Australian Government

Department of Sustainability, Environment, Water, Population and Communities
Supervising Scientist

# SUPERVISING SCIENTIST

*Annual Report*
2012–13

This report should be cited as follows:

Supervising Scientist 2013. *Annual Report 2012–13*. Supervising Scientist, Darwin.

**ISSN: 0 158-4030**
**ISBN-13: 978-1-921069-22-2**

The Supervising Scientist is part of the environmental program of the Australian Government Department of the Environment.

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Printed in Canberra by Union Offset on Australian paper from sustainable plantation timber.

**Australian Government**

**Department of the Environment**

**Supervising Scientist**

Senator the Hon Simon Birmingham
Parliamentary Secretary to the Minister for the Environment
Parliament House
CANBERRA ACT 2600

16 October 2013

Dear Senator

In accordance with subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* (the Act), I submit to you the thirty-fourth Annual Report of the Supervising Scientist on the operation of the Act during the period of 1 July 2012 to 30 June 2013.

Please note the Annual Report retains the previous title to reflect the department's name during the reporting period from 1 July 2012 until 30 June 2013.

Yours sincerely

Richard McAllister
Acting Supervising Scientist

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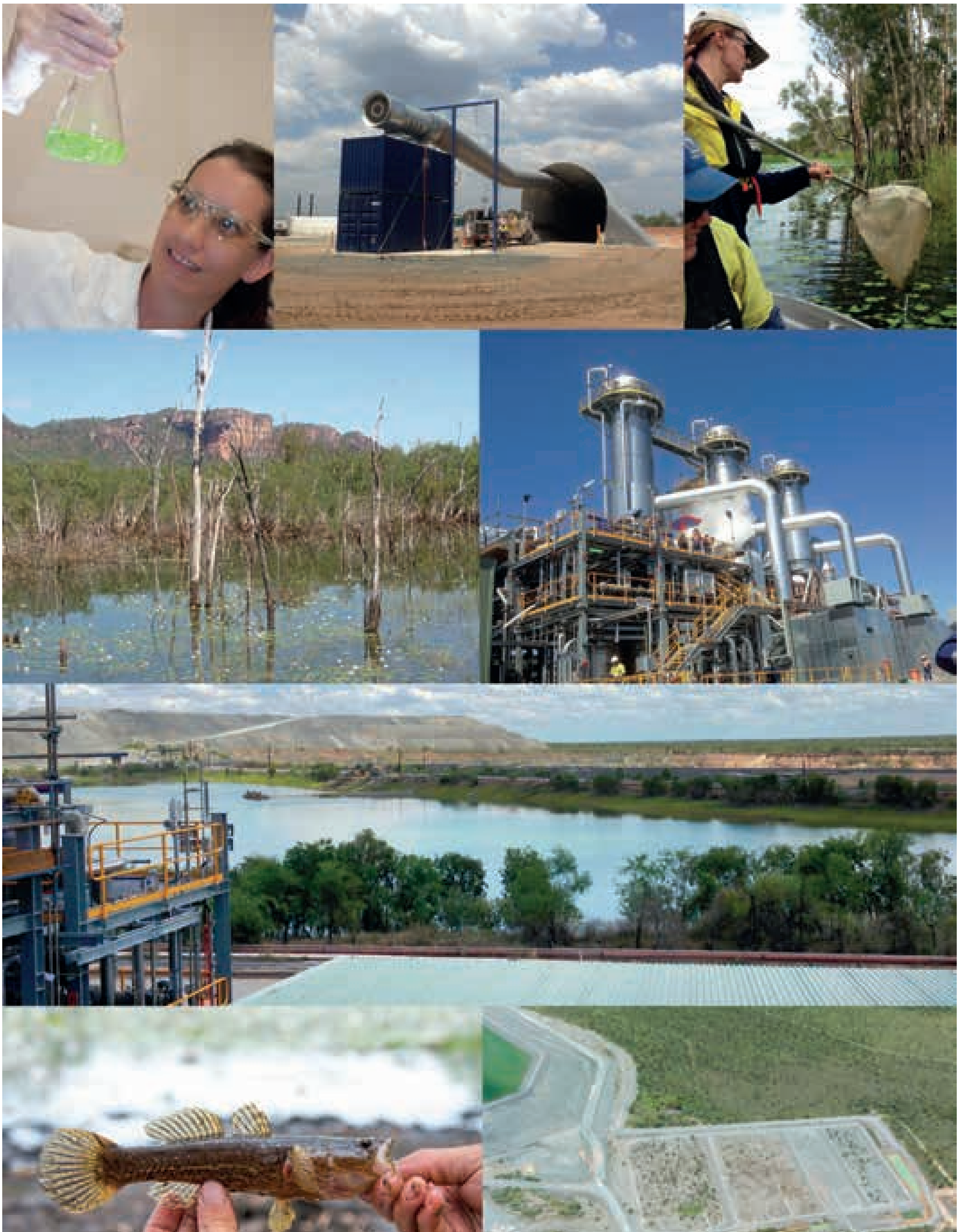

Photos (from top left): SSD staff member with a sample of *Lemna aequinoctialis* (duckweed); Exploration decline ventilation; Macroinvertebrate monitoring at Georgetown Billabong; GCMBL with Mount Brockman in the background; Brine concentrator at Ranger Uranium Mine; RP2 (viewed from the brine concentrator at Ranger Uranium Mine); *Oxyeleotris selheimi* (giant gudgeon) identified and released as part of a fish monitoring program; aerial view of the Ranger Trial Landform.

