016
Project duration (months)	28	**Date required**	
In-house or outsourced	Internal	**Actual completion date**	10/10/2016
Lead team	Ecotox	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	N/A		
Project manager	Pease, Ceiwen	**Project total estimated internal resources (person weeks)**	5
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**	N/A

Aims

- To refine (minimise) the nutrient concentrations used in the reference toxicity test for *Chlorella sp*.
- To reduce the starting density of algae used in the tests in order to increase sensitivity of the algae to contaminants.

Background

Previous studies have shown that where nutrient concentrations in algal tests can be minimised this will increase the sensitivity of the algae to test contaminants. It was recognised that the nutrient concentrations that have been used in the *Chlorella* sp growth test are not as low as they could be.

A comparison of our algal test protocol with other recent freshwater tests also shows that we were not using as low a starting cell density as we could be.

Progress against plan

- Toxicity tests have been completed trialling different nutrient concentrations and different starting cell densities.
- An Internal Report has been completed to communicate the results of these changes to the algal test protocol.

Key findings

The test protocol has now been adapted to use a quarter of the nutrients that we were previously using in the method and to also use a starting cell density that is an order of magnitude lower. We have already observed that our effect concentrations in our routine uranium tests are lower than they were previously suggesting that we have been successful in increasing the sensitivity of this test species.

Workplan for 2016–17

Planned project outputs and associated outcomes

Internal Report 645 describing new method

Planned communication activities

Published as an Internal report. The results may also be communicated at a conference in 2017.

Project publications to date (if applicable)

Pease C, Mooney T, Trenfield M, Costello C & Harford A 2016. Updated procedure for the 72 hour algal growth inhibition toxicity test using *Chlorella* sp. Internal Report 645, September, Supervising Scientist, Darwin.

Project details					
Project title	Desktop assessment of historical WET data to evaluate multiple single toxicant water quality Limits (including the Mg Limit)				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Informs the water quality limits, especially Mg at different Mg:Ca ratios				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 1	**Timeframe**	2
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2015-018	**Project commencement date**			1/3/2016
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	Ecotox	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	N/A				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**			5
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

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

Background

To date, the Ecotoxicology program has produced site-specific Water Quality Guideline Values (WQGVs) for the key contaminants of potential concern (COPC) from the Ranger mine, i.e. uranium (U), magnesium (Mg) and manganese (Mn). A WQGV for ammonia is in the process of being derived. These COPC have been assessed individually. However, modelling from Pit 1 and 3 shows that contaminated groundwater will reach surrounding creeks and billabongs as a mixture of these contaminants. Hence, a key question remains to be answered. Are the single contaminant WQGVs protective of the environment for mixtures of the COPC?

Guidance from ANZECC and ARMCANZ (2000) recommends that, where 5 or less significant contaminants are present then an additive calculation (i.e. sum of toxic units approach) can be used to predict toxicity, so long as the toxicity is not known to be more than additive or non-additive. In cases where there is uncertainty, Direct Toxicity Assessments are recommended. However, over many decades numerous studies have aimed to predict if contaminant mixtures result in less-than-additive, additive or more than additive effects. Reviews of these studies have concluded that there is no clear pattern that would allow quantitative, or even qualitative, prediction of the effect of contaminant mixtures (Meyer et al

2015). Consequently, this project is needed to provide assurance that the WQGVs will protect the environment.

Progress against plan

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

Key findings

- Summary of chemistry data determined that an average Mg:Ca ratio on site is ~ 5:1, although for process water this is 13-23:1. For Magela and Gulungul Creeks the ratio is 2-3:1
- Only minimal sections of the toxicity data could be reanalysed and used but indicated that in all cases the toxicity observed in the DTAs (RP2, Pit 3 and Djalkmara Billabong) was due to U and not Mg or Mn.

Workplan for 2016–17

Desktop analyses are complete and results will be written up.

Planned project outputs and associated outcomes

The data and analyses will be included in the Internal report on the toxicity of seepage water from the GCT2 tributary.

Planned communication activities

A summary of this data was included in a presentation to ARRTC. It may also be presented at a conference in 2017.

Project publications to date (if applicable)

No publications to date.

Project details					
Project title	Development of a model for radium-226 uptake in *Velesunio angasi* (freshwater mussel)				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Completed		
What business need does this project inform?	(i) Community assurance that mussels downstream of Ranger are not accumulating radiocunclides to unsafe levels; (ii) Reduced WHS risks to staff; (iii) Staff time-saving by no longer needing to collect and analyse mussels; (iv) reduces environmental impact by no longer collecting and killing mussels each year.				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance**	2	**Timeframe** 1/ongoing
			Importance	2	**Time buffer** A
Project number (if already commenced)	RES-2015-013	**Project commencement date**			1/6/2015
		Estimated completion date			1/4/2016
Project duration (months)	6	**Date required**			1/10/2016
In-house or outsourced	Internal	**Actual completion date**			1/10/2016
Lead team	EnRad	**Reason for project delay (where applicable)**			Staff departures and competing priorities
Supporting team(s)	N/A				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**			4
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

- To develop a model to predict the radium-226 concentration in freshwater mussels from the radium-226 and calcium concentrations in water
- To reduce workplace health and safety risks and environmental impacts on aquatic ecosystems by eliminating the need to collect freshwater mussels.

Background

Freshwater mussels have an excellent capacity for bioaccumulating radium-226. This is a consequence of the low calcium concentration waters of Magela Creek and radium having a similar chemistry to calcium. Freshwater mussels uptake radium-226 as an analogue of calcium, thinking it is an essential nutrient for their growth. It has been hypothesised that the ratio between radium-226 and calcium in water influences the radium-226 uptake in mussels and that this uptake can be predicted if the radium-226 and calcium concentrations in water are known.

Progress against plan

Early delays were overcome, and the model was finalised and manuscript subsequently written and submitted for publication.

Key findings

A ^{226}Ra bioaccumulation-water hardness model was developed that can potentially streamline bioaccumulation monitoring downstream of Ranger uranium mine.

Workplan for 2016–17

Model finalised and work written up as scientific paper for journal.

Planned project outputs and associated outcomes

The primary output for the project is:

- A model to predict radium-226 concentrations in freshwater mussels from radium-226 and calcium concentrations in water.

The outcomes that this project will achieve are ongoing public reassurance that freshwater mussels remain 'safe' to eat and at the same time reduce workplace health and safety risks to staff and our own impacts on aquatic ecosystems within Kakadu National Park.

Planned communication activities

The primary communication activities for the project are:

- Reporting and presentations to key stakeholders as necessary.
- Reporting in Supervising Scientist Annual Technical Report and publication in scientific journal.

Project publications to date (if applicable)

Doering C & Bollhöfer A. Submitted for publication. Water hardness determines ^{226}Ra uptake in the tropical freshwater mussel (*Velesunio angasi*). Journal of Environmental Radioactivity.

Project details					
Project title	Developing videography-based methods for monitoring fish				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Development of a replacement monitoring method for SSB's fish channel billabong study, based on improved WH&S				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 1	**Timeframe**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2013-016	**Project commencement date**			1/3/2015
		Estimated completion date			1/3/2018
Project duration (months)	36	**Date required**			1/3/2018
In-house or outsourced	Collaboration	**Actual completion date**			N/A
Lead team	AEP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	CDU				
Project manager	Ellis, MarkB.	**Project total estimated internal resources (person weeks)**			4
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

This project aims to:

- Identify and develop a quantitative, accountable and easily repeatable fish monitoring method using remote cameras which could replace the current visual census method used in channel billabongs (MON-1989-001) which has significant (crocodile) safety concerns.
- Develop and apply the methods to explore comparative visual vs video use in various wetland habitats of Kakadu National Park.

Background

To meet requirements of KKN 1.3.1, an annual visual fish monitoring technique has been conducted in two channel billabongs by SSB since 1989 (MON-1989-001). This method employed a small custom-made boat with a clear Perspex dome, in which an observer lies to identify and count fish. While this method has produced a valuable long-term dataset of fish community structure along the littoral margins of the channel billabongs, the risk of crocodile attack associated with this technique has increased in recent years. Since a larger (unwieldy) replacement boat is not a suitable option for the habitats sampled, underwater videography has been identified as a potential alternative technology.

Initial research and development was conducted in channel and shallow lowland billabongs of the ARR in 2015 to assess different cameras and relative locations of the cameras (near-surface, benthic, littoral and central channel). These findings have guided decisions for work being conducted in 2016.

Progress against plan

- Draft report of initial study with recommendations provided to SSB by CDU (May 2016)

- Fieldwork planned for May 2016 was cancelled due to equipment failure and other monitoring priorities.
- Fish videography fieldwork to replace the previous visual census method was undertaken on the 4-8 July 2016. The design imitated that of the previous method, utilising five existing 50 meter transects at both Mudginberri (exposed) and Sandy (control) Billabongs, deploying 10 GoPro cameras at five meter intervals for each transect. The cameras were randomly orientated for surface or benthic deployment (five of each) and set to record for 1 hour and 30 minutes each. A subsample of six randomly picked videos for each transect (three benthic, three surface) is currently being analysed by Charles Darwin University with further training on counting methodology to be provided to eriss staff.

Key findings

The key aims of the 2015 pilot study were to conduct comparative assessments of:

- several brands of underwater camera,
- moving versus stationary deployment,
- benthic versus surface orientation, and
- suitability of baited vs. unbaited cameras.

This was assessed for both fish community survey billabong types, deep channel and shallow lowland.

Results of the pilot study provided in the draft report recommended the GoPro Hero4 camera.

The draft report also recommended the most suitable method for both billabong types was of stationary, unbaited cameras, in either surface or benthic orientation.

A further eight specific recommendations for ERISS for direction of future research was provided in the draft report.

These findings along with further discussions with CDU helped inform ERISS on a suitable methodology for replicating the fish communities in channel billabongs monitoring project MON-1989-001 for the 2015-2016 wetseason.

Workplan for 2016–17

- Undertake fieldwork utilising new techniques in July 2016.
- CDU to undertake computer analysis of the fish videography imagery acquired in the July 2016 field work (July-December 2016).
- Provision of final analysed imagery data from CDU (December 2016).
- CDU to provide SSB with a report outlining the previous 12 months data, including summary results and information on fish videography relevant to SSB's channel billabong fish surveys (June 2017).

Planned project outputs and associated outcomes

The primary output for this project is a report outlining the previous 12 months work, including summary results and information on fish videography relevant to SSB's channel billabong fish surveys (June 2017).

The project outcome is the establishment of a complementary and replacement monitoring method to that of previous observations to enable continued public assurance of environmental protection.

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 to ARRTC and ARRAC meetings.

Project publications to date (if applicable)

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

Project details					
Project title	Toxicity of ammonia to freshwater mussels				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Informs the ammonia surface water quality Limit for operations as well as the rehabilitation standard.				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 1	**Timeframe**	2
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2015-025	**Project commencement date**			1/9/2015
		Estimated completion date			1/7/2017
Project duration (months)	12	**Date required**			1/7/2016
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	Ecotox	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	AEP, RMIT University				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**			26
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**			1

Aims

The aims of this project are to:

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

Background

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

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

Progress against plan

- A preliminary literature review has been completed.
- *Velesunio angasi* have been collected and cultured in the aquaria facility in Darwin.
- A genetic study on diversity of *V. angasi* has been conducted.
- An acute test method has been developed, and a chronic test method is in development.
- Toxicity testing has been carried out on *V. angasi* larvae with ammonia using the acute test method.
- Journal paper describing the acute toxicity test method is nearly complete.

Key findings

- The genetic study has revealed species differences between mussels collected from 10 different sites.
- Acute toxicity estimates indicate that tropical *Velesunio sp.* were highly sensitive to ammonia.
- The 24-h exposures to ammonium sulfate at pH 6.1 and 27.5°Cgenerated an LC50 of 9.2 mg TAN/L, and an LC10 of 3.4 mg TAN/L.
- When normalised to pH 7 and 20°C, the LC50 is estimated as 11.7 mg/L, which is the second lowest toxicity estimate for all mussel species, and the lowest amongst all tropical freshwater species from other taxa.
- Transformation of mussel glochidia into juveniles was successful using *M. mogurnda* as a host fish.
- Juvenile mussel growth is improved with the addition of sediment and algae.

Workplan for 2016–17

- 2016: Collection of wild *Velesunio angasi* and culturing mussels in the aquaria facility in Darwin involving development of culturing methods, followed by development of acute and chronic testing methods.
- 2017: Continued toxicity testing and publication writing

Planned project outputs and associated outcomes

The primary outputs for the project are:

- An acute and chronic toxicity test using larvae and juveniles of the freshwater mussel *Velesunio angasi* specifically for testing the toxicity of ammonia.
- Use these tests to also assess the toxicity of other mine-related contaminants such as U, Mn and Mg.
- This will be documented in the form of an internal report as well as at least one peer reviewed journal article.

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

No publications to date.

Project details					
Project title	Evaluating the appropriateness of the water quality limit for Mg				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Informs operational water quality limits and closure criteria, especially Mg at different Mg:Ca ratios				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe** 2	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	RES-2015-018	**Project commencement date**		1/8/2016	
		Estimated completion date		1/12/2017	
Project duration (months)	12	**Date required**			
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	Ecotox	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	N/A				
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**		11	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

The aims of this project are to:

- Prepare a rehabilitation standard paper discussing the validity of the current site-specific Mg water quality limit.
- If necessary, conduct laboratory toxicity testing to further characterise the toxicity of Mg at a range of Mg:Ca ratios or at a range of different mixture scenarios.

Background

The current water quality limit for magnesium (3 mg/L) has been derived for soft, fresh waters with Mg:Ca ratios less than 9:1 (van Dam et al 2010). This limit (which was derived based on assessments using six local species), was the recommended concentration of Mg that should not be exceeded in order to protect 99% of the aquatic species in this ecosystem (the Magela Creek catchment). However, during the wet season of 2014–15, a Direct Toxicity Assessment of water from Gulungul Creek Tributary 2 (GCT2), which was high in EC (~2435 µs/cm) and magnesium (350 mg/L), with a Mg:Ca ratio of 5:1 (Ca = 69 mg/L), indicated minimal to no toxicity to the three freshwater tropical species tested. The order of sensitivity for these species was *H. viridissima* > *A. cumingi* > *L. aequinoctialis*, with no toxic response to 100% GCT2 water detected for *L. aequinoctialis*. The sensitivity of *H. viridissima* to GCT2 water (at a 5:1 Mg:Ca ratio) was greater than expected based on its response to Mg observed by van Dam et al (2010) at a 9:1 Mg:Ca ratio.

The minimal toxicity observed observed for *A. cumingi* and *L. aequinoctialis* may have been due to the elevated level of calcium, also present in the water from GCT2, which has been shown to ameliorate magnesium sulfate toxicity (van Dam et al 2010). However based on the responses shown by van Dam et

al (2010), even at that level of Ca, the toxic responses were less than anticipated, suggesting other potential causes of amelioration of Mg toxicity.

It should be noted, however, that only three species were successfully tested, and for one sample only. Ideally, all six species of the ecotoxicology suite at eriss, would have been tested several times.

Investigating the relationship between Mg and Ca in different waters, both across the site and off-site, will help inform decisions about whether additional Mg toxicity studies, more tailored to site conditions, will need to be undertaken in order to improve the existing Mg limit. This work will also directly inform the development of the Mg closure criterion for rehabilitation.

Progress against plan

The rehabilitation standard paper is completed and currently under review.

Key findings

- The rehabilitation standard for Mg remains at 3 mg/L where the Mg:Ca ratio is <9:1;
- The evidence indicates that the standard shjould not be relaxed at lower Mg:Ca ratios; and
- There remains the potential for higher Mg toxicity where the Mg:Ca ratio is >9:1.

Workplan for 2016–17

The outcome of the assessment will determine whether additional toxicity testing needs to be done in relation to Mg.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A 'rehabilitation standard' paper discussing the validity of the current site-specific Mg water quality limit
- A journal paper presenting a formal weight of evidence approach to deermining the rehabilitation standard for Mg.

The outcome that this project will achieve isgreater confidence in the site-specific water quality operational limit and closure criterion for Mg in surface waters.

Planned communication activities

The primary communication activities for the above-mentioned publications and reports/presentations to key stakeholders as required.

Project publications to date (if applicable)

No publications to date as this is a new project.

Project details					
Project title	Genomics-based identification of macroinvertebrates to species level				
SSB function	Research	**Site**	Ranger		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Optimising SSB's stream monitoring program				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 2	**Timeframe** 3	
			Importance 3	**Time buffer** D	
Project number (if already commenced)	RES-2015-019	**Project commencement date**		1/4/2015	
		Estimated completion date		1/4/2018	
Project duration (months)	60	**Date required**		1/8/2018	
In-house or outsourced	External	**Actual completion date**		N/A	
Lead team	AEP	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	CDU/NTG				
Project manager	Buccella, Constanza	**Project total estimated internal resources (person weeks)**		2	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

To build a baseline DNA barcode library for freshwater macroinvertebrate species from ARR and streams, commencing with caddisflies (Trichoptera) and mayflies (Ephemeroptera).

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, CDU and Griffith University researchers to pilot a proof of concept using two aquatic insect orders, caddisflies (Trichoptera) and mayflies (Ephemeroptera). Material for this study is being drawn from NT Top End streams, including the ARR.

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

Progress against plan

SSB, Charles Darwin University and NT Government researchers have arranged meetings to coordinate and integrate information needs. The first meeting is proposed for late October 2016.

Key findings

There are no key findings to date.

Workplan for 2016–17

- Scope amongst potential collaborators the development of a regional, baseline DNA barcode library for freshwater NT invertebrates.
- Provide material for genetic analysis.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Initial proof of concept, development of a regional, baseline DNA barcode library for caddisflies (Trichoptera) and mayflies (Ephemeroptera).

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Northern Territory Government is the lead for this project. They have not produced any publications to date.

Project details					
Project title	Developing a short-term chronic toxicity test for the fish, *Mogurnda mogurnda*				
SSB function	Research	**Site**	Other		
Project category	Operational phase	**Project status**	Active		
What business need does this project inform?	Improves the suitability of fish toxicity estimates used in all Water Quality Guideline Values				
Closure criteria theme (if applicable)	N/A	**Project Priority**	**Relevance** 2	**Timeframe**	1/ongoing
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2015-028	**Project commencement date**		1/6/2015	
		Estimated completion date		1/12/2016	
Project duration (months)	6	**Date required**			
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	Ecotox	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	N/A				
Project manager	Pease, Ceiwen	**Project total estimated internal resources (person weeks)**		5	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- Develop a chronic toxicity test for *Mogurnda mogurnda* with the incorporation of sub-lethal endpoints.
- Use the new methodology to inform guideline values for contaminants of potential concern in Magela Creek and Gulungul Creek in Kakadu National Park.

Background

In the ERISS ecotoxicology laboratory, a suite of local species has been routinely used to derive Water Quality Guideline Values (WQGV) for two creeks adjacent to Ranger Uranium Mine, Magela Creek and Gulungul Creek, in Kakadu National Park. The current routine toxicity test for the Northern Trout Gudgeon, *Mogurnda mogurnda*, is an acute 96-h exposure (using a survival endpoint). This test is typically a less sensitive indicator of toxicity than the chronic tests used for the other species in the suite. The acute data generated from this test are not ideal for WQ GV derivation as it does not represent the long term effects of the contaminant within the environment. Thus, there was a need to update the current method to a cost-effective, chronic test based on sub-lethal endpoints.

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

Progress against plan

- Method is almost complete with some refinements to the feeding method required to boost growth rates.
- Two toxicity tests have been performed with ammonia as the toxicant.
- Three toxicity tests have been performed with uranium as the toxicant.
- Journal manuscript in early stages.

Key findings

A chronic sub lethal toxicity test method has been successfully developed for *Mogurnda mogurnda*.

Workplan for 2016–17

- Complete methodology for the chronic toxicity test including refinements to feeding method.
- Perform a series of 14 d tests to establish whether sensitivity increases with test duration or whether 7 d is sufficient to gain a sufficiently sensitive toxicity estimate.
- Incorporate new method into reference toxicity testing schedule.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- An Internal Report stating the new methodology
- A journal article published in a peer reviewed journal paper .
- Annual reporting to Alligator Rivers Region Technical Committee (ARRTC)

The outcomes that this project will achieve are:

- This project will improve the relevance of the toxicity testing suite employed at ERISS, and will ultimately improve confidence in site-specific water quality limits and closure criteria for several contaminants of potential concern for Ranger mine.

Planned communication activities

The primary communication activities for the project are:

- Presentation at the annual SETAC Australasia conference
- A peer reviewed journal article
- Reports/presentations to key stakeholders as appropriate.

Project publications to date (if applicable)

No publications to date.

Monitoring (1 project)

Project details					
Project title	Upper Gulungul catchment assessment				
SSB function	Monitoring	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Active		
What business need does this project inform?	Assess the increase in electrical conductivity from upstream Gulungul Creek. This will affect closure criteria of the mine site if a source is not delineated.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	TBA	**Project commencement date**	1/9/2016		
		Estimated completion date	1/4/2017		
Project duration (months)	18	**Date required**	1/4/2017		
In-house or outsourced	Internal	**Actual completion date**	N/A		
Lead team	S&M	**Reason for project delay (where applicable)**	N/A		
Supporting team(s)	N/A				
Project manager	Felmingham, Ty	**Project total estimated internal resources (person weeks)**	6		
Project sponsor	Turner, Kate	**Project total estimated collaborator resources (person weeks)**	N/A		

Aims

Identify the source/s that are contributing the elevated electrical conductivity (EC) values at Gulungul Creek upstream site (GCUS).

Background

This project seeks to indentify through surface water monitoring, the source/s that are contributing to the elevated electrical conductivity (EC) values at the Gulungul Creek upstream site (GCUS). It is critical to identify if these high EC occurrences are natural or mine related. Mine related sources need to be addressed in order to prevent any potential environmental degradation.

Progress against plan

Project was started in 2015, with a literature review conducted and divers installed along tributaries of Gulugul Creek prior to the 2015-16 wet season.

Project resumed in September 2016 with analysis of the diver data and a plan is currently being formulated to install the divers for the 2016-17 wet season and subeqeuntually report on the findings.

Key findings

Findings will be reported once the diver data for the 2016/2017 wet season have been analysed. Pending the findings of the report, the project may be completed.

Workplan for 2016–17

The work plan for the 2016-17 period is as follows:

Install divers prior to the the commencement of the 2016-17 wet season at select locations along the tributaries of Gulungul Creek.

During periods of flow of Gulungul Creek, undertake field water quality readings of the tributaries.

Download the divers at the end of the wet season.

Analyse and report on the findings.

Planned project outputs and associated outcomes

The planned output would be to identify the source of the increased electrical conductivity readings at GCUS.

Planned communication activities

These results will be communicated internally and with ARRTC.

Project publications to date (if applicable)

Not applicable.

REHABILITATION - CLOSURE CRITERIA (CC)

CC theme: Overarching (2 projects)

Project details					
Project title	Critical Groundwater Research Needs for Ranger Mine and the Alligator Rivers Region				
SSB function	Research	**Site**	Ranger		
Project category	Rehabilitation - overarching	**Project status**	Completed		
What business need does this project inform?	Understanding of groundwater systems at Ranger and their role as pathways and potential receptors of contaminants.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe**	2
			Importance 2	**Time buffer**	B
Project number (if already commenced)	RES-2015-012	**Project commencement date**			1/2/2015
		Estimated completion date			1/5/2015
Project duration (months)	9 months	**Date required**			30/12/2015
In-house or outsourced	Internal	**Actual completion date**			30/12/2015
Lead team	HGCP	**Reason for project delay (where applicable)**			Competing demands
Supporting team(s)	N/A				
Project manager	Lytton, Lucy	**Project total estimated internal resources (person weeks)**			0
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

To identify critical groundwater research needs related to the operational and rehabilitation activities at Ranger uranium mine.

Background

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

This project attempted to identify what is known in relation to groundwater systems at Ranger and identify key knowledge gaps that need to be addressed.

Progress against plan

- A progress report was presented to ARRTC at its 35th meeting.
- The report was finalised and has been published as IR641

Key findings

- Much research and monitoring has been undertaken at Ranger, but much of the information has not been fully integrated and consolidated into a site-wide understanding.
- Conceptualisation of groundwater at Ranger appears incomplete and not linked to the groundwater monitoring strategy.
- Limited observation of available groundwater data, and its presentation in reports or meeting documents, indicate that the management, presentation and accessibility of the full record of groundwater data remains suboptimal.
- Much of the effort is in collating and interpreting existing material prior to launching new research.
- Seven research recommendations were made to address the above-noted deficiencies.

Workplan for 2016–17

Not applicable.

Planned project outputs and associated outcomes

Outputs:

- An internal report documenting the process, findings and recommendations.

Outcomes:

- Greater understanding of the body of groundwater monitoring and research that has been undertaken; and
- a clear view of what is required to result in a clear and comprehensive understanding of the groundwater systems and their role in transporting contaminants.

Planned communication activities

- Presentation to ARRTC
- Production of an Internal Report.

Project publications to date (if applicable)

Lytton L & Marshall S 2016. Critical groundwater research needs for Ranger mine and the Alligator Rivers Region. Internal Report 641. Darwin, NT, 75 pp.

Project details					
Project title	Cumulative risk assessment for Ranger rehabilitation and closure				
SSB function	Research	**Site**	Ranger		
Project category	Rehabilitation - overarching	**Project status**	Proposed		
What business need does this project inform?	Underpins research priorities and research program.				
Closure criteria theme (if applicable)	Overarching	**Project Priority**	**Relevance** 1	**Timeframe** 2	
			Importance 2	**Time buffer** B	
Project number (if already commenced)		**Project commencement date**		1/2/2017	
		Estimated completion date		31/12/2017	
Project duration (months)	24	**Date required**		31/12/2017	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	RLE	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	CSIRO				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**		4	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		TBC	

Aims

The aims of this project for 2016-17 are to:

- Identify and catalogue datasets across ERISS that will be used in the cumulative risk assessment.
- Undertake a cumulative risk assessment for the rehabilitation and closure phases at Ranger.

Background

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

The US EPA has published a framework for cumulative risk assessment which is the first step in a long-term effort to develop cumulative risk assessment guidelines. Cumulative risk assessment is defined as "an analysis, characterisation, and possible quantification of the combined risks to health or the environment from multiple agents or stressors". Cumulative risk is specifically defined by the US EPA as "the combined risks from aggregate exposures to multiple agents or stressors". Key aspects framing the use of cumulative risk assessment include:

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

Given the large amount of environmental data ERISS has collected over the decades, a quantitative cumulative risk assessment can be undertaken.

Progress against plan

Not applicable – this is a new project.

Key findings

Not applicable – this is a new project.

Workplan for 2016–17

- Dataset identification and cataloguing across ERISS programs for use in quantitative analysis (May 2017)
- Undertake quantitative cumulative risk assessment (December 2017)

Planned project outputs and associated outcomes

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

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

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

The primary outputs for the project are:

- Report detailing the cumulative risk assessment.
- Catalogue of ERISS data used in the cumulative risk assessment.

Planned communication activities

The primary communication activities for the project are:

- Presentation to ARRTC on the results of cumulative risk assessment.
- Plain language summary of the results of the cumulative risk assessment.

Project publications to date (if applicable)

Not applicable–this is a new project.

CC theme: Water and sediment (11 projects)

Developing closure criteria

Project details			
Project title	Toxicity of ammonia to freshwater biota and derivation of a site-specific water quality guideline value		
SSB function	Research	**Site**	Ranger
Project category	Developing closure criteria	**Project status**	Completed
What business need does this project inform?	Derivation of a site-specific water quality guibeline value for ammonia.		
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1 **Timeframe** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	RES-2012-014	**Project commencement date**	1/12/2012
		Estimated completion date	1/1/2015
Project duration (months)	24	**Date required**	
In-house or outsourced	Internal	**Actual completion date**	N/A
Lead team	Ecotox	**Reason for project delay (where applicable)**	technical issues with data analysis
Supporting team(s)	N/A		
Project manager	Mooney, Tom	**Project total estimated internal resources (person weeks)**	3
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**	N/A

Aims

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

Background

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

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

Progress against plan

The toxicity of ammonia to six local species has been assessed at approximately pH 6 and 29°C.

Toxicity estimates from these species have been used in the derivation of a site-specific water quality guideline value for Magela and Gulungal Creeks.

Key findings

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

Workplan for 2016–17

Complete manuscript and communicate results to the MTC and Closure Criteria working group.

Planned project outputs and associated outcomes

- Assess the toxicity of ammonia to six local species.
- Derivation of a site-specific water quality guideline value for Magela and Gulungal Creeks.

Planned communication activities

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

Project publications to date (if applicable)

Mooney TJ, Pease C, Hogan A, van Dam R, Kleinhenz L and Harford AJ 'Ammonia Toxicity to Aquatic Tropical Biota in Low pH Waters', Environmental Science and Technology, In review

Project details			
Project title	Scope and undertake a pilot study to inform design of detailed study for chemical and biological characterisation of Magela sand channel		
SSB function	Research	**Site**	Ranger
Project category	Developing closure criteria	**Project status**	Proposed
What business need does this project inform?	Assessing impacts of surface water runoff and groundwater egress from current operations and the final landform on Magela Creek sand channels		
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1 **Timeframe** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	TBA	**Project commencement date**	1/7/2016
		Estimated completion date	1/7/2018
Project duration (months)	24	**Date required**	1/7/2018
In-house or outsourced	Internal	**Actual completion date**	N/A
Lead team	AEP	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	Macqarie University (to be confirmed)		
Project manager	Chandler, Lisa	**Project total estimated internal resources (person weeks)**	30
Project sponsor	Tomlinson, Moya	**Project total estimated collaborator resources (person weeks)**	N/A

Aims

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

Background

The site-specific limit for magnesium (Mg) in Magela Creek is 3 mg/L. Preliminary sampling in December 2015 identified elevated Mg in Magela Creek 5 km downstream of Ranger (MCDW). There have been several previous occurrences of Mg contamination, either unusually high concentrations or outside the period of main creek flows. Efflorescence of magnesium sulfate (MgSO4) in the Magela Creek area was first noticed at the base of the Magela Creek Land Application Area and on the creek banks in the 1993 dry season. Conductivity in small residual pools in the creek bed in the affected area was much higher than in other pools (1450 µS/cm cf. 22 – 115 µS/cm), and pH was much lower (3.26 cf. 6.04 – 7.05). There has also been efflorescence of MgSO4 in the Djalkmara Land Application Area in 2007 and 2009, resulting in an estimated Mg concentration of 5.4 mg/L entering Magela Creek and 6 mg/L entering Coonjimba Billabong due to transport during first flush. In 2014, several EC events and elevated levels of Mg and SO4 were observed in Magela Creek, primarily associated with flushing of solutes from Gulungul Creek Tributary 2. In addition, modelling of post-closure solute migration from Pit 3 predicts that a plume of Mg will intersect the Magela Creek sandbed within 10 years if no mitigation is in place.

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

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

Progress against plan

- Preliminary faunal and water quality samples taken in December 2015
- Groundwater ecology workshop held in March 2016
- Surface water quality samples collected, and field parameters measured, in June 2016
- Twelve piezometers installed longitudinally in the Magela Creek sandbed in July 2016. Samples taken for fauna and full suite water chemistry analysis.
- Data loggers installed in all piezometers.
- Fauna and water chemistry samples collected from piezometers in August 2016.
- Protocol for collection and processing of samples for genomic analysis tested in August 2016.
- Sampling in September 2016 not possible due to flow in Magela Creek.