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# FOREWORD

Subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* requires the Supervising Scientist to provide an Annual Report to Parliament on the operation of the Act and on certain related matters. The Act requires the following information to be reported:

- all directions given to the Supervising Scientist by the Minister who, for this reporting period, was the Minister for Sustainability, Environment, Water, Population and Communities
- information on the collection and assessment of scientific data relating to the environmental effects of mining in the Alligator Rivers Region
- standards, practices and procedures in relation to mining operations adopted or changed during the year, and the environmental effects of those changes
- measures taken to protect the environment, or restore it from the effects of mining in the region
- requirements under prescribed instruments that were enacted, made, adopted or issued and that relate to mining operations in the Alligator Rivers Region and the environment;
- implementation of the above requirements
- a statement of the cost of operations of the Supervising Scientist.

# SUPERVISING SCIENTIST'S OVERVIEW

The Supervising Scientist plays an important role in the protection of the environment of the Alligator Rivers Region of the Northern Territory through the supervision, monitoring and audit of uranium mines, as well as through the conduct of research into the possible impact of uranium mining on the environment of the Region.

Ranger is currently the only operational uranium mine in the Region, and is owned and operated by Energy Resources of Australia Ltd (ERA). Production commenced at Ranger in August 1981, with milling of stockpiled ore expected to continue through until 2020. Mining in Pit 3 ceased in December 2012 and the pit is currently in the process of being backfilled. A proposal to develop the Ranger 3 Deeps underground operation was referred under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in January 2013. A decision was made in March 2013 that the proposal would be assessed at the EIS level. The proposal is not expected to impact on the closure of operations at Ranger. Mining and Milling are currently required to cease by 2021 with closure of Ranger by 2026.

During the year there were no reported incidents that resulted in any environmental impact to the surrounding environment. The extensive monitoring and research programs of the Supervising Scientist Division (SSD) confirm that the environment has remained protected through the period.

The 2012–13 wet season was one of the driest on record. This has significantly reduced water inventories on site and enabled a number of key projects to progress ahead of schedule. Following completion of mining in Pit 3 in early December 2012 progress has been made on the backfill of the pit in preparation for the transfer of tailings from the tailings storage facility (TSF) into Pit 3. Works will also commence in Q3 2013 on the close out of Pit 1 with the potential to remove Pit 1 from the process water catchment. This combined with the commissioning of a Brine Concentrator process water treatment plant in Q3/Q4 of 2013 will result in further reductions in process water inventory over the next few years.

As in previous years, the management of the TSF remains a focus. Capacity increases over the past few years combined with a contingency pumping system, a lower than average wet season, and the imminent commissioning of the Brine Concentrator process water treatment plant, have resulted in increased capacity to manage process water within the TSF over the coming 2013/14 wet season.

Monitoring programs by ERA, the Northern Territory Department of Resources and SSD continue to indicate that there is no evidence of seepage from the base of the Ranger tailings storage facility impacting on Kakadu National Park. ERA installed additional monitoring bores around the tailings storage facility during 2011 at the request of stakeholders, including SSD. Monitoring of these bores continued throughout 2012/13.

As reported previously, in 2011–12 ERA undertook pilot scale testing of its preferred brine concentrator technology for the treatment of process water. The positive conclusions from this test, including the findings from an ecotoxicological assessment conducted by the SSD, lead to the approval from ERA's Board to install this technology on site. Construction of the brine concentrator is now complete and at the time of writing ERA are undertaking commissioning of the plant with a view to seeking approval from the Supervising Scientist for release of the treated water.

Works continue on the construction of an exploration decline into the Ranger 3 Deeps (R3D). To date approximately 1.6 km of decline and portal works have been completed. Exploratory drilling has commenced into the ore body with early results confirming the R3D resource. As discussed above, an EIS is currently in production for the development of the R3D ore body and is expected to be released to the public early 2014.

The 2012–13 wet season represents the third season for which continuous monitoring of pH, electrical conductivity (EC) and turbidity in Magela and Gulungul Creeks upstream and downstream of the Ranger mine has been the primary early warning monitoring method employed by the SSD. The monitoring stations are equipped with autosamplers that collect water samples triggered by in-stream events such as increases in EC or turbidity exceeding defined threshold levels. The SSD's surface water monitoring results, together with explanatory notes, were posted weekly on the internet throughout the wet season. Overall, the water qualities measured in Magela and Gulungul Creeks for the 2012–13 wet season were comparable with previous wet seasons, with the results indicating that the aquatic environment in the creek has remained protected from mining activities.