Key findings

- Elevated EC (220 microsiemens/cm) and Mg (14 mg/L), and low pH (3.1–3.4), recorded in Magela Ck sandbed adjacent to the Magela Land Application Area and Coonjimba Billabong in July 2016.
- Elevated EC (370 microsiemens/cm) recorded at sites adjacent to Coonjimba Billabong again in August 2016.
- Water chemistry and continuous EC data collected to date is currently being examined further

Workplan for 2016–17

Monthly from July 2016:

- Sample sub-surface fauna longitudinally along Magela Creek at sites sampled in December 2015 (MCUS, and MCDW) and a new site at Coonjimba confluence.
- Collect subsurface water samples, and surface water field parameters and samples where possible for analysis of total ionic composition plus alkalinity at the three main sites
- At intermediate sites, sample shallow subsurface fauna and field water quality parameters.

Planned project outputs and associated outcomes

The primary output for the project is:

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

The results will improve understanding of the location and movement of current contamination in Magela Creek sandbed. It will also provide an understanding of the potential impacts of elevated Mg on the subsurface ecology in Magela Creek, and inform more detailed sampling for 2017–18 and out-years, that could also include Nourlangie and Gulungul creeks, possible sampling of monitoring bores for groundwater fauna, and characterisation of subsurface bacterial activity.

Planned communication activities

The primary communication activities for the project are:

- Presentations as required to key stakeholders and at conferences
- Publication in an Internal report and, if possible, a perr-reviewed publication.

Project publications to date (if applicable)

Not applicable–new project.

Project details					
Project title	Billabong macroinvertebrates responses to mine-derived solutes				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	A line of evidence informing closure criteria for MgSO4				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2005-002	**Project commencement date**			1/5/2006
		Estimated completion date			1/9/2016
Project duration (months)	2	**Date required**			1/6/2016
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	AEP	**Reason for project delay (where applicable)**			Competing demands
Supporting team(s)	N/A				
Project manager	Chandler, Lisa	**Project total estimated internal resources (person weeks)**			3
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

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

Background

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

Progress against plan

- Analysis of the full macroinvertebrate dataset from lentic waterbodies (exposed and reference) completed in June 2016, with a derived Mg value protective of ecosystems.
- The report is currently being internally reviewed prior to peer review, and will be considered as part of a wider weight of evidence evaluation of other lines of evidence relevant to Mg effects associated with Ranger.

Key findings

Responses of macroinvertebrate communities in shallow waterbodies across a spatial and temporal gradient of exposure to Ranger mine wastewaters dominated by $MgSO_4$ were used to infer effects and derive protective concentrations. Using the 34-year record (seven annual sampling occasions between 1979 and 2013) and 14 waterbodies, minewater-exposed and reference, 1% effectconcentrations (EC1) for community structure and taxa number response measures were 5.6 and 3.9 mg/L magnesium respectively. For the exposed waterbody demonstrating highest biological sensitivity, the magnesium:calcium ratio was ~3.5:1, indicating lack of calcium amelioration.

Workplan for 2016–17

- August 2016: The results have been written up for peer review in a Supervising Scientist Report
- September 2016: Results to be considered as part of a wider weight of evidence evaluation of other lines of evidence relevant to Mg, which will report final closure criteria for this contaminant of potential concern.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Supervising Scientist Report: Use of field-effects information to inform surface water closure criteria for magnesium sulfate in Magela Creek.
- Presentation to SETAC Asia-Pacific Conference in Singapore, September 2016.
- Weight of evidence evaluation of lines of evidence relevant to Mg effects on Ranger receiving waters

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

Planned communication activities

The primary communication activities for the project are:

- Presentation to SETAC Asia-Pacific Conference in Singapore, September 2016
- ARRAC and ARRTC meetings for 2016-17
- Website updates

Project publications to date (if applicable)

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

Project details					
Project title	The toxicity of U to sediment biota of Gulungul Billabong				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Provides closure criteria for uranium in sediments				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe** 3	
			Importance 3	**Time buffer** D	
Project number (if already commenced)	RES-2009-002	**Project commencement date**		1/7/2008	
		Estimated completion date		1/12/2016	
Project duration (months)	6	**Date required**		1/1/2020	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	Ecotox	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	CSIRO				
Project manager	Harford, Andrew	**Project total estimated internal resources (person weeks)**		5	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

The aim of this project is to derive a sediment quality guideline value for uranium (U)

Background

A project that aims to derive a sediment Guideline Value (GV) for uranium (U) has been on-going since 2009. Following an initial site characterisation during the 2008–09 wet season, two pilot studies were conducted during the 2009-10 and 2010-11 wet seasons. 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), micro- and macro-invertebrates (eukaryotes) using a combination of ecogenomic and traditional taxonomic methods.

The analyses showed that benthic macro-invertebrate 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 micro-invertebrate eukaryotes across the U concentration range, as well as effects at lower concentrations. Numerous statistical analyses found statically significant results and thresholds of change between 40–420 mg kg^{-1} U. Future work will include further analysis of the datasets and publication of the results in peer-reviewed journals. The results will be used in discussions with stakeholders in order to derive a sediment quality Guideline Value (GV) for U for current operations and closure of the mine.

Progress against plan

- All field experiments have been completed
- Write-up of results has been delayed due to competing priorities.

Key findings

A sediment quality guideline for U of 94 mg/kg (AEM) or 115 mg/kg (TRM) was derived and communicated to the Water and Sediment Closure Criteria Work Group. However, this still needs to be finalised using a formal weight of evidence approach across the results of the multiple statistical analyses that were undertaken.

Workplan for 2016–17

March 2017–three papers completed and submitted for peer-review.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Four journal papers in peer-reviewed journals

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

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 details					
Project title	Re-analysis of magnesium toxicity mesocosm study data				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Proposed		
What business need does this project inform?	Informs the Mg GV for operations and closure - an additional line of evidence				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)		**Project commencement date**			1/5/2016
		Estimated completion date			1/4/2016
Project duration (months)	2	**Date required**			1/8/2016
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	AEP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	Ecotox				
Project manager		**Project total estimated internal resources (person weeks)**			6
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

- Assess the effects of Mg on assemblage structure of biota in Magela Creek
- Determine assemblage-based Mg toxicity estimate(s) for biota in Magela Creek

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, a weight-of-evidence approach is required which encompasses field assessments of the toxicity of Mg to biota in Magela Creek. Previously, McCullough (2002) 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-1) and left for 2 months. Periodically, the mesocosms were sampled for a range of community biota, including: macroinvertebrates, microinvertebrates, diatoms and algal communities. Changes to these assemblages were assessed across 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 Clint McCullough's PhD thesis "A multi-scale assessment of the ecological risk of Mg sulphate to aquatic biota of Magela Creek, Northern territory, Australia".
- Recently, a re-analysis of the results of the PhD has commenced. Data for zooplankton and phytoplankton have been re-analysed.

Key findings

Results of this work, including recent re-analyses, demonstrated sensitivity after four-week exposure of phytoplankton (algal biomass viz chlorophyll a) and zooplankton, with inferred trophic interaction (i.e. grazing impact of zooplankton on algae). The 1% effect concentrations (EC1) for algal biomass and community structure response measures for zooplankton were 1.5 and 2.3 mg/L magnesium respectively.

Workplan for 2016–17

- Re-analyse data from the early 2000s Mg mesocosm study.
- Write journal manuscript

Planned project outputs and associated outcomes

The primary outputs for the project are community based toxicity estimate(s) for Mg.

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

Planned communication activities

The primary communication activities for the project are:

- Journal manuscript
- Presentations a relevant fora (e.g. ARRTC)

Project publications to date (if applicable)

McCullough (2002), A multi-scale assessment of the ecological risk of magnesium sulphate to aquatic biota of Magela Creek, Northern territory, Australia. Charles Darwin University, PhD Thesis

Project details					
Project title	A review of the risks associated with nutrient inputs from the rehabilitated mine site				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Proposed		
What business need does this project inform?	It will assess the potential impact of nutrients inputs to the creeks and billabongs and determine a suitable closure criteria				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	TBA	**Project commencement date**			1/7/2016
		Estimated completion date			1/6/2017
Project duration (months)		**Date required**			1/12/2016
In-house or outsourced	External	**Actual completion date**			N/A
Lead team	Ecotox	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	TBC				
Project manager	TBC	**Project total estimated internal resources (person weeks)**			2
Project sponsor	TBC	**Project total estimated collaborator resources (person weeks)**			TBC

Aims

The aim of this project is to determine if nutrient inputs from the rehabilitated site will lead to impacts (e.g. toxicity and/or stimulation of aquatic plant growth) of the billabongs and creeks.

Background

The interim site-specific water quality limit for ammonia is based on its potential toxicity. During the post-decommissioning phase, nutrients will primarily be transported to Magela and Gulungul creeks via the groundwater pathway. The nutrients of primary concern following rehabilitation of Ranger are ammonia, from buried tailings, and nitrate, from explosive residues in the waste rock covering the landform. Other than the toxicity of ammonia, aspects relating to the risks of these compounds to the local aquatic ecosystems are not well understood. This includes the transport and fate of ammonia and nitrate, and potential ecological effects of the nutrients associated with stimulation of plant growth.

Progress against plan

Not applicable – this is a new project.

Key findings

Not applicable as this is a new project.

Workplan for 2016–17

- Commission a review of the geochemistry (transport and fate) of ammonia and nitrate related to the rehabilitated Ranger site, including an assessment of the rigour of the outputs of ERA's groundwater and surface water hydrodynamic modelling data

- Undertake an assessment (internal or external – to be confirmed) of the ecological risks of nutrient inputs to the local creek and billabong systems, in the context of natural seasonal water quality variability.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- A consultancy report and/or position paper on the geochemistry review.
- A report (internal or consultancy) on the ecological risks

The outcome that this project will achieve is an understanding of the ecological risk of nutrient inputs to the local billabongs and creeks. This will inform the need for any additional or refined closure criteria.

Planned communication activities

The primary communication activities for the project are:

- Reports and presentations to relevant stakeholders (e.g. Water & Sediment Closure Criteria Technical Working Group)
- Potentially, a peer-reviewed journal publication.

Project publications to date (if applicable)

Not applicable – this is a new project.

Project details			
Project title	Developing a rehabilitation standard for sulfate (acid sulfate soils)		
SSB function	Research	**Site**	Ranger
Project category	Developing closure criteria	**Project status**	Active
What business need does this project inform?	This project will lead to the development of a rehabilitation standard for acid sulfate soils that can inform Ranger of the desired sulfate concentrations that should be met at closure.		
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1 **Timeframe** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	TBA	**Project commencement date**	1/9/2016
		Estimated completion date	30/12/2016
Project duration (months)	2	**Date required**	30/12/2016
In-house or outsourced	Internal	**Actual completion date**	N/A
Lead team	Ecotox	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	AEP		
Project manager	Trenfield, Melanie	**Project total estimated internal resources (person weeks)**	2
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**	N/A

Aims

- To assess available information on acid sulfate soils (ASS) and safe sulfate concentrations in water and sediment.
- To develop a rehabilitation standard for sulfate as a guide to prevent the formation of ASS in off-site local water bodies.

Background

- Sulfate itself is not considered to be very toxic to aquatic organisms but, at high enough concentrations and under the right conditions, it can lead to the formation of acid sulfate soils.
- There are no existing water quality guidelines for sulfate but there has been some investigation into the effects of sulfate in on-site and off-site local waters and the formation of ASS.
- Coonjimba Billabong has shown evidence of extreme acid events since the wet season of 2013, accompanised by sulfate water concentrations of 57 mg/L, and with potential to impact on aquatic biota.

Progress against plan

A draft rehabilitation standard has been commenced, but requires input from an external ASS expert.

Key findings

This project has only just commenced, and there are no key findings as such.

Workplan for 2016–17

- Draft sulfate/ASS rehabiltiation standard
- Seek expert advice in order to be able to finalise the standard.

Planned project outputs and associated outcomes

The key output will be a rehabilitation standard for sulfate (acid sulfate soils). This standard will ensure that sulfate concentrations and, where possible, certain environmental conditions remain such that the risk of formation of ASS is low.

Planned communication activities

- Communication of rehabilitation standard to the Water and Sediment Closure Criteria Technical Working Group
- If pssoble, a peer-reviewed publication..

Project publications to date (if applicable)

None.

CC theme: Water and sediment

Demonstrating achievement of closure criteria

Project details			
Project title	Aquatic ecosystem knowledge assessment and evaluation		
SSB function	Research	**Site**	All
Project category	Demonstrating achievement of closure criteria	**Project status**	Completed
What business need does this project inform?	The project considered knowledge gaps informing the development of closure criteria for aquatic ecosystems.		
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1 **Timeframe** 1 **Importance** 1 **Time buffer** A
Project number (if already commenced)	RES-2013-010	**Project commencement date**	31/1/2014
		Estimated completion date	31/1/2015
Project duration (months)		**Date required**	
In-house or outsourced	Collaboration	**Actual completion date**	31/1/2015
Lead team	AEP	**Reason for project delay (where applicable)**	N/A
Supporting team(s)	Clarke, Kyla (ERA)		
Project manager	George, Amy	**Project total estimated internal resources (person weeks)**	0
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**	N/A

Aims

- Evaluate existing available literature on aquatic ecosystems of the Alligator Rivers Region
- From this, identify key areas requiring research effort to meet the rehabilitation requirements for Ranger minesite.

Background

Biological and ecological research has been conducted on and around the Ranger minesite since the early 1980s. Both SSD and ERA have active research programs which continue to address these areas of interest. A significant portion of this work is widely available through external peer reviewed journals and much of the information has been captured in internal documents.

While these literature sources are readily available, the overall volume of information often complicates the dissemination of the key learnings from the studies. Key learnings are often retained as 'corporate knowledge' which can be lost through attrition. Aquatic ecosystems benefit from a long-standing retention of corporate knowledge, but there is still a need to collate the existing information on this topic. A literature review ensures that any research program developed for aquatic ecosystem establishment will address actual knowledge gaps, rather than attempting to direct work into areas which may have already been addressed, albeit not in the recent past

Progress against plan

Recent risk assessments and revision of the KKNs have superseded this overarching study, with more targeted aquatic research identified for Ranger closure. As a consequence the project ceased in early 2015.

Key findings

Not applicable

Workplan for 2016–17

Nil

Planned project outputs and associated outcomes

Outcome

- Identify and develop key knowledge gaps for aquatic ecosystem establishment (viz revised KKNs).

Outputs of the project

- Aquatic ecosystem knowledge database (an updatable type of annotated bibliography on aquatic ecosystems) (database held by ERA)
- Identified knowledge gaps that fed into recent risk assessments and KKN revisions. Identified knowledge gaps that fed into recent risk assessments and KKN revisions.

Note that this project was ceased prior to significant progress, due to it being superseded by other knowledge generating activities.