In situ toxicity monitoring using fresh water snails in Magela and Gulungul Creeks upstream and downstream of the mine, with test organisms deployed in containers immersed in the creek water, is a biological-based method that complements the finding from the continuous monitoring. The measured responses of the snails during the 2012–13 wet season, combined with the results from monitoring of fish and macroinvertebrates conducted in the recessional flow period towards the end of the wet season, continue to confirm that the downstream aquatic environment remains protected from the effects of the mining of uranium at Ranger.

As noted in previous years, work is continuing on further enhancing interpretation of the results from the Supervising Scientist's surface water monitoring program. Work to establish a quantitative relationship between the trigger value for Mg and exposure durations, was finalised during 2012 to a point such that an applicable trigger value can be derived for any given pulse duration and magnitude detected by the continuous water quality monitoring system. This work has been published in peer-reviewed international journals, and been presented to the Minesite Technical Committee with a view to instituting it as part of the regulatory regime for compliance in Magela Creek in the near future. This represents world's leading practice in applying ecotoxicological derived limits to continuous monitoring data.

Determination of radionuclide levels in mussels from Mudginberri Billabong has been a continuing element of the SSD assurance monitoring program downstream of Ranger. The results from the most recent sampling and analysis conducted in October 2012 show that the levels of uranium and radium in mussels collected downstream of Ranger continue to pose no risk to human or ecological health.

The Jabiluka project remains in long-term care and maintenance. Agreement was reached during 2012 between ERA and traditional owners on rehabilitation of the remaining infrastructure on site. Dewatering of the Interim Water Management Pond (IWMP) commenced at the end of the 2012/13 wet season with a view to its removal during the 2013 dry season. Works are currently now underway to remove the pond and revegetate the site. SSD will increase its monitoring of the site over the next 2 wet seasons in response to the ground disturbance of the remedial activities.

The Nabarlek mine in western Arnhem Land was decommissioned in 1995 and the rehabilitation of this site remains under ongoing assessment. During the 2012 Uranium Equities Limited undertook limited exploration and rehabilitation activities at Nabarlek. No activities are planned for 2013. SSD participated in stakeholder inspections and audits of these activities and there were no significant environmental issues identified.

In May 2006, the Australian Government announced funding to undertake rehabilitation of former uranium mining sites in the South Alligator River Valley in the southern part of Kakadu National Park. This project has now been completed. SSD continues to provide advice and assistance to the Director of National Parks on aspects relating to ongoing monitoring of the work.

The Alligator Rivers Region Technical Committee (ARRTC) continues to play a vital role in assessing the key knowledge required, and the robustness of the science used, to make judgements about the protection of the environment from the impacts of uranium mining. During the year ARRTC focused on the current ERA Closure Risk Assessment Project with a view of informing the revision of the Key Knowledge Needs. This work is ongoing and will evolve as Ranger approaches closure, informing both closure criteria and key gaps in knowledge.

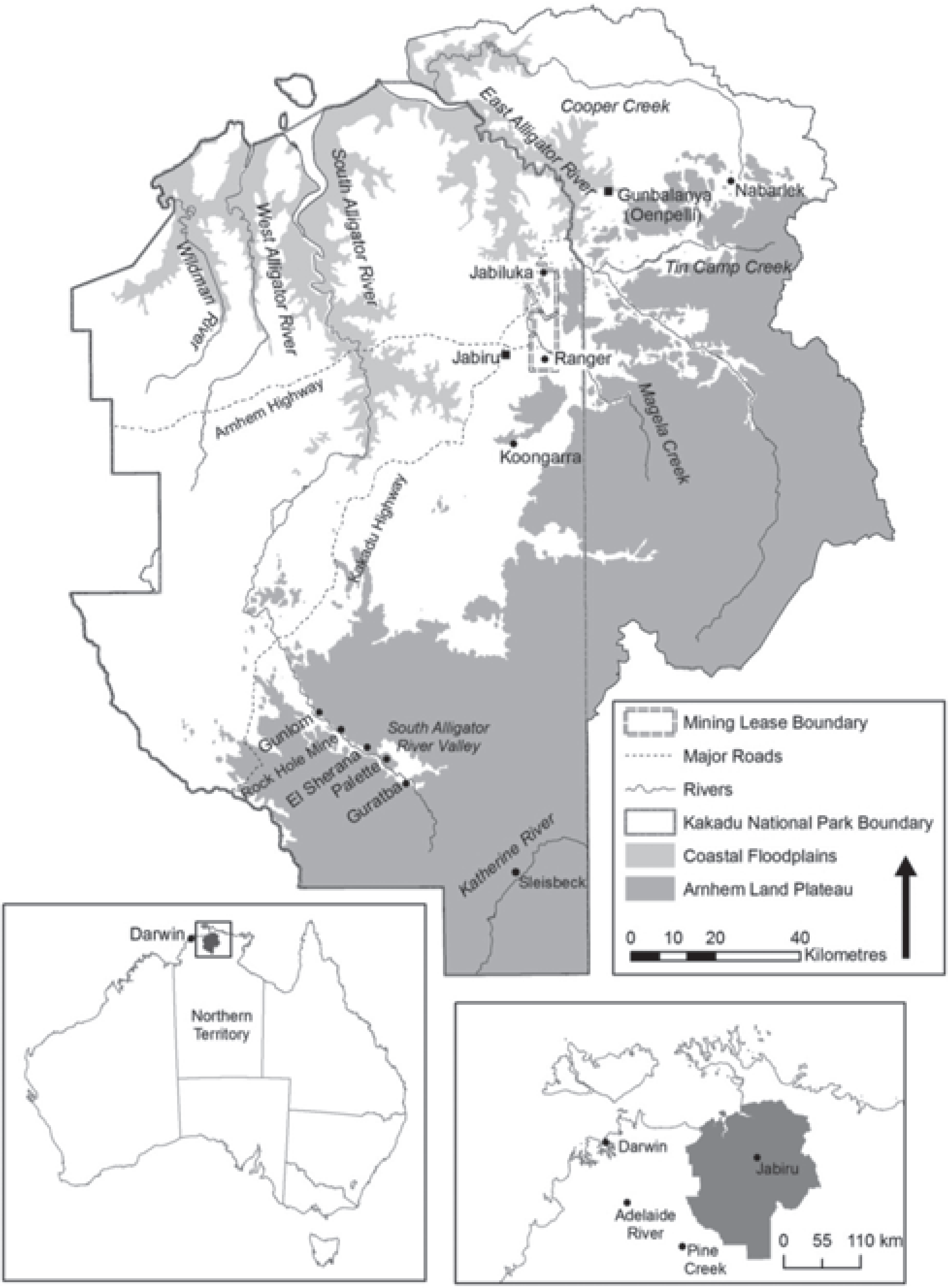
Detailed outcomes from the Environmental Research Institute of the Supervising Scientist (***eriss***) research program are published in journal and conference papers and in the Supervising Scientist and Internal Report series. Highlights of this work are described in this annual report.

During the reporting period, SSD provided advice to the Environment Assessment and Compliance Division of the Department on referrals submitted in accordance with the EPBC Act for proposed new and expanding uranium mines.

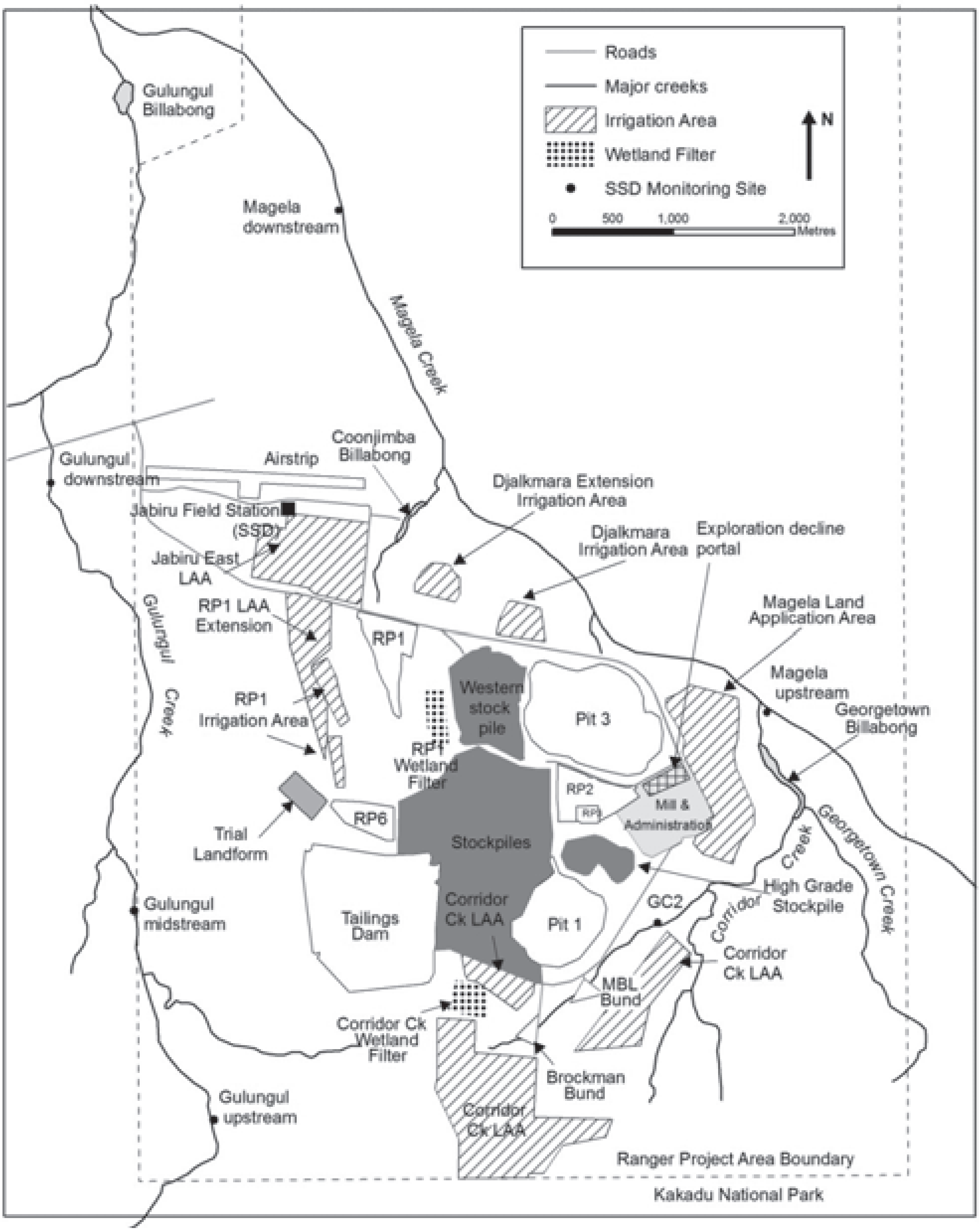
Funds were provided in the 2009–10 Federal Budget for a four-year program to progress and implement environmental maintenance activities, conduct appropriate environmental monitoring programs and develop contemporary site rehabilitation strategies at Rum Jungle under a national partnership agreement between the Northern Territory and the Australian Governments. The Rum Jungle Technical Working Group comprises representatives from the Northern Territory Department of Resources, Northern Territory Department of Natural Resources, Environment, the Arts and Sport, Australian Government Department of Resources, Energy and Tourism, the Northern Land Council and SSD. SSD contributed to the work of the Rum Jungle Technical Working Group during the reporting period, including the selection of preferred rehabilitation strategies that have now formed part of a further submission for funding over the next 3 years.