Planned communication activities

Not applicable

Project publications to date (if applicable)

- Not applicable

Planned communication activities

Project publications to date (if applicable)

Project details					
Project title	Literature and data review of seasonal utility of Magela channel for connectivity processes				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Assessing impacts of surface water runoff and groundwater egress from the final landform on Magela Creek sand channels				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 2	**Timeframe** 2	
			Importance 2	**Time buffer** B	
Project number (if already commenced)		**Project commencement date**		1/4/2016	
		Estimated completion date		1/9/2016	
Project duration (months)	6	**Date required**		1/12/2016	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	AEP	**Reason for project delay (where applicable)**		Redirection of project staff to other priorities	
Supporting team(s)	N/A				
Project manager	Tomlinson, Moya	**Project total estimated internal resources (person weeks)**		8	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

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

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

Background

The main contaminant of potential concern in Magela Creek, arising from mining at Ranger, is magnesium (Mg), derived primarily from weathering of Mg-dominant, chlorite schists in the mine waste rock. Solute modelling predicts egress of a plume of Mg contamination from (at least) Pit 3 into Magela Creek sand channel following filling of the pit with tailings and waste rock. Natural EC levels in Magela Creek are very low. Magela Creek is a conduit for fish movement between the floodplain and the upstream dry season refugia. With the start of flow, fish from permanent waterbodies move into seasonally- inundated floodplains, lowland sandy channels and backflow billabongs to breed and feed. In the second half of the wet season including recessional flow, individuals representing a large number of

fish species from a number of lowland habitats (floodplains, billabongs and creek channels) move upstream along the length of the creek to dry season refuges. The effect on fish movement of elevated Mg concentrations in Magela Creek is unknown. Macroinvertebrate communities of the Magela sand channels are diverse, observe successional changes over the wet season and may colonise the creek at first-flow through downstream drift. Potential disruption to dispersion and recruitment processes of these assemblages arising from solute egress also needs to be assessed. This literature review will review the available data on fish migration, invertebrate recruitment processes and the scientific literature to identify the implications of potential disruption to ecological connectivity caused by Mg contamination.

Progress against plan

- Literature review commenced in May. Graduate project (carried out May - August) involved collation of stream discharge, rainfall and fish migration data and generating plots of numbers migrating versus stream flow for ten species for nine years.
- Graduate (Nick Metherall) presented his findings at a seminar on 25 August attended by SSB staff and CDU researchers.
- The findings will be incorporated into the literature review. Analysis of fish migration and stream flow data is continuing.
- Completion of literature review is delayed by one month.

Key findings

- Fish movement counts often peak after a peak in discharge, but this response is variable. Peak fish movement does not always follow the highest peak of stream discharge.
- Some fish (*Ambassis* spp. and rainbow fish) may be identified as 'early starters" which respond to peaks in stream discharge early in the wet season. Movement of others (the terapontids) is more often associated with recessional flow. This is likely to be associated with the breeding and dry season refuge sites for these two groups, being the floodplain and upstream billabongs respectively.

Workplan for 2016–17

Complete literature review by end October.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Presentations as required
- Internal report

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

Planned communication activities

The primary communication activities for the project are:

- Presentations as required
- Internal report

Project publications to date (if applicable)

Not applicable–this is a new project.

Project details					
Project title	Effects of pH on ammonia toxicity to local species				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Tests the suitability of alogrithms used to derive ammonia GVs for high pH conditions.				
Closure criteria theme (if applicable)	Water and Sediment	**Project Priority**	**Relevance** 1	**Timeframe** 1	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	TBA	**Project commencement date**		1/12/2012	
		Estimated completion date		1/12/2016	
Project duration (months)	6	**Date required**		31/12/2016	
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	Ecotox	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	N/A				
Project manager		**Project total estimated internal resources (person weeks)**		25	
Project sponsor	Harford, Andrew	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- Assess the toxicity of ammonia to *Hydra viridissima* over the pH range 6.5 to 8.5.
- To validate algorithm-derived ammonia site-specific water quality guidelines for water bodies with a pH greater than 6.

Background

A project was undertaken to assess the toxicity of ammonia to six local species of the Alligator Rivers Region, at environmentally relevant conditions (approximately pH 6 and 29°C). Toxicity estimates were used to derive site-specific water quality guideline values (GVs) for ammonia to be applied to Magela and Gulungul Creeks. In the environment, the toxicity of ammonia increases to biota as both pH and temperature increase, due to the greater availability of NH3.

During the dry season, natural diurnal pH fluctuations in billabongs have the potential to increase ammonia toxicity from the disassociation of NH4+ to NH3 with increasing pH. Therefore, it is important to ensure the guideline values that were derived for Magela Creek are also protective for environments of a different pH. Specifically, this project will contribute by validating whether the matrix of ammonia water quality GVs (dependent on pH and temperature) derived for Magela Creek are appropriate for application to billabongs and other freshwater bodies.

Progress against plan

- The toxicity of ammonia has been assessed at approximately pH 6 and 29°C for six local species (previous project).
- Water quality guidelines have been derived for Magela and Gulungul creeks.

- Ammonia toxicity has been tested at pH 6.5, 7, 7.5, 8 & 8.5 for *Hydra viridissima*

Key findings

Analyses are not yet complete but preliminary results show a trend of increasing toxicity with increasing pH.

Workplan for 2016–17

Dec 2016: complete toxicity testing.

Mar 2017: publication of journal manuscript.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Ammonia toxicity estimates for *Hydra viridissima* in waters ranging in pH 6.5-8.5.
- Journal publication

The outcomes that this project will achieve are:

- Validation of algorithm derived GVs for water bodies of differing pHs within the Alligator Rivers Region

Planned communication activities

The primary communication activities for the project are:

- Peer reviewed journal manuscript
- Presentation at key fora

Project publications to date (if applicable)

No publications to date.

CC theme: Water and sediment

Monitoring of closure criteria

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

Aims

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

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

Background

The Supervising Scientist conducts an independent surface water quality monitoring program that includes measurement of chemical and physical variables and biological monitoring in Magela and Gulungul Creeks as well as other reference creeks and waterbodies in the region. This is a point sampling program and as such does not capture spatial variability in water quality variables such as turbidity.

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

Furthermore, maps showing the spatially continuous distribution of suspended sediments can be useful aids in designing or improving point sampling monitoring programs through highlighting the best

locations for sampling. This may become more relevant during the decommissioning and rehabilitation phase of the mine with potential fluctuations in suspended sediments within Magela Creek.

Progress against plan

The project has been completed with the Honours thesis submission. Once the thesis has been reviewed a journal publication will be prepared.

Key findings

Water quality calibration algorithms under turbid inland water conditions were investigated for Coonjimba Billabong. A reflectance-based approach was developed to map billabong turbidity. Five bands of ultra high resolution spectral digital data were collected from a Micasense sensor on board a 3DR-X8 octocopter and the observations of turbidity values were obtained near-simultaneously using turbidity sensors on an Autonomous Surface Vehicle (ASV). The relationships between reflectance and water turbidity were assessed using single-band reflectance, band ratios, and water-related indices. Results show the Normalised Difference Water Index (NDWI) is a good indicator for water turbidity. Its linear model had a coefficient of determination of 0.7231. This study developed a new method to process multi-spectral RPAS imagery for turbidity monitoring in inland water bodies.

Workplan for 2016–17

Completed.

Planned project outputs and associated outcomes

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

Specific outputs are:

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

Planned communication activities

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

Project publications to date (if applicable)

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

CC theme: Landform (9 projects)

Developing closure criteria

Project details					
Project title	Analysis of historical unpublished erosion studies in the ARR				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Analysis of historical unpublished erosion data to inform/validate the CAESAR-Lisflood landform evolution model.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Timeframe**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2015-022	**Project commencement date**			1/7/2016
		Estimated completion date			1/12/2016
Project duration (months)	2	**Date required**			1/12/2016
In-house or outsourced	External	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	Professor Ken Evans, CDU				
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**			2
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

Analyse the erosion data collected by Steve Riley in the early 1990's that was not published.

Background

In the late 1980s and early 1990s, a series of experiments was undertaken by Steve Riley (former eriss employee) to investigate erosion from and around the Ranger mine site. These experiments included monitoring of natural events, concentrated flume experiments and rainfall simulation. These experiments were undertaken at the Ranger site (Waste Rock dumps –cap and batter slopes) and at natural sites adjacent to the mine site and at Tin Camp Creek in Arnhem Land. The majority of this work has not been published. This project involves sifting through the data to see what might be useful particularly with regard to landform evolution modelling. It is planned to outsource the work as a small non-consultancy to Professor Ken Evans (Charles Darwin University).

Progress against plan

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

Key findings

Not applicable as the project is yet to sufficiently progress.

Workplan for 2016–17

- Finalise screening of unpublished data, and scope and set up a small non-consultancy with Ken Evans at CDU.
- Comment on report.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Analysis of results from previously unpublished experiments for purposes of informing/validating CAESAR-Lisflood model.
- One report, which will developed into a journal publication.

The outcomes that this project will achieve is further validation and confidence that the CAESAR-Lisflood model is accurately predicting observed erosion rates.

Planned communication activities

The primary communication activities for the project are:

- Discussion at the Landform Closure Criteria Technical Working Group.
- Journal publication.
- Reporting and presentations to key stakeholders as necessary.

Project publications to date (if applicable)

Not applicable as project is not yet completed.

Project details					
Project title	Calibrating suspended sediment outputs of the the CAESAR-Lisflood LEM for application to a rehabilitated ranger mine - Gulungul Creek scale				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Ensure confidence in landform model predictions of suspended sediment output reflect actual measured / monitored output.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Timeframe**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	Res-2016-002	**Project commencement date**			1/7/2016
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			1/12/2016
In-house or outsourced	Collaboration	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	Professor Ken Evans, CDU				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**			5
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

Calibrate and validate CAESAR-Lisflood outputs of suspended sediment loads at the catchment scale.

Background

This project will contribute to the work of the Supervising Scientist by assessing what effect the transport of suspended sediment will have on the on-site and off-site habitats of the rehabilitated landform. Specifically, the project will assist with the calibration of the CAESAR-Lisflood model to enable it to reliably predict the quantity of suspended sediment material that may be produced by the rehabilitated landform under a range of scenarios, by comparing simulated outputs with field measured values. This project is being undertaken as a Masters-by-coursework student at Charles Darwin University, supervised by Professor Ken Evans.

Progress against plan

Not applicable–this is a new project.

Key findings

Not applicable as this is a new project.

Workplan for 2016–17

March–June 2016: Data collation and integration.

April–August 2016: Analysis and calibration of field data

May–August 2016: Comparison of field data with model outputs

May–September 2016: Calibration and validation of suspended sediment outputs from CAESAR-Lisflood project.

November 2016: Masters thesis complete.

December 2016: Internal report on calibration methodology and results.

Planned project outputs and associated outcomes

The primary outputs for the project are:

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

The outcomes that this project will achieve are an enhance capacity of the CAESAR-Lisflood model to simulate the amount of suspended sediment that may be produced at a catchment scale on a rehabilitated landform. The project will provide a better idea of how the undisturbed environment around the Ranger mine will evolve over an extended period of time into the future. For example, the project will identify whether features in the landscape will have infilled through the transport of sediment.

Planned communication activities

The primary communication activities for the project are:

- Internal Report–December 2016.
- Input into landform technical working group discussions.

Project publications to date (if applicable)

Not applicable–this is a new project.

Project details					
Project title	Model geomorphic stability of pre-mine landform for up to 10,000 years				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Calibration of landform evolution model for different surfaces, i.e. pre- and post-mine				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 3	**Timeframe**	1/ongoing
			Importance 3	**Time buffer**	A
Project number (if already commenced)	RES-2015-017	**Project commencement date**			1/7/2016
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			1/12/2017
In-house or outsourced	Collaboration	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	Professor Ken Evans and Dr Monishka Narayan, CDU				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**			2
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

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

Background

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

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

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

Progress against plan

- Comparative catchment areas delineated from pre-mine surface.
- Model parameters revised and enhanced for modelling undisturbed model conditions.
- Initial multi-millennial simulations run using the same rainfall scenario datasets as simulations on the post-mining surface.

Key findings

- Landform modelling simulations of a pre-mining landscape using same the rainfall scenarios as simulations of a post-mining landscape indicate denudation rates are within the background environmental range (0.01-0.4 mm/yr) from the commencement of simulation. This contrasts with the post-mining landscape where it is predicted to take thousands of years for the denudation rate to reach the background level.
- This indicates that the model is correctly calibrated and is able to model both natural and disturbed / rehabilitated surfaces.

Workplan for 2016–17

- Incorporate effects of billabongs and backwater billabongs into model simulations, to determine natural rate of infilling (October 2016).
- Apply enhanced CAESAR model features–weathering, vegetation–to additional simulations, to better understand how pre-mine landscape may evolve (January 2017).

Planned project outputs and associated outcomes

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

The outcomes that this project will achieve are a better understanding of the performance of the CAESAR-Lisflood evolution model in a natural, undisturbed environment; and how an undisturbed landscape may evolve in the long term.

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Not applicable–this is a new project.

Project details					
Project title	Trial Landform Research				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Gather real data on suspended sediment and bedload transport of a rehabilitated site in order to validate predictions from the landform evolution model, CAESAR-Lisflood, which will be used to determine the long-term stability of the Ranger rehabilitated mine site.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Timeframe**	1
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2009-011	**Project commencement date**			1/7/2016
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			1/12/2016
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	N/A				
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**			30
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

- To measure, through time, erosion rates in terms of bedload, suspended load and solute load from a constructed trial landform at the Ranger mine to assess effects of different surface treatments and vegetation establishment strategies.
- To provide data which may be used to assist validate the predictions of long term landform evolution modelling of proposed landform designs.
- To determine loads of key contaminants present in the dissolved and suspended-sediment fractions available for export from the trial landform via the surface water pathway.

Background

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

Progress against plan

- Rainfall, runoff and bedload data have been collected for seven wet seasons 2009–2010 to 2015–16.
- Rainfall and runoff data has been cleaned, QA/QC and archived in Hydstra for all for plots for the wet season 2009–2010 to 2015–2016.

- Bedload yields have been completed for all 4 plots for seven wet seasons (2009–2010 to 2015–2016).
- Continuous monitoring of EC, turbidity and stage has been done at each of the four plots over the five wet seasons (2009/2010 to 2013/2014), and these data will be used to derive total loads of suspended sediment and solutes.
- Chemical analysis was completed for selected runoff samples collected by turbidity and/or EC activated auto samplers during the first five wet seasons (2009/2010 to 2013/2014).
- Particle size distribution was completed for samples of bedload, and selected sediment samples were analysed for metal content and radionuclide activity.
- Particle size distribution has also been completed for the surface samples collected in 2009, 2012 and in 2014 and the earlier data have been reported in an internal report.
- The project was scaled back during the 2014/2015 wet season with only rainfall runoff and bedload collected during the 2014–2015 and 2015–2016 wet seasons. ERA burnt two plots on the laterite waste rock mix in May 2016.

Key findings

- Hydrology, (rainfall and runoff) and bedload collected for seven wet seasons from 4 erosion plots
- Bedload erosion from the erosion plots is reducing exponentially from all plots
- Bedload erosion has always been higher from erosion plot 2 which is observed to have the least established vegetation
- Preliminary work on the suspended sediment suggests that makes up between 5 and 25% of the total sediment load

Workplan for 2016–17

- Finalise the suspended sediment turbidity relationship from the trial landform so that total loads leaving the erosion plots can be calculated.
- Finalise a Supervising Scientist report about the trial landform project.
- Test and validate CAESAR using erosion results from the trial landform.
- Prepare a journal paper on the hydrology of the erosion plots on the trial landform.
- Monitor some of the erosion plots on the trial landform during the 2016–2017 wet season.

Planned project outputs and associated outcomes

The primary outputs for the project is to determine rainfall, runoff, solute, suspended sediment and bedload yields from the trial landform.

- Development of suspended-sediment turbidity relationships for the trial landform so that suspended-sediment losses can be indirectly monitored by continuous turbidity measurements; and use of these relationships to derive event-based and annual loads of suspended sediment.
- Development of relationships between solute concentrations and electrical conductivity to derive solute loads from the continuous measurements of EC and discharge.
- Determining the concentrations of metals and radionuclides in the suspended sediment fraction. Sediment loads – (bedload and suspended sediment including turbidity relationship)–December 2016.
- Landform evolution modelling, calibration of model parameters and validation of model predictions.