In closing I offer my personal thanks to all the staff of the Supervising Scientist Division for their continued enthusiasm and efforts during the year. It is through the commitment and professionalism of the Division's staff that the Division able to fulfil its role in ensuring environmental protection to such a highly respected level. In particular I would like to highlight the efforts of those staff who have departed after many years of service, including Joan Mount and Caroline Camilleri who have provided over 20 years of service to SSD, and Ann Webb who has been the mainstay in the preparation and publication of this report over many years. I would also like to recognise the significant contribution of both Dr David Jones who retired as the Director of *eriss* towards the end of 2012, and Mr Alan Hughes who is on long term leave and will retire from the position as Supervising Scientist early 2014. Alan leaves us as the second longest serving Supervising Scientist.

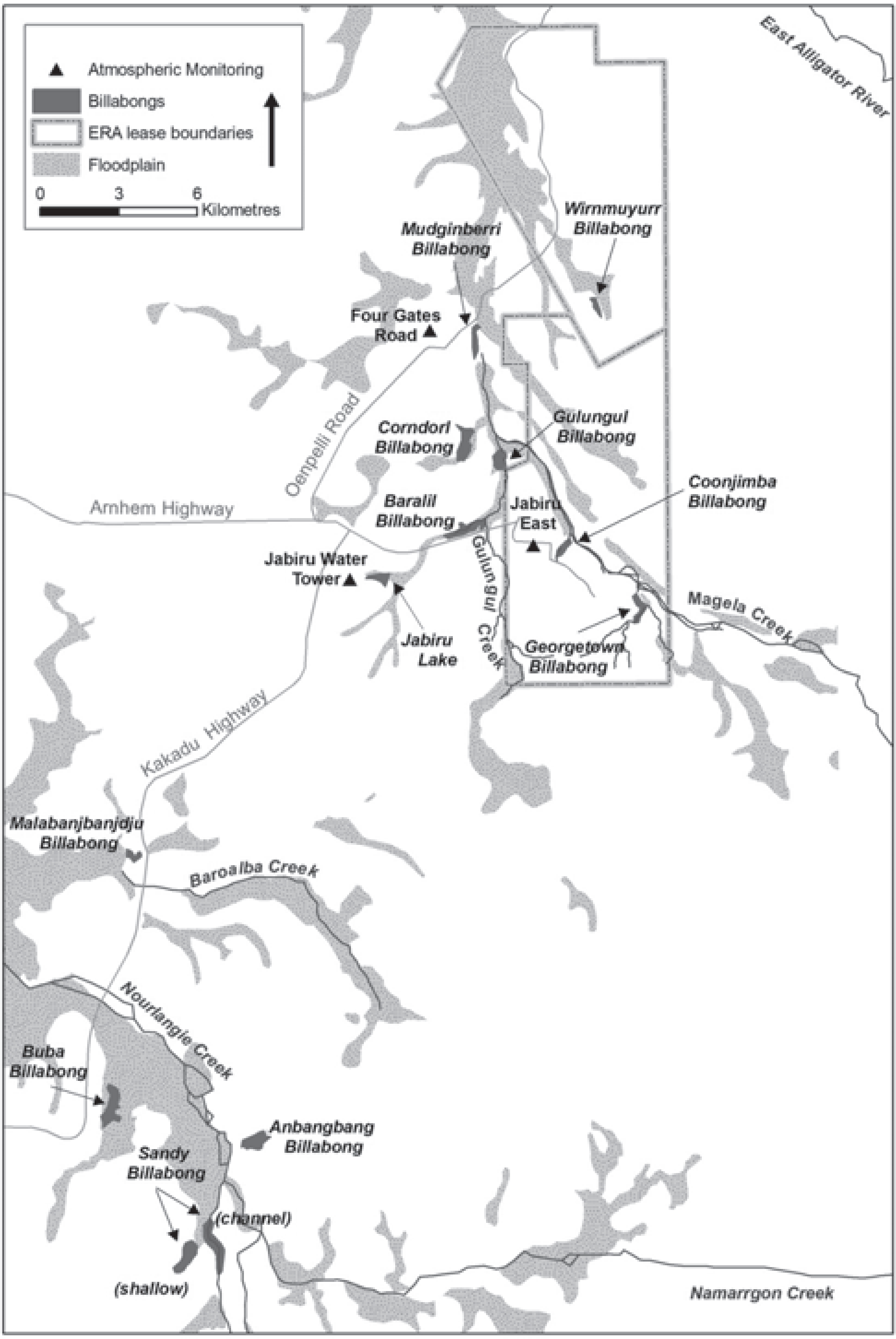
Richard McAllister
Acting Supervising Scientist