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

Planned communication activities

The primary communication activities for the project are:

- Conference presentations.
- Presentations and discussions with the Landform Closure Criteria echnical Working Group.
- Internal reports and annual research summaries.
- Journal publications.

Project publications to date (if applicable)

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

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

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

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

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

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

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

Project details					
Project title	Establishing updated/new site specific relationships between suspended sediment and turbidity to enable use of turbidity as a surrogate for suspended sediment				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Proposed		
What business need does this project inform?	Determine site specific turbidity suspended sediment relationships for Gulungul and Magela Creeks - timeframe needs revisiting				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Timeframe** 3	
			Importance 3	**Time buffer** A	
Project number (if already commenced)		**Project commencement date**		1/7/2016	
		Estimated completion date		1/12/2019	
Project duration (months)	6	**Date required**		1/12/2018	
In-house or outsourced	External	**Actual completion date**		N/A	
Lead team	HGCP	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	CDU				
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**		2	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

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

Background

Fine suspended sediment (FSS) concentration in streams has been measured indirectly using turbidimeters in numerous studies (listed in Moliere & Evans (2010) in the Alligator Rivers Region. As part of several studies in the ARR, in situ turbidimeters were installed at gauging stations within the Magela Creek catchment to measure turbidity values on an almost continuous basis.

The measurement of suspended sediment is a time and resource dependant activity. Water samples collected at gauging stations by an automatic pump sampler during larger rainfall-runoff events have the FSS concentration determined by sieving, filtering and oven drying techniques. These FSS data along with concurrent in situ turbidity can be used to derive statistically significant relationships between FSS concentration and turbidity for gauging stations. These relationships allow the continuous turbidity data to be used to derive surrogate continuous FSS (Moliere et al 2005). In Moliere and Evans (2010), suspended sediment and turbidity relationships were developed up until 2008 for stations on Magela and Gulungul Creeks.

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

Progress against plan

Initial work has been undertaken by Professor Ken Evans from CDU. Interim report focussing on Gulungul Creek has been provided.

Key findings

Not applicable – project is not yet sufficient progressed.

Workplan for 2016–17

- Assess FSS samples collected since 2008 to see if the relationships determined are still applicable for Magela and Gulungul Creeks.
- Assess event FSS loads using the established BACIP approach and regression relationships to see if they are still current and update as necessary.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Suspended sediment turbidity relationships using turbidity as a surrogate for suspended sediment. These relationships will be used to assess suspended sediment in the creek from the rehabilitated landform.

The site-specific suspended sediment turbidity relationships will enable continuous suspended sediment loads to be determined. This will be used in either a BACIP approach or regression equations to asses mine related impacts downstream of the rehabilitated landform.

Planned communication activities

The primary communication activities for the project are:

- Communication to the Landform Closure Criteria Technical Working Group.
- Publication in peer reviewed journal.

Project publications to date (if applicable)

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

Moliere DR, Saynor MJ, Evans KG & Smith BL 2007. Hydrology and suspended sediment transport in the Gulungul Creek catchment, Northern Territory: 2005–2006 wet season monitoring. Internal Report 518, January, Supervising Scientist, Darwin. Unpublished paper.

Moliere DR, Evans KG & Saynor MJ 2007. Hydrology and suspended sediment transport in the Gulungul Creek catchment, Northern Territory: 2006–2007 wet season monitoring. Internal Report 531, June, Supervising Scientist, Darwin. Unpublished paper.

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

CC theme: Landform

Demonstrating achievement of closure criteria

Project details					
Project title	Model the geomorphic stability of the landform for up to 10,000 years				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Ensuring the rehabilitated landform is designed to minimise erosion and sediment transport off the site, trhough rigorous modelling of long-term stability under different rainfal/climate scenarios.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Timeframe**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2012-005	**Project commencement date**			1/7/2016
		Estimated completion date			1/12/2018
Project duration (months)	30	**Date required**			1/12/2016
In-house or outsourced	Collaboration	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	Professor Tom Coulthard, University of Hull, Associate Professor Greg Hancock, University of Newcastle				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**			35
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

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

Background

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

Progress against plan

- Weathering module developed and implemented.
- Long-term rainfall datasets developed and progressively being incorporated into simulations.
- Enhanced vegetation modelling component developed–about to commence validation/testing.
- Peer-reviewed paper on long-term modelling published in Journal of Geomorphology May 2016.

Key findings

- CAESAR-Lisflood simulations indicate that it will take several thousand years for the denudation rate of the rehabilitated landform to reach the background denudation rate of 0.01-0.04 mm/yr
- Landform modelling shows that modification of the conceptual landform design has reduced erosion in the areas around Pit 1 and Pit 3.
- Simulations utilising different synthetic rainfall datasets indicates that sediment output may vary, based on rainfall scenarios, but the location of key erosion points / gullies are constant.
- The maximum gully depth predicted after 10,000 years on the landform is up to 14 metres deep, in the catchment of Coonjimba Creek.

Workplan for 2016–17

- Test and validate weathering effects into model simulations (November 2016).
- Test / validate and implement rainfall datasets into long term simulations (December 2016).
- Implement enhanced vegetation component into simulations (January 2017).
- Model updated / revised landform supplied by ERA (June 2017).

Planned project outputs and associated outcomes

The main outputs for this project will be:

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

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

Planned communication activities

The primary communication activities for the project are:

- Conference presentations – Life of Mine conference–two papers; Climate Adaptation conference–one paper.
- Technical Working Group presentations.
- Journal publications–two journal papers in preparation.

Project publications to date (if applicable)

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

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

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

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

Hancock GR, Coulthard TJ & Lowry JBC 2016b. Use of landform evolution models to assess uncertainty in long-term evolution of post-mining landscapes. In *Proceedings of the Life-of-Mine 2016 Conference*, 28-30 September, Brisbane Australia, The Australiasian Instititute of Mining and Metallurgy, pp. 67-70

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

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

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

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

Project details					
Project title	Development of enhanced vegetation component for the CAESAR model				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Enhance the capacity to incorporate vegetation growth patterns into long term land form evolution modelling, thereby increasing confidence in the accuracy and reliability of long-term model predictions.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 1	**Timeframe**	1/ongoing
			Importance 1	**Time buffer**	A
Project number (if already commenced)	RES-2015-027	**Project commencement date**			1/7/2016
		Estimated completion date			30/6/2017
Project duration (months)	6	**Date required**			1/12/2017
In-house or outsourced	Collaboration	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	Professor Tom Coulthard, University of Hull; Associate Professor Greg Hancock, University of Newcastle				
Project manager	Lowry, John	**Project total estimated internal resources (person weeks)**			3
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

- Finalise collation and analysis of remotely sensed data delineating temporal vegetation growth patterns for input into the CAESAR-Lisflood vegetation growth model.
- Calibrate vegetation parameters of the CAESAR-Lisflood LEM for the Ranger mine site and so inform closure design for the final rehabilitated landform.
- Prepare material for presentation at Life of Mine conference and in publication of special edition.

Background

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

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

important considerations in LEM calibration. Remote sensing enables patterns in vegetation to be measured at extents and spatial and temporal scales relevant to landscape evolution.

Progress against plan

- Multi-scale remotely sensed data and field observations collated for integration and input into enhanced vegetation cover growth model developed for CAESAR-Lisflood.
- Initial phase of vegetation growth model development complete.
- Methodology for calibration and validation of vegetation developed.

Key findings

Not applicable as project is not yet sufficiently progressed.

Workplan for 2016–17

- Finalise collation of remotely sensed data for validating landform model predictions of vegetation cover. (September 2016)
- Prepare material for presentation at Life of Mine conference (September 2016)
- Test and validate model predictions of vegetation growth (November 2016).
- Journal paper on development of enhanced vegetation component to CAESAR model (June 2017)

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Conference presentation at Life of Mine 2016.
- (Planned) peer-reviewed journal paper on development of vegetation component of CAEASAR model

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

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

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

Aims

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

Background

This project contributes to the understanding and quantification of the impact that rip lines have on runoff and erosion using the landform evolution model, CAESAR. There are differing ideas on the impacts rip lines have on erosion and runoff off rehabilitated landforms while there is concern regarding the costs associated with the construction of rip lines. This project will of assist with the development and assessment of the final rehabilitated landform at the Ranger mine. It will inform closure on whether rip lines are required on the final landform to reduce both runoff and erosion.

Progress against plan

Slopes or 0, 2, 4, 8 and 12% with rip lines and without rip lines have been modelled using CAESAR for time periods up to six years. Output are being analysed.

Key findings

Initial modelling indicates that riplines reduce runoff when compared to non ripped plots.

Workplan for 2016–17

- Analyse the results for the modelling that has been undertaken, potentially model for periods up to 50 years.
- Write up results by December 2016.

Planned project outputs and associated outcomes

The main outputs for the project will be:

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

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

No publications to date

CC theme: Landform

Monitoring of closure criteria

Project details					
Project title	Determine natural bedload movements (non mine impacted) in Magela and Gulungul Creeks.				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Active		
What business need does this project inform?	Determine natural bedload and channel morphology of Gulungul and Magela Creeks.				
Closure criteria theme (if applicable)	Landform	**Project Priority**	**Relevance** 3	**Timeframe**	2
			Importance 3	**Time buffer**	C
Project number (if already commenced)	RES-2005-005	**Project commencement date**			1/7/2016
		Estimated completion date			1/7/2022
Project duration (months)	60	**Date required**			1/12/2019
In-house or outsourced	External	**Actual completion date**			N/A
Lead team	HGCP	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	N/A				
Project manager	Saynor, Mike	**Project total estimated internal resources (person weeks)**			1
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

- To determine natural bedload movements in Magela and Gulungul Creeks.
- To determine the geomorphic, channel and floodplain characteristics in Gulungul Creek to provide a reference condition for assessing mine site impact and rehabilitation success.

Background

This project will characterise bedload movement in Magela and Gulungul Creeks. The data will be used to determine baseline sediment loads (this includes bedload) for the derivation of a complete sediment budget. The sediment budget will be used as baseline for monitoring the performance of the rehabilitated landform.

The bedload movement in Gulungul Creek is a component of a much larger project investigating the geomorphology, channel and floodplain characteristics in Gulungul Creek. These are being determined to establish baseline catchment conditions against which post rehabilitation conditions can be assessed. Limited bedload data has been collected for both Gulungul and Magela Creeks.

Stream channel stability along Gulungul Creek will be determined by annual dry season measurements of cross sectional change, scour and fill, and bed particle size at numerous locations along the main channel. Data from Gulungul Creek has been collected almost annually during each dry season since 2004. These

data will be used to develop knowledge of the geomorphic behaviour of the creek under current conditions.

Progress against plan

Data for the stream channel stability has been collected since 2004. Whilst the data collection has taken place there has been limited analysis of this data.

Key findings

Initial observations of the annual surveyed cross sections indicate that the banks are relatively stable and there hasn't been any lateral migration of the channel. Changes occur mainly with bed levels as sand moves down the creek channel.

Workplan for 2016–17

- Proposed to set a consultancy with Professor Wayne Erskine to analyse and write up aspects of the channel morphology of Gulungul Creek.
- It is not proposed to undertake any bedload sampling during 2016-17.

The primary outputs for the project are to establish:

- Baseline geomorphic conditions of Gulungul Creek.
- Natural bedload movements in the creeks around the Ranger mine.

The outcome that this project will achieve is an understating of the baseline channel morphology of Gulungul Creeks incorporating natural bedload movements for both Gulungul and Magela Creek.

Planned project outputs and associated outcomes

The primary outputs for the project are:

- SSR/Journal paper on geomorphic characteristics of Gulungul Creek.
- Although not part of 2016–17 year a planned output is to understand the natural rates of bedload movement in the creeks surrounding Ranger Mine.

The outcome that this project will achieve is a better understanding of the geomorphic characteristics of Gulungul Creek, including natural bedload rates.

Planned communication activities

The primary communication activities for the project are:

- Conference presentations.
- Communication to the landform technical working group.
- Publication in peer reviewed journal.

Project publications to date (if applicable)

Erskine, WD, Saynor, MJ, Turner, KA, Whiteside, T, Boyden, J, & Evans, KG (2015). Do suspended sediment and bedload move progressively from the summit to the sea along Magela Creek, northern Australia. *Proceedings of the International Association of Hydrological Sciences* 367 (2015): 283.

Saynor M, Houghton R, Erskine W, Smith B & Crisp E 2010. Cross section, scour chain and particle size data for Gulungul and Ngarradj Creeks: 2006 to 2009. Internal Report 574, April, Supervising Scientist, Darwin.

Saynor MJ & Smith BL 2006. Cross section, scour chain and particle size data for Gulungul and Ngarradj Creeks 2005. Internal Report 514, February, Supervising Scientist, Darwin. Unpublished paper.

Saynor MJ, Smith BL, Fox G & Evans KG 2005. Cross section, scour chain and particle size in Gulungul Creek for 2002 to 2004. Internal Report 500, February, Supervising Scientist, Darwin. Unpublished paper.

CC theme: Radiation (5 projects)

Developing closure criteria

Nil.

CC theme: Radiation

Demonstrating achievement of closure criteria

Project details					
Project title	Radionuclide uptake in traditional Aboriginal foods				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Completed		
What business need does this project inform?	Provides concentration ratios for the uptake of radionuclides in bush foods. Needed as part of the assessment of ingestion doses (and, ultimately, overall doses) to traditional owners and whether or not radiological closure criteria can be met.				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Timeframe**	1
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-1996-002	**Project commencement date**			1/1/1996
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			1/6/2016
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	EnRad	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	JFS				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**			10
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

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

Background

Bush foods form the traditional diet of Aboriginal people. Areas downstream and surrounding Ranger mine serve as bush food reservoirs for Aboriginal people. Concerns have been raised about potential radionuclide contamination of bush foods in these reservoirs due to the operation and pending rehabilitation of the mine. Supervising Scientist has been collecting bush foods and measuring radionuclides in them for more than 30 years, resulting in a substantial database of bush food

radionuclide activity concentrations. This database can be used to calculate bush food concentration ratios and facilitate ingestion dose assessments.

Progress against plan

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

Key findings

- Dose scaling factors between radionuclide levels in terrestrial and aquatic ecosystems and dose from bush foods have been calculated.
- The scaling factors allow radiation doses from bush foods to be estimated once post-rehabilitation radiological conditions are known.

Workplan for 2016–17

- July 2016: Finalise/revise manuscript on concentration ratio tool for journal publication.
- August 2016: Finalise/revise manuscript on bush food dose calculator for journal publication.
- June 2017: Finish all outstanding measurements (limiting factor is detector availability and long counting times)

Planned project outputs and associated outcomes

The primary outputs for the project are:

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

The outcomes that this project will achieve are:

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Past five years:

Doering, C., Bollhöfer, A., Medley, P., 2016. Estimating doses from Aboriginal bush foods post-remediation of a uranium mine. *Journal of Environmental Radioactivity* (submitted for review).

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

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

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

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

Project details					
Project title	Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Completed		
What business need does this project inform?	Knowledge of the radon-222 source term for the rehabilitated landform, which is needed to assess the radon-222 inhalation pathway.				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 1	**Timeframe** 1	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	N/A	**Project commencement date**		1/1/2012	
		Estimated completion date		1/9/2015	
Project duration (months)	72	**Date required**			
In-house or outsourced	Internal	**Actual completion date**		1/9/2015	
Lead team	EnRad	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	JFS				
Project manager	Bollhoefer, Andreas	**Project total estimated internal resources (person weeks)**			
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- To measure radon-222 exhalation flux densities from waste rock, including seasonal and longer-term variability.
- To determine a value for the radon-222 exhalation flux density normalised to radium-226 activity concentration in waste rock.