**Map 1** Alligator Rivers Region




**Map 2** Ranger minesite




**Map 3** Location of waterbodies and atmospheric monitoring sites used in the SSD environmental research and monitoring programs

# 1 INTRODUCTION

## 1.1 Role and function of the Supervising Scientist

The position of Supervising Scientist was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* (the EPARR Act) in response to a recommendation of the second and final Fox Commission report in May 1977.

The roles and responsibilities of the Supervising Scientist are to:

- develop, coordinate and manage programs of research into the effects on the environment of uranium mining within the Alligator Rivers Region
- develop standards, practices and procedures that will protect the environment and people from the effects of uranium mining within the Alligator Rivers Region
- develop measures for the protection and restoration of the environment
- coordinate and supervise the implementation of requirements made under laws applicable to environmental aspects of uranium mining in the Alligator Rivers Region
- provide the Minister for Sustainability, Environment, Water, Population and Communities with scientific and technical advice on mining in the Alligator Rivers Region
- on request, provide the Minister for Sustainability, Environment, Water, Population and Communities with scientific and technical advice on environmental matters elsewhere in Australia.

The Supervising Scientist heads the **Supervising Scientist Division (SSD)** within the Department of Sustainability, Environment, Water, Population and Communities. The Division comprises two Branches.

The **Office of the Supervising Scientist** (***oss***) undertakes supervision, audit and assessment activities and provides policy advice to the Australian Government in relation to the environmental performance of uranium mines in the Alligator Rivers Region. The Branch also provides business and administrative support to the Supervising Scientist Division.

The **Environmental Research Institute of the Supervising Scientist (*eriss*)** undertakes environmental monitoring and scientific research into the impact of uranium mining on the environment within the Alligator Rivers Region to support the role of the Supervising Scientist.

## 1.2 Performance summary

As a Division of the Department of Sustainability, Environment, Water, Population and Communities, SSD is funded under the Portfolio's departmental output appropriation and contributes to the delivery of Outcome 5:

> Increased protection, awareness and appreciation of Australia's environment and heritage through regulating matters of national environmental significance and the identification, conservation and celebration of natural, Indigenous and historic places of national and World Heritage significance.

Outcome 5 is divided into two programs. During the 2012–13 financial year, the Supervising Scientist contributed to Program 5.2 Environmental Regulation.

Further details on SSD activities during 2012–13 contributing to Program 5.2 are provided in Chapters 3 and 4 of this Annual Report.

Communicating the outcomes of research, monitoring and supervision activities to relevant stakeholders and the broader scientific community is a key part of the work of the Division. Of particular importance is the ongoing communication and consultation SSD undertakes with the Aboriginal people living in the Alligator Rivers Region. Further details on SSD communications activities during 2012–13 are provided in Chapter 6.

## 1.3 Business planning

SSD undertakes a strategic business planning approach and inputs into Departmental strategic business planning processes to ensure outputs are achieved in the most effective and efficient way. SSD prepares an annual Business Plan that outlines the main goals and challenges for the Division over the coming year, the range of activities and programs to be undertaken and associated performance measures. Progress against strategic priorities and key result areas is assessed on an ongoing basis as part of Departmental performance management processes.

## 1.4 The Alligator Rivers Region and its uranium deposits

The Alligator Rivers Region is located 220 km east of Darwin and encompasses an area of approximately 28 000 $km^2$ (see Map 1). The Region includes the catchments of the West Alligator, South Alligator and East Alligator Rivers, and extends into western Arnhem Land. The World Heritage listed Kakadu National Park lies entirely within the Alligator Rivers Region.

The Ranger and Jabiluka uranium deposits within the Alligator Rivers Region are not, and never have been, located within Kakadu National Park. Nabarlek is situated to the east of Kakadu National Park within Arnhem Land. Commonwealth legislation incorporating the Koongarra project area into Kakadu National Park came into effect in March 2013.

Ranger is currently the only operational uranium mine in the Region. Mining at Ranger ceased in 2012, however processing of stockpiled ore is continuing. Mining ceased at Jabiluka in 1999 and the site is under long-term care and maintenance. Mining at Nabarlek ceased in 1980 and the site has been decommissioned and is subject to ongoing rehabilitation. There are also a number of former uranium mine sites in the South Alligator River Valley that operated during the 1950s and 1960s. The Australian Government funded the rehabilitation of these sites, which was completed in 2009.

### 1.4.1 Ranger

Energy Resources of Australia Ltd (ERA) operates the Ranger uranium mine, which is located 8 km east of the township of Jabiru. The mine lies within the 78 $km^2$ Ranger Project Area and is adjacent to Magela Creek, a tributary of the East Alligator River. Ranger is an open cut mine and commercial production of uranium concentrate ($U_3O_8$) has been under way since 1981. Orebody No 1 was exhausted in late 1994 and excavation of Orebody No 3 began in 1997. Mining in Pit 3 at Ranger ceased in 2012 and the pit is currently being backfilled. Processing of stockpiled ore is expected to continue until 2021.

In January 2013, ERA submitted a proposal for the development of an underground mine at Ranger under the NT *Environmental Assessment Act* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. In March 2013, it was determined that the Ranger 3 Deeps Underground Mine proposal would be subject to assessment at the Environmental Impact Statement level under both the Commonwealth and Northern Territory environmental approval processes.

### 1.4.2 Jabiluka

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

Unlike the Ranger and Nabarlek deposits, the Jabiluka orebody lies beneath a cover of cliff-forming sandstone. It is in the catchment of the East Alligator River, adjacent to Ngarradj (Swift Creek), which drains north to the Magela floodplain. The Australian Government completed its assessment of ERA's Environmental Impact Statement, which provided for milling of Jabiluka ore at Ranger, in 1997.

Development work at Jabiluka took place in the late 1990s but ceased in September 1999, at which time the site was placed in an environmental management and standby phase that lasted until 2003. During 2003, discussions commenced between ERA, the Commonwealth and Northern Territory Governments, the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) which represents the area's traditional Aboriginal owners, the Mirarr people. Following these discussions, an agreement was reached between the parties that resulted in Jabiluka being placed in long-term care and maintenance.

This agreement included an undertaking by ERA not to engage in mining activities at Jabiluka without the consent of the Mirarr people. The agreement was endorsed by the NLC in 2004 and was approved by the then Australian Government Minister for Immigration and Multicultural and Indigenous Affairs in 2005.

### 1.4.3 Nabarlek

Nabarlek is about 280 km east of Darwin. Queensland Mines Ltd undertook mining at Nabarlek during the dry season of 1979 and milling of the ore continued until 1988. Some 10 857 t of uranium concentrate ($U_3O_8$) was produced while the mill was operational.

Decommissioning of the mine was completed in 1995 and the performance of the rehabilitation and revegetation program continues to be monitored by SSD.

In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd thereby acquiring the Nabarlek lease. Since then, UEL has undertaken further exploration on the lease as well as a range of weed control, revegetation and other rehabilitation works.

### 1.4.4 Koongarra

The Koongarra deposit is located about 25 km south-west 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 *Completion of Kakadu National Park (Koongarra Project Area Repeal) Act 2013*, which repealed the *Koongarra Project Area Act 1981*, and incorporated the lease area into Kakadu National Park, came into effect on 31 March 2013.

### 1.4.5 South Alligator Valley mines

During the 1950s and 1960s, a number of small uranium mines and milling facilities operated in the South Alligator River Valley, in the southern part of the Alligator Rivers Region. Mining occurred at several locations – principally at El Sherana, El Sherana West, Rockhole Creek and Coronation Hill (Guratba). Milling also occurred at Rockhole Creek within the South Alligator Valley and at nearby Moline which lies outside the Alligator Rivers Region.

Output from these mines was relatively small. It is estimated that less than 1000 t of uranium concentrate was produced at the Rockhole Creek and Moline mills from the ore mined in the South Alligator Valley during this period.

These sites, excluding Moline, are the responsibility of the Australian Government Director of National Parks and are administered through Parks Australia. In May 2006, the Australian Government provided funding over four years for the rehabilitation of a number of these sites. This rehabilitation work was completed in 2009.

During 2012–13, SSD continued to assist Parks Australia with technical advice related to the ongoing monitoring of these rehabilitated sites. Further details on SSD involvement in this work are provided in Section 3.5.1 of this Annual Report.

# 2 STATUTORY COMMITTEES

## 2.1 Introduction

During 2012–13, SSD provided secretariat and administrative support to two statutory committees: the Alligator Rivers Region Advisory Committee and the Alligator Rivers Region Technical Committee.

These committees play important roles in facilitating stakeholder consultation in relation to the environmental effects of uranium mining in the Alligator Rivers Region, and the independent review of the outcomes of scientific research and monitoring undertaken by SSD, ERA and others.

## 2.2 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (ARRAC) was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978*. Members of ARRAC are appointed by the Australian Government Minister for Sustainability, Environment, Water, Population and Communities.