Background

Radon-222 is a radioactive gas produced through the decay of radium-226 in the uranium decay series. It exhales from rocks and soils into the atmosphere where it is transported and dispersed by wind. The decay of radon-222 produces a series of short-lived radioactive progeny that can deliver a dose upon inhalation.

The proposed rehabilitation strategy for Ranger uranium mine is to build a final landform overlaid with several metres of waste rock. Radioactivity levels in waste rock are elevated compared to the surrounding environment. The final landform will thus be a source of above-background radiation exposure to traditional owners and the regional community. All pathways contributing to above-background radiation exposure must be assessed to provide assurance that doses do not exceed dose limits.

This project will provide site-specific information that enables characterisation of the radon-222 source term for the rehabilitated landform in dose assessment models.

Progress against plan

- More than 1000 radon exhalation flux density measurements made over 5-years, covering both wet and dry seasons.

- Measurements made of the radium-226 activity concentration in waste rock.
- Data analysed to determine the radon-222 exhalation flux density normalised to radium-226 activity concentration in waste rock.

Key findings

- Radon-222 exhalation flux density is higher in the dry season than in the wet.
- Dry season radon-222 exhalation flux density increased over the 5-year study period due to weathering of the waste rock into finer particles.
- The dry season radon-222 exhalation flux density normalised to radium-226 activity concentration in waste rock was 0.47 mBq m^{-2} s^{-1} per Bq kg^{-1}.

Workplan for 2016–17

Not applicable, project complete.

Planned project outputs and associated outcomes

Value for radon-222 exhalation flux density normalised to radium-226 activity concentration in waste rock that can be used to characterise the radon-222 source term for the rehabilitated landform in dose assessment models.

Planned communication activities

Presentation at SPERA2014 and publication in Journal of Environmental Radioactivity.

Project publications to date (if applicable)

Bollhofer A & Doering C 2016. Long-term temporal variability of the radon-222 exhalation flux from a landform covered by low uranium grade waste rock. Journal of Environmental Radioactivity 151, 593-600.

Project details					
Project title	Environmental fate and transport of Ac-227 and Pa-231				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Addresses whether or not actinium series radionuclides are of radiological significance to people and non-human biota, and will enable their incorporation into dose estimates to compare against closure criteria.				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Timeframe**	3
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2015-004	**Project commencement date**			1/2/2015
		Estimated completion date			1/2/2021
Project duration (months)	60	**Date required**			1/12/2019
In-house or outsourced	Internal	**Actual completion date**			N/A
Lead team	EnRad	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	ANU				
Project manager	Medley, Peter	**Project total estimated internal resources (person weeks)**			20
Project sponsor	Doering, Che	**Project total estimated collaborator resources (person weeks)**			24

Aims

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

Background

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

to the natural state creating the potential for these isotopes to be released into the environment and potentially leading to increased exposure to ionising radiation for humans and non-human biota.

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

Progress against plan

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

Key findings

No key findings yet as project is still in its initial stages.

Workplan for 2016–17

- Calibration of the Accelerator Mass Spectrometer for measurement of protactinium-231 and the Liquid Scintillation Counter for measurement of actinium-227
- Assessment of potential chemical analogues of Ac and Pa for estimating concentration ratios in traditional bush foods and non-human biota
- Development of a sample preparation protocol for samples requiring measurement of actinium-227 and protactinium-231
- Measurement of actinium-227 via LSC on a limited suite of environmental samples

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Development of methods for:
  - preparation of a protactinium-233 tracer for radiochemical measurement of protactinium-231
  - separation of protactinium-231 from environmental samples and measurement via Accelerator Mass Spectrometry (AMS)separation of actinium-227 in environmental samples and measurement via Liquid Scintillation Counting (LSC)
- Measurement of protactinium-231 via AMS and actinium-227 via LSC on a selected suite of environmental samples

The outcomes that this project will achieve are:

- An understanding of the contribution of actinium-series radionuclides to the RUM whole-of-site dose model

Planned communication activities

The primary communication activities for the project are:

- Reporting and presentations to key stakeholders as necessary.

- Reporting in Supervising Scientist Annual Technical Report
- Publication in a scientific journal on: methods for the preparation of a protactinium-233 tracer, for separation of protactinium-231 from environmental samples and measurement of protactinium-231 via AMS; methods for the separation of actinium-227 from environmental samples and measurement via Liquid Scintillation Counting (LSC); results from LSC measurements of actinium-227 in a selected suite of environmental samples and implications for the RUM whole-of-site dose model; and results from AMS measurements of protactinium-231 in a selected suite of environmental samples.

Project publications to date (if applicable)

None.

Project details					
Project title	Atmospheric dispersion of radon and radon daughters from the rehabilitated landform				
SSB function	Research	**Site**	Ranger		
Project category	Demonstrating achievement of closure criteria	**Project status**	Active		
What business need does this project inform?	Models the activity concentration of radon in air as a function of distance and direction from the rehabilitated landform. Needed as part of the assessment of inhalation doses (and, ultimately, overall doses) to traditional owners and whether or not radiological closure criteria can be met.				
Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Timeframe**	1
			Importance 2	**Time buffer**	A
Project number (if already commenced)	RES-2014-004	**Project commencement date**			1/2/2016
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			1/6/2016
In-house or outsourced	External	**Actual completion date**			N/A
Lead team	EnRad	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	ANSTO				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**			6
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			4

Aims

- To model the atmospheric dispersion of radon and radon progeny from the Ranger rehabilitated landform
- To estimate doses to Aboriginal people from radon and radon progeny coming from the rehabilitated landform
- To demonstrate (in part) the achievement of radiological closure criteria for the mine

Background

Radon-222 is an inert radioactive gas formed from the decay of radium-226 in the uranium decay series. When radium-226 in soil or rock decays, the resulting radon-222 atom can emanate into the pore space, be transported to the ground surface and exhale to the atmosphere. It is then dispersed in the atmosphere by wind and thermal currents. When radon-222 decays it produces a series of short-lived progeny radionuclides. Unlike radon, these progeny radionuclides are metals (not gases) and can attach to aerosols. The main contribution to dose from the radon exposure pathway comes from the inhalation of progeny radionuclides because of their retention in the lung tissue and subsequent alpha decay. Radon-222 itself does not contribute much to inhalation dose, as it is immediately exhaled from the lung, with little decay occurring inside the lung due to its long half-life of ~3.8 days.

The current rehabilitation strategy for Ranger mine involves the creation of a final landform overlaid with several metres of waste rock. Waste rock (or grade 1 material) contains approximate equilibrium activity concentrations of uranium decay series radionuclides of up to 2100 Bq/kg. This is distinctively elevated

compared to the surrounding natural environment (~30–100 Bq/kg) and the average pre-mining baseline of the Ranger site (~260 Bq/kg). Thus, the rehabilitated landform looms as a source of above baseline radon progeny exposure to Aboriginal people using the landform and surrounding environment of Kakadu National Park.

Progress against plan

- Atmospheric dispersion modelling of radon from the rehabilitated landform undertaken by the Australian Nuclear Science and Technology Organisation (ANSTO) using the RESRAD OFFSITE computer code developed by the United States Department of Energy.
- The dispersion modelling has provided flux-dose scaling factors for radon coming from the rehabilitated landform at on- and off-site locations out to 10 km.

Key findings

No key findings yet. Once the results of this project have been combined with those from the radon exhalation project, key results will indicate potential radiological significance (i.e. doses) to the public.

Workplan for 2016–17

- July–August: Flux-dose scaling factors to be adjusted for site-specific radon exhalation fluxes previously measured for waste rock (dry and wet season)
- September–October: Investigate the possibility of developing a radon dose calculator or dose-distance maps
- November–December: Final results to be written up as journal paper

Planned project outputs and associated outcomes

The primary output for the project is:

- Scaling factors between radium-226 activity concentration in surface waste rock on the rehabilitated landform and dose to Aboriginal people at various locations on- and off-site of the landform.

The outcome that this project will achieve is:

- Demonstrating (in part) the achievement of radiological closure criteria for the mine

Planned communication activities

The primary communication activities for the project are:

- Publication of results in Supervising Scientist Annual Technical Report and scientific journal.
- Reporting and presentations to key stakeholders as necessary.

Project publications to date (if applicable)

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

Project details			
Project title	Dose rates to non-human biota		
SSB function	Research	**Site**	Ranger
Project category	Demonstrating achievement of closure criteria	**Project status**	Active
What business need does this project inform?	Provides an estimate of dose rates to non-human biota. Needed to compare to closure criteria and assess overall radiological protection of aquatic and terrestrial ecosystems.		

Closure criteria theme (if applicable)	Radiation	**Project Priority**	**Relevance** 2	**Timeframe** 1	
			Importance 2	**Time buffer** A	
Project number (if already commenced)	RES-2012-002	**Project commencement date**			1/5/2016
		Estimated completion date			1/12/2016
Project duration (months)	6	**Date required**			1/6/2016
In-house or outsourced	External	**Actual completion date**			N/A
Lead team	EnRad	**Reason for project delay (where applicable)**			N/A
Supporting team(s)	ARPANSA				
Project manager	Doering, Che	**Project total estimated internal resources (person weeks)**			6
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**			N/A

Aims

- To estimate radiation doses to aquatic non-human biota post-rehabilitation of Ranger mine
- To demonstrate the achievement of radiological closure criteria for aquatic non-human biota

Background

The International Commission on Radiological Protection has recognised the need to consider radiation exposures to non-human biota in addition to those to people. The reason being is to demonstrate directly and provide greater confidence that the environment is protected from deleterious radiological impacts.

The Ranger rehabilitated landform may be a source of elevated radionuclide activity concentrations to the creeks and waterbodies surrounding the site due to rainfall runoff and the expression of groundwater impingent on buried tailings and waste. These elevated water concentrations will give rise to elevated dose rates to aquatic non-human biota. These dose rates need to be assessed and compared to agreed benchmark values in order to determine whether the aquatic environment is likely to suffer significant radiological harm.

Progress against plan

- Memoranduum of understanding established with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) to undertake the work.
- Tissue to whole organism conversion factors calculated to convert concentration ratio data into the required format for wildlife dose assessment.
- Whole organism concentration ratios calculated from site-specific data.

- Sediment-water distribution coefficients calculated from site-specific data.
- Scaling factors calculated between radionuclide activity concentrations in water and dose rates to aquatic organisms.
- Draft report received from ARPANSA

Key findings

No key findings yet as draft report is still under review.

Workplan for 2016–17

- July 2016: Determination of tissue to whole organism conversion factors for radionuclides
- August 2016: Determination of whole organism concentration ratios for selected wildlife groups (internal exposure pathway)
- September 2016: Determination of in situ sediment-water distribution coefficients for radionuclides (external exposure pathway)
- October 2016: Determination of concentration-dose scaling factors between radionuclide activity concentrations in water and dose rates to aquatic organisms
- November 2016: Written report from ARPANSA of methods and results
- December 216–January 2017: Write up of paper for scientific journal

Planned project outputs and associated outcomes

The primary output for the project is:

- Concentration-dose scaling factors that allow dose rates to aquatic non-human biota to be calculated directly from water radionuclide activity concentrations

The outcome that this project will achieve is:

- Demonstration of the achievement of radiological closure criteria for aquatic non-human biota

Planned communication activities

The primary communication activities for the project are:Reporting and presentations to key stakeholders as necessary.

- Reporting in Supervising Scientist Annual Technical
- Report and scientific journal

Project publications to date (if applicable)

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

CC theme: Radiation

Monitoring of closure criteria

Nil.

CC theme: Flora and fauna (5 projects)

Developing closure criteria

Project details					
Project title	Evaluation of aquatic vegetation data				
SSB function	Research	**Site**	All		
Project category	Developing closure criteria	**Project status**	Completed		
What business need does this project inform?	Assessing impacts of surface water runoff from current operations and the final landform on aquatic vegetation				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 1	**Timeframe** 1	
			Importance 1	**Time buffer** A	
Project number (if already commenced)	RES-2014-010	**Project commencement date**		1/12/2014	
		Estimated completion date		29/5/2015	
Project duration (months)		**Date required**			
In-house or outsourced	Internal	**Actual completion date**		N/A	
Lead team	AEP	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Chandler, Lisa				
Project manager	George, Amy	**Project total estimated internal resources (person weeks)**		0	
Project sponsor	Humphrey, Chris	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- Address the gap in understanding about the spatial and temporal variations in aquatic plant communities in natural and mine-disturbed waterbodies adjacent to Ranger
- Use this knowledge to inform establishment methods and targets for rehabilitation of aquatic systems both on- (within the RPA) and offsite.

Background

A review of aquatic ecosystem literature for the ARR highlighted a knowledge gap related to aquatic vegetation. While aquatic vegetation data are collected as the 'habitat' component of current monitoring projects on macro invertebrate and fish communities, these data have not been analysed and evaluated for their own value, both in terms of responses of aquatic vegetation to natural and mine-related stressors, and in the context of ecosystem establishment and rehabilitation targets. Such an evaluation was

proposed during the ARRTC meeting in November 2014. It was agreed that evaluation of current data would be beneficial for determining variation in aquatic vegetation.

This project contributes to knowledge needs associated with the effects of mine waste waters upon aquatic vegetation both during current operations and at closure.

The project also benefits the core work of the Supervising Scientist by comprehensively evaluating vegetation habitat data from each (macro invertebrate and fish) monitoring project. This will add value to the data already being collected.

Progress against plan

Key findings

Results were reported in the Supervising Scientist's Annual Report for 2014-15 (Section 4.3) with additional analyses reported in Humphrey and Chandler (in review). (Latter is an SSR titled: Use of field-effects information to inform surface water closure criteria for magnesium sulfate in Magela Creek.)

No strong relationships were observed between aquatic vegetation and water quality in ARR waterbodies, including natural billabongs on the Ranger minesite.

The key researcher undertaking these studies left SSB in late 2015 and so no further work has been undertaken. Remaining work has not been regarded as high priority at this stage.

Workplan for 2016–17

Planned project outputs and associated outcomes

Outcomes

- Characterisation of aquatic vegetation community composition
- Characterisation of spatial (different types of billabongs) and temporal compositional variation in aquatic vegetation communities (potential shifts between seasons and years)

Outputs

- Database–Comprehensive compilation of aquatic vegetation data from multiple monitoring projects
- Report–Conveyance of key findings from the desktop analyses related to rehabilitation and management of observable aquatic vegetation on- and off-site of Ranger.

Planned communication activities

Project publications to date (if applicable)

Supervising Scientist 2015. Annual Report 2014–15, Commonwealth of Australia. Section 4.3, Analysis of aquatic vegetation community data from shallow waterbodies of the Alligator Rivers Region. Pp. 80–86.

Project details					
Project title	Quantifying trajectories for savanna habitat at Ranger to inform revegetation closure criteria				
SSB function	Research	**Site**	Ranger		
Project category	Developing closure criteria	**Project status**	Active		
What business need does this project inform?	Develop and monitor closure criteria				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 1	**Timeframe** 2	
			Importance 2	**Time buffer** D	
Project number (if already commenced)	RES-2013-002	**Project commencement date**		1/9/2015	
		Estimated completion date		1/11/2016	
Project duration (months)	5	**Date required**		1/11/2018	
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	R&L	**Reason for project delay (where applicable)**		Other priorities have impacted on the delivery time of this project	
Supporting team(s)	University of Tasmania				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**		25	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

- Develop a timeline of landscape disturbances and change for Kakadu National Park, and in particular the Ranger mine site area (1950-2015).
- Characterise vegetation change for a 'stable' temporal envelope (1996-2015) using the aerial photography record.
- Characterise vegetation recovery using the aerial photography record, (a) immediately post BTEC from 1996, and (b) post Cyclone Monica (from 2006)
- Characterise vegetation trajectory under a disturbance regime (1950 – 1981) using the aerial photography record.

Background

It is important that closure criteria and our understanding of analogue sites for the Ranger mine site, are developed in the context of temporal change in the landscape and disturbance of the site. The Environmental Requirements refer specifically to revegetation under the primary environmental objectives for rehabilitation: "revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park".

There are both spatial and temporal components in this objective that need to be addressed and a landscape ecology approach is an appropriate framework to do this by. The aerial photography record provides a suitable dataset to analyse vegetation change and trajectories for the surrounding environment at Ranger mine site 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 not the whole picture. A major limitation of all ground-based surveys is that only small samples in the landscape are taken. A landscape approach, such as deriving measures from remote sensing, provides a total dataset to compare an area of interest with the surrounding landscape. More importantly, natural variability, change and disturbance have not been taken into account in previous research.

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

Progress against plan

- Obtained digital aerial photographs and pre-processed registered mosaics for further analysis: 1950, 1964, 1976, 1978, 1981, 1984, 1987, 1991, and 2004.
- Processed WorldView-3 data for 2016 to include in the analysis.
- Landscape change timeline completed.
- Developed and applied rule sets for extraction of vegetation parameters.
- Rule set validation completed.
- Compiled descriptive statistics on tree cover, change in tree cover and fate attributes derived from landscape metrics.

Key findings

Workplan for 2016–17

- Source and process 2010 and 2016 satellite imagery (July 2016)
- Validate rule sets for extraction of vegetation cover for analysis for all years (August 2016).
- Generate shape files using landscape metrics for change analysis (October 2016).
- Analysis of changes in landscape metrics and production of statistical results for reporting (December 2016).
- Statistical inference with parameters such as fire, rainfall and buffalo–to be undertaken in collaboration with the University of Tasmania (April 2017).
- Reporting and journal paper production (May 2017).

Planned project outputs and associated outcomes

The primary outputs for the project are:

- Historical digital air photo mosaics of the Ranger area that can be used for spatial analysis (1950, 1964, 1776, 1978, 1984, 1987, and 2004 including satellite imagery for 2010 and 2016).
- Quantitative methods for assessing vegetation change from aerial photography records.
- A spatial definition of adjacency in the context of the Environmental Requirements.
- Report to the Closure Criteria Working Group with key recommendations for setting vegetation closure criteria.

- Timeline infographic completed in collaboration with PAA. Made available for presentations and closure criteria technical working groups.
- Internal report: Documentation of data, methods, rule sets, tool boxes and validation processes.
- Journal paper: Woody cover mapping method compared with traditional ecological methods.
- Journal article: landscape metrics tool box and application to savanna temporal.
- Journal paper: Time series of decadal change in savanna.

The outcomes that this project will achieve are:

- Characteristics of savanna habitat over a 'stable' temporal scale that can be used to specify a trajectory for closure criteria.
- Timeline of landscape changes and disturbances for the region will provide a useful guide for the flora and fauna closure criteria sub-group. It provides a history and context when setting and reviewing criteria.
- By looking at recovery period, we may be able to provide a timeline for when monitoring for closure criteria is no longer required (i.e. can the site be closed out based on revegetation?).
- If density is a suitable closure criteria and monitoring measure we can provide a numerical range for criteria to be set on. If density is found not to be a suitable closure criteria and monitoring measure, the project will be able to suggest an alternative.
- The information produced by this project can be used to inform the revegetation strategy.

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

No publications to date. Refer to planned project outputs for scheduled publications.

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

Aims

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

Background

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

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

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

Progress against plan

Not applicable – this is a new project.

Key findings

Workplan for 2016–17

- Review existing vegetation analogue research and catalogue the data (February 2017)
- Compare existing analogue data to data derived from remotely sensed imagery and map those communities at landscape scale using Random Forest Classifier (RFC) approach (March 2017)
- Use species information from existing analogue research and scale to develop closure criteria for the rehabilitated area (May 2017)
- Preliminary assessment of understorey characteristics using existing UAV data over an analogue site (May 2017)
- Synthesis of information from above activities and communication activities (June 2017)

Planned project outputs and associated outcomes

The primary outputs for the project are:

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

The outcomes that this project will achieve are:

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

Planned communication activities

The primary communication activities for the project are:

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

Project publications to date (if applicable)

Not applicable – this is a new project.

CC theme: Flora and fauna

Demonstrating achievement of closure criteria

Nil.

CC theme: Flora and fauna

Monitoring of closure criteria

Project details					
Project title	Preliminary mapping of groundwater dependent ecosystems (GDEs) on the Ranger Lease.				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Completed		
What business need does this project inform?	Identifies areas to monitor for potential environmental impacts.				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 3	**Timeframe** 3	
			Importance 3	**Time buffer** C	
Project number (if already commenced)	RES-2015-010	**Project commencement date**		2/2/2015	
		Estimated completion date		30/4/2015	
Project duration (months)	3	**Date required**		30/4/2015	
In-house or outsourced	Collaboration	**Actual completion date**		30/4/2015	
Lead team	RLE	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Charles Darwin University Student Placement Project				
Project manager	Bartolo, Renee	**Project total estimated internal resources (person weeks)**		2	
Project sponsor	Van Dam, Rick	**Project total estimated collaborator resources (person weeks)**		N/A	

Aims

The aim of this project was to produce a preliminary map of the distribution of groundwater dependent ecosystems (GDEs) on the Ranger Project Area (RPA).

Background

This project was a student professional placement project undertaken by a student from Charles Darwin University.

The seepage to groundwater to surface water pathway was identified as stressor pathway when developing conceptual models of stressor pathways and assessing relative importance of pathways during the operational phase of ranger Mine. With Ranger Mine entering the decommissioning phase, this pathway is of increasing importance. This pathway involves the potential transport of stressors via seepage from the mine site to groundwater and then to the water column within Magela and Gulungul creeks or their

tributaries. In this context GDEs are a potential reviving habitat for stressors transported by this pathway (i.e. inorganic toxicants, radionuclides and organic toxicants).

GDEs may be a useful habitat to monitor for any potential impacts from groundwater transported stressors. To investigate this further, we need an understanding of the location and type of GDEs present on the Ranger Lease.

Preliminary mapping undertaken with existing data (e.g. the GDE Atlas) will provide a high level screening of GDEs and subsequent satellite imagery analysis will highlight areas for further investigation.

Progress against plan

Completed project.

Key findings

There are limited existing spatial data directly related to GDEs for the RPA. Neither aquifer data nor detailed spatial data is readily accessible. Therefore the accuracy of the output mapping product is limited. The purpose of this project was to provide a preliminary base map for potential GDE's in the local region using available datasets and existing mapping methodologies. Potential data gaps for GDEs highlighted by this project could be further investigated through the use of Remotely Piloted Aircraft Systems (RPAS).

Terrestrial GDEs were distinguished visually from remote sensing images according to their vegetation vigour (greenness) in the late dry season. The accuracy of this process could be significantly improved by using NDVI or other spectral analysis using high resolution remotely sensed data. The identification of potential terrestrial GDEs highlights areas for further investigation.

Workplan for 2016–17

Completed project

Planned project outputs and associated outcomes

The outcome was to provide SSB with a better understanding of the location of GDEs at Ranger and the type of GDEs found in the local region. This in turn will inform the ecological risk assessment of the rehabilitation and closure phases of the mine as well as current assessments of issues on site (such as the salts in the region west of the TSF).

This project may highlight potential data gaps for GDEs that could be addressed through the use of the UAV.

Specific outputs were:

Internal report providing a summary of the datasets used to produce a GDE GIS coverage and the approach/methods undertaken for mapping GDEs.

GIS coverage–GIS file showing GDEs for the Ranger Lease based on the Queensland GDE Mapping and Classification method.

Planned communication activities

Publication of the internal report.

Project publications to date (if applicable)

Li, X & Bartolo, R 2016. Preliminary mapping of Groundwater Dependent Ecosystems (GDEs) on the Ranger Lease. Internal Report 635, October, Supervising Scientist, Darwin.

Project details					
Project title	Development of a low cost method for continuous monitoring of water stress in eucalypt vegetation on a rehabilitated mine site.				
SSB function	Research	**Site**	Ranger		
Project category	Monitoring of closure criteria	**Project status**	Active		
What business need does this project inform?	Develop and monitor closure criteria				
Closure criteria theme (if applicable)	Flora and Fauna	**Project Priority**	**Relevance** 3	**Timeframe** 3	
			Importance 3	**Time buffer** C	
Project number (if already commenced)	RES-2013-017	**Project commencement date**		1/7/2013	
		Estimated completion date		28/2/2017	
Project duration (months)	10	**Date required**			
In-house or outsourced	Collaboration	**Actual completion date**		N/A	
Lead team	RLE	**Reason for project delay (where applicable)**		N/A	
Supporting team(s)	Charles Darwin University				
Project manager	Esparon, Andrew	**Project total estimated internal resources (person weeks)**		4	
Project sponsor	Bartolo, Renee	**Project total estimated collaborator resources (person weeks)**		2	

Aims

The project aims are:

- Determine spectral changes in both E. miniata and E. tetradonta due to water stress using a spectrometer.
- Develop a low cost Light Emitting Diode (LED) continuous monitoring of vegetation regrowth on the Ranger TLF.
- Determine the relationship between stomatal conductance and leaf temperature. Specifically, how to remotely monitor E. miniata and E. tetradonta stomatal conductance via plant/leaf temperature.
- Deploy a number of LED devices with a built-in infrared temperature sensor to continuously monitor both E. miniata and E. tetrodonta on the trial landform.

Background

Ranger mine site is entering the rehabilitation and closure phase where monitoring and assessment of early revegetation efforts needs to be undertaken in a cost and time effective manner. A traditional remote sensing method for monitoring plant vigour and health involves using a field spectrometer to calculate Spectral Vegetation Indices (SVIs) such as the commonly used Normalised Difference Vegetation Index (NDVI). These measurements can be taken in the field with a spectrometer, but the advantage of a simple spectroradiometer in the form of an LED is that the device is low cost, stable, and enables continuous measurement of the NDVI and other SVIs.

These measurements can be used to determine the health of the vegetation and the fraction of vegetation green cover. More importantly, the continuous measurements will enable investigation of diurnal and annual variations in vegetation structure and metabolism allowing early detection of water stress on the final rehabilitated mine site.

Progress against plan

- Potted trials of E. tetradonta and E. miniata conducted to determine spectral characteristics of water stress.
- Five LEDs constructed and deployed to the TLF for the 2014 and 2015 dry seasons for water stress testing and stomatal conductance measurements.
- Data collected and analysed.

Key findings

Preliminary results show that the LED sensors are able to record fluctuations in plant health that can be related to water stress. The inclusion of a built-in infrared tempertaure sensor was used to monitor leaf tempertaure which controls stomatal conductance which can be indicative of water stress also.

The temperature sensor is a more timely and sensitive measure for water stress when compared with the spectral measurement.

The method developed can potentially be adapted to detect early signs of water stress using a remotely piloted aircraft (RPA) with a hyperspectral and thermal sensors, across a revegetated site.

Workplan for 2016–17

Internal Report to be completed in Q1 2017

Planned project outputs and associated outcomes

The knowledge gained from this project will contribute to assessing the success of mine site rehabilitation by detecting changes in ecosystem condition as they relate to mine closure criteria and will contribute to the research and development of a remotely sensed monitoring program for mine site rehabilitation.

The outputs include:

LED sensors designed and built.

Internal Report documenting the method development and data collection and analysis.

Planned communication activities

Publication of an internal report.

Project publications to date (if applicable)

No publications to date.

Other sites

Research
Nil.

Monitoring
Nil.

APPENDIX 4 PROJECT SCHEDULING RELATIVE TO TIMELINES FOR THE DEVELOPMENT OF CLOSURE CRITERIA

Notes: There may be some minor discrepancies between the information here and the final project summaries in Appendix 3, due to minor revisions/updates to the latter upon preparing the report.

Figure A4.1 Water and sediment closure criteria

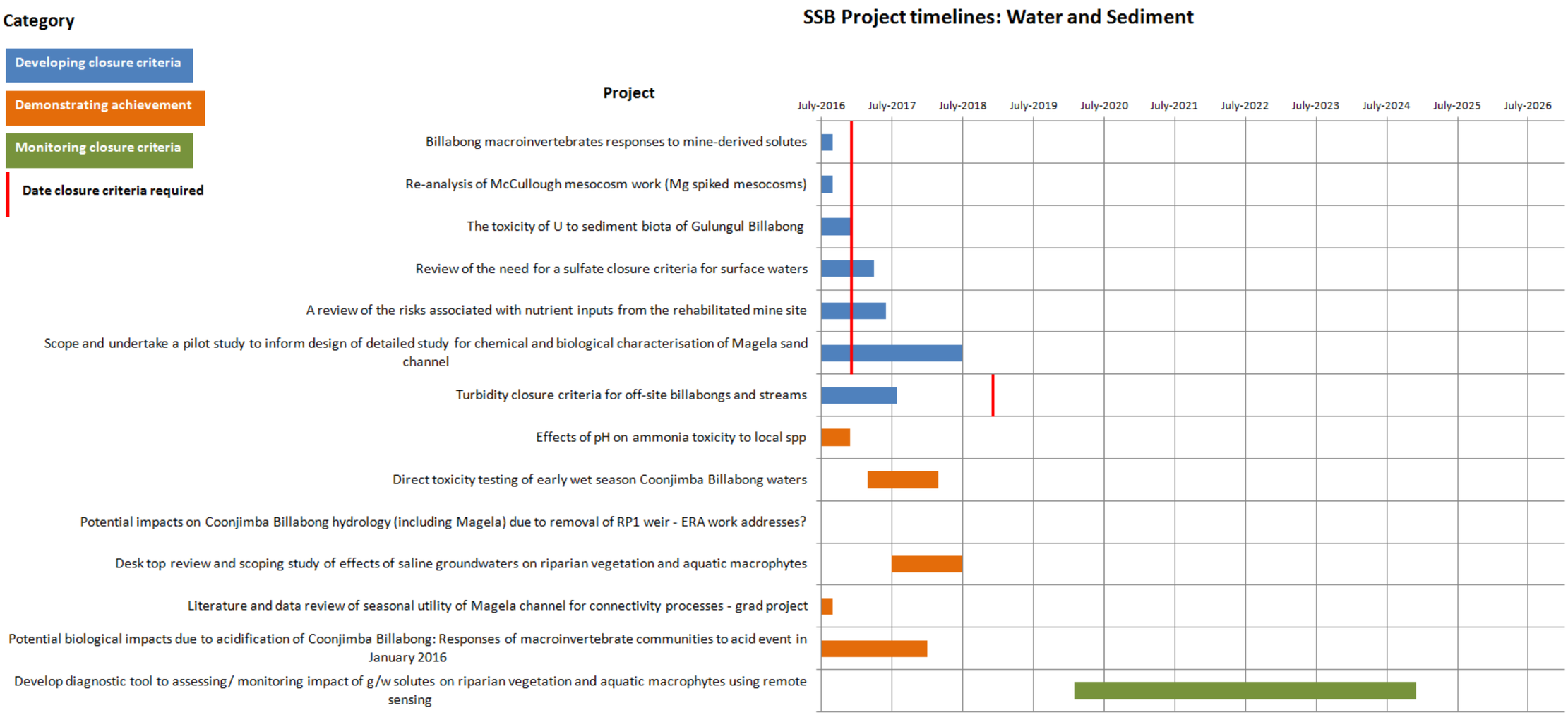


Figure A4.2 Landform closure criteria

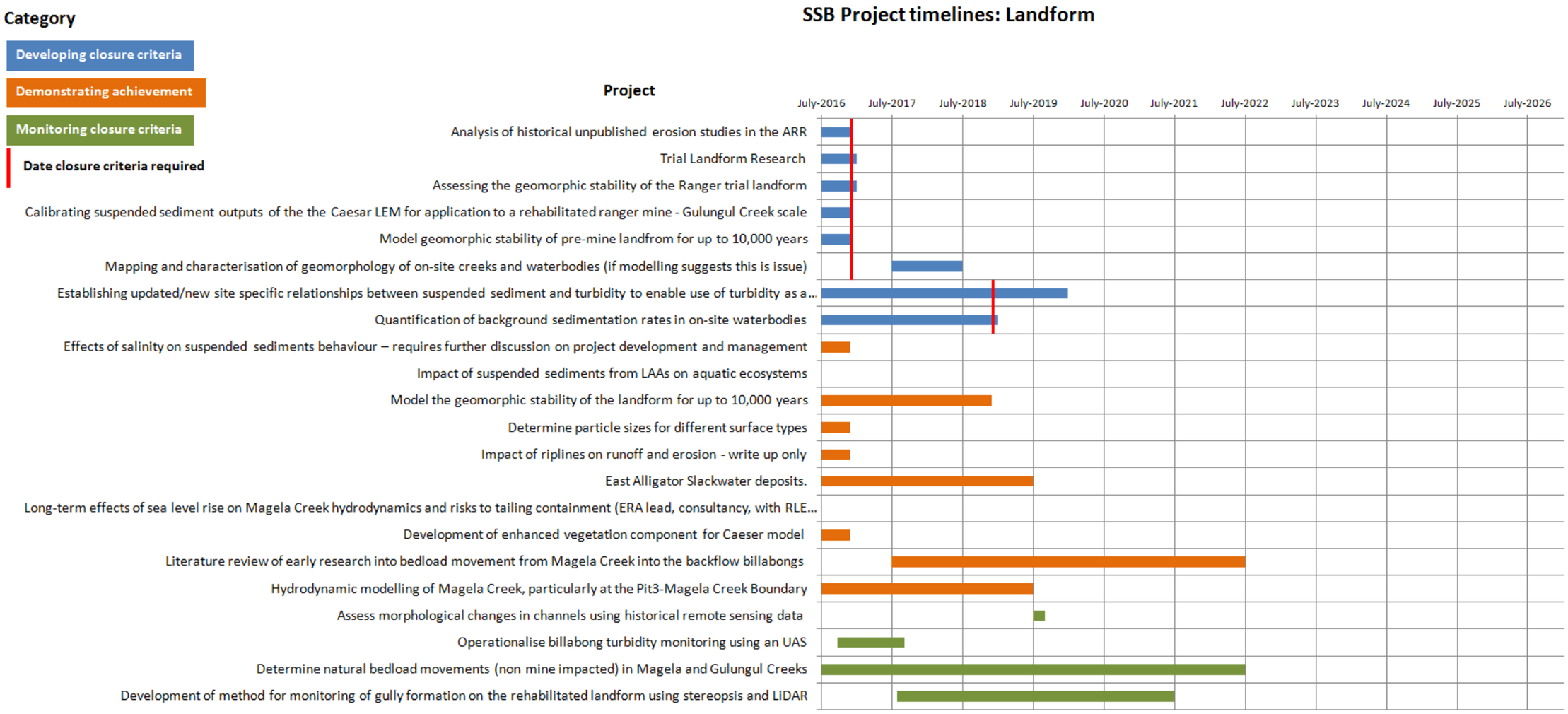


Figure A4.3 Radiation closure criteria

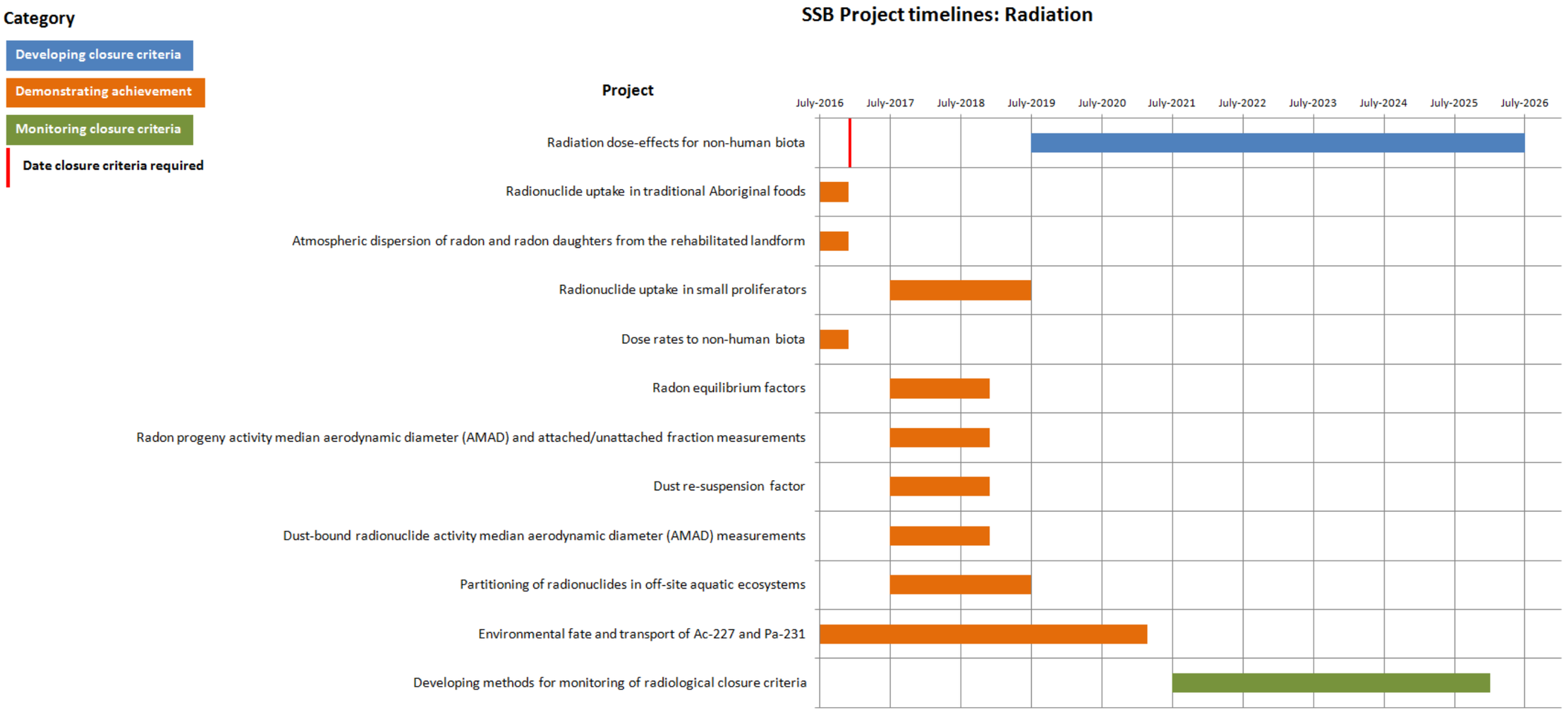
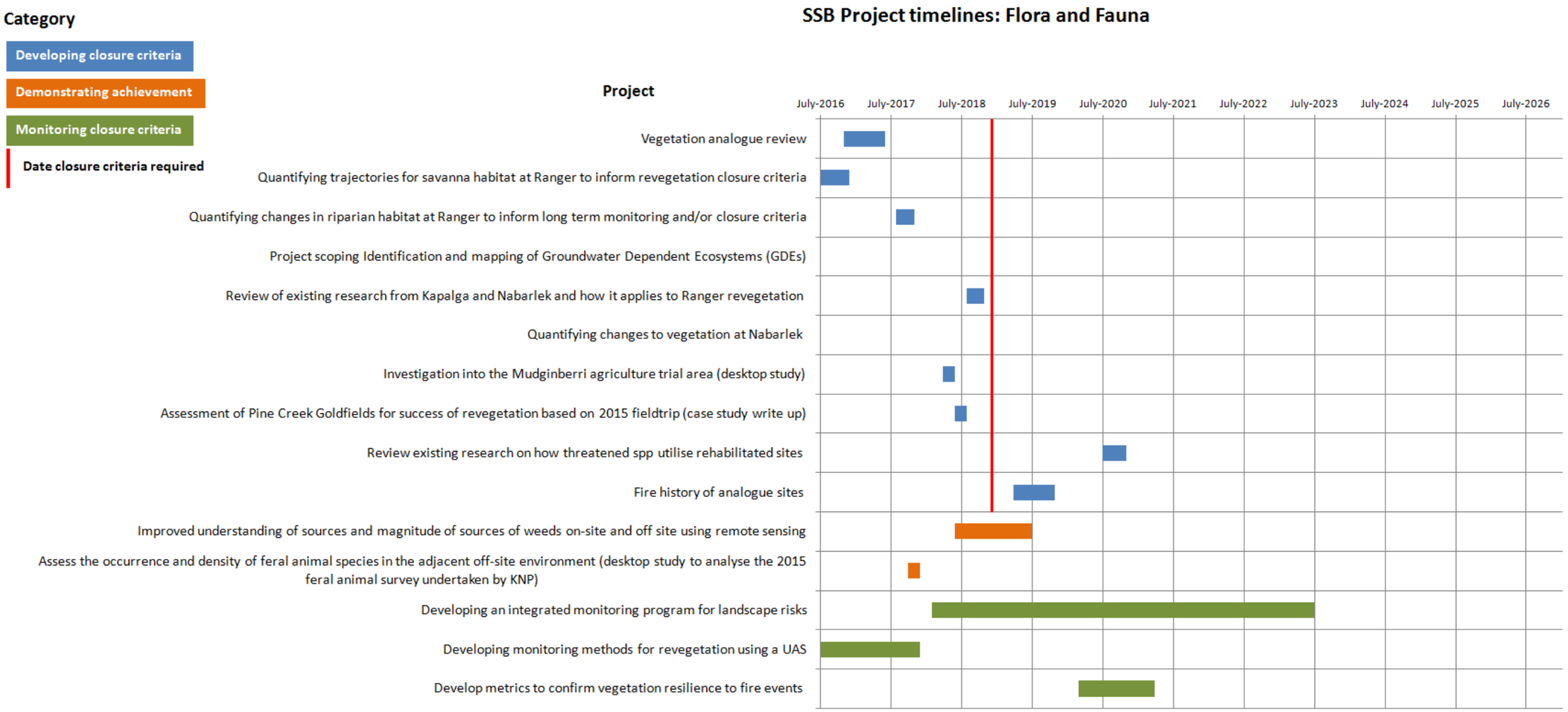


Figure A4.4 Flora and fauna closure criteria



GLOSSARY OF TERMS, ABBREVIATIONS AND ACRONYMS

ANOVA	ANalysis of VAriance testing
application	A document stating how the mining operator proposes to change the conditions set out in the mining Authorisation. These changes need to be approved by all MTC stakeholders.
AREVA	AREVA, France – (formerly - Afmeco Mining and Exploration Pty Ltd)
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARR	Alligator Rivers Region
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
authorisation	For mining activities authorisation is required under the Northern Territory *Mining Management Act 2008* (MMA*)* for activities that will result in substantial disturbance of the ground. It details the authorised operations of a mine, based on the submitted mining management plan and any other conditions that the Northern Territory Minister considers appropriate.
BACIP	Before-After Control-Impact Paired design
Bq (becquerel)	SI unit for the activity of a radioactive substance in decays per second [s^{-1}].
CC (Closure Criteria)	Performance measures used to assess the success of minesite rehabilitation.
concentration factor	The metal or radionuclide activity concentration measured in biota divided by the respective concentration measured in the underlying soil (for terrestrial biota) or water (for aquatic biota).
CCWG	Closure Criteria Working Group
CDU	Charles Darwin University
DME	Northern Territory Department of Mines and Energy (formerly Northern Territory Department of Resources)
dose coefficient	The committed tissue equivalent dose or committed effective dose Sievert [Sv] per unit intake Becquerel [Bq] of a radionuclide. See definition of Sievert and Becquerel.
dose constraint	The International Commission on Radiation Protection (ICRP) defines dose constraint as '*a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation*' for assessing site remediation options.
early detection	Measurable early warning biological, physical or chemical response in relation to a particular stress, prior to significant adverse effects occurring on the system of interest.
EC (electrical conductivity)	A measure of the total concentration of salts dissolved in water.
ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
ERs	Environmental Requirements
GCT2	Gulungul Creek Tributary 2
GCUS	Gulungul Creek Upstream (upstream monitoring site)
GDEs	groundwater dependent ecosystems
half-life	Time required to reduce by one-half the concentration (or activity in the case of a radionuclide) of a material in a medium (e.g. soil or water) or organism (e.g. fish tissue) by transport, degradation or transformation.
ICRP	International Commission on Radiological Protection
ionising radiation	Sub-atomic particles (α, β) or electromagnetic (γ, x-rays) radiation that have enough energy to knock out an electron from the electron shell of molecules or atoms, thereby ionising them.
in situ	a Latin phrase that translates to 'on site'
IT	Information Technology

IWMP	Interim Water Management Pond
JFS	Jabiru Field Station
KKN	Key Knowledge Needs
KNP	Kakadu National Park
LAA	Land Application Area
laterite	In the Ranger mine context, laterite is a local term used to describe well weathered rock and soil profile material that consists primarily of a mixture of sand and silt/clay size particles. It may or may not exhibit characteristics of a fully-developed laterite profile.
LC50	The concentration of a compound that causes the death of 50% of a group of organisms relative to that of a control group of organisms (i.e. a group of organisms not exposed to the compound).
LLAA	Long-lived alpha activity
mRL	Reduced Level metres
MTC	Minesite Technical Committee
NT	Northern Territory
ore	A type of rock that bears minerals, or metals, which can be extracted.
OSS	Office of the Supervising Scientist
PAEC	Potential alpha energy concentration
PERMANOVA	PERmutational Multivariate Analysis Of Variance testing
permeate	The higher purity stream produced by passage of water through a reverse osmosis (RO) treatment process.
pH	a measure of the acidity or basicity of an aqueous solution
polished	Water that has been passed through a wetland filter.
polonium (Po)	A radioactive chemical element that is found in trace amounts in uranium ores.
pond water	Water derived from seepage and surface water runoff from mineralised rock stockpiles as well as runoff from the processing areas that are not part of the process water circuit.
process water	Water that has passed through the uranium extraction circuit, and all water that has come into contact with the circuit. It has a relatively high dissolved salt load constituting the most impacted water class on site.
RAA	Radiologically Anomalous Area. Area that displays significantly above background levels of radioactivity.
radionuclide	An atom with an unstable nucleus that loses its excess energy via radioactive decay. There are natural and artificial radionuclides. Natural radionuclides are those in the uranium (^{238}U), actinium (^{235}U) and thorium (^{232}Th) decay series for example, which are characteristic of the naturally occurring radioactive material in uranium orebodies.
radium (Ra)	A radioactive chemical element that is found in trace amounts in uranium ores.
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 the mine in Kakadu 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 Science Division, Department of the Environment, which incorporates the Environmental Research Institute of the Supervising Scientist (ERISS)and Office of the Supervising Scientist (OSS).
tailings	A slurry of ground rock and process effluents left over once the target product, in this case uranium, has been extracted from mineralised ore.
TAN	Total Ammonia Nitrogen
TBM	Tailings and Brine Management
toxicity monitoring	The means by which the toxicity of a chemical or other test material is determined in the field over time. The monitoring comprises field toxicity tests which are used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical).
trigger values	Concentrations (or loads) of the key performance indicators measured for an ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should 'trigger' some action, either further ecosystem specific investigations or implementation of management/remedial actions.
TSF	Tailings Storage Facility
UAS	Unmanned Aerial System
UEL	Uranium Equities Ltd
U (uranium)	The product mined from the Ranger mine.
WTP	Water Treatment Plants
WHS	Work Health and Safety
WQGV	Water Quality Guideline Value