ARRAC comprises an independent Chair and representatives from the following stakeholder organisations:

- NT Department of Mines and Energy
- NT Environment Protection Authority
- NT Department of Health
- Office of the Administrator of the NT
- Australian Radiation Protection and Nuclear Safety Agency
- Energy Resources of Australia Ltd
- Cameco Australia Pty Ltd
- Uranium Equities Ltd
- Afmeco Mining and Exploration Pty Ltd
- Northern Land Council
- Gundjeihmi Aboriginal Corporation
- Environment Centre Northern Territory
- West Arnhem Shire Council
- Australian Government Department of Resources, Energy and Tourism
- Parks Australia, Australian Government Department of Sustainability, Environment, Water, Population and Communities
- SSD, Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC).

ARRAC provides a valuable forum for relevant stakeholders to exchange views and information relating to the protection and rehabilitation of the Alligator Rivers Region environment from the effects of uranium mining. Public disclosure of environmental performance data through ARRAC is an important means of ensuring transparency and enhancing trust between the various stakeholder organisations.

At each ARRAC meeting, stakeholder members provide an update report on their activities during the reporting period. SSD also provides a detailed report covering the outcomes of audit and assessment activities and the results from SSD environmental monitoring programs to each meeting.

ARRAC met twice during 2012–13: in Jabiru in September 2012 and in Darwin in March 2013. Key issues considered by ARRAC at these meetings included:

- the status of mine operations, planning and development at Ranger
- the results of chemical, biological and radiological monitoring for Ranger and Jabiluka
- SSD communication and research activities
- the outcomes of environmental audits and assessments of Ranger, Jabiluka and Nabarlek
- the outcomes of Minesite Technical Committee (MTC) meetings and other regulatory processes
- the status of mine rehabilitation projects in the South Alligator Valley
- the Northern Land Council's work with the Alligator Rivers Region stakeholders and traditional owners.

ARRAC meeting minutes are available from the ARRAC website at: www.environment.gov.au/ssd/communication/committees/arrac/meeting.html

## 2.3 Alligator Rivers Region Technical Committee

The Alligator Rivers Region Technical Committee (ARRTC) was established under the *Environment Protection (Alligator Rivers Region) Act 1978*.

ARRTC plays an important role in ensuring the scientific research conducted by ***eriss***, ERA, NT Government agencies and others into the protection of the environment from the impacts of uranium mining in the Alligator Rivers Region is appropriately targeted and of the highest possible standard. ARRTC also reviews the quality and adequacy of the science used for the regulatory assessment and approval of uranium mining related applications and proposals in the Alligator Rivers Region.

The members of ARRTC are appointed by the Australian Government Minister for Sustainability, Environment, Water, Population and Communities and include:

- an independent Chair
- the Supervising Scientist

- a number of independent scientific members (including the Chair) with specific expertise nominated by Science and Technology Australia – formerly the Federation of Australian Scientific and Technological Societies (FASTS)
- a member representing Environmental Non–government Organisation interests
- a number of members representing other relevant stakeholders including the Northern Land Council, the NT Department of Mines and Energy, Energy Resources of Australia Ltd (for Ranger and Jabiluka), Uranium Equities Ltd (for Nabarlek) and Parks Australia.

The Committee is chaired by Dr Simon Barry, who is also the Independent Scientific Member with expertise in Ecological Risk Assessment.

ARRTC held two meetings in 2012–13: in December 2012 and May 2013. Key issues considered by ARRTC at these meetings included:

- current and proposed scientific research activities for ***eriss*** and ERA, in the context of the ARRTC Key Knowledge Needs (KKN);
- outcomes of chemical, biological and radiological research and monitoring being undertaken by SSD, ERA and NT Department of Mines and Energy (DME);
- scientific and technical issues relating to Ranger, Jabiluka and Nabarlek
- the science underpinning Minesite Technical Committee (MTC) meetings and other regulatory decision making
- the status of South Alligator Valley rehabilitation activities
- activity reports from relevant stakeholder organisations.

At its meeting in May 2013, ARRTC endorsed the proposed ***eriss*** scientific research program for 2013–14. ARRTC also reviewed the status of the current ERA Rehabilitation/Closure Risk Assessment Project, the outcomes of which are being used to inform the ongoing revision of the ARRTC Key Knowledge Needs.

The ARRTC Key Knowledge Needs are included in Appendix 1 of this Annual Report. ARRTC meeting minutes are available on the ARRTC website at: www.environment.gov.au/ssd/communication/committees/arrtc

# 3 ENVIRONMENTAL ASSESSMENTS OF URANIUM MINES

## 3.1 Supervision process

SSD utilises a structured program of audits and inspections, in conjunction with DME and the NLC, to supervise uranium mining operations in the Alligator Rivers Region ARR. The outcomes of these activities are considered by the Supervising Scientist, together with environmental monitoring data and other information, to draw conclusions regarding the effectiveness of environmental management at uranium mining sites.

### 3.1.1 Minesite Technical Committees

Minesite Technical Committees (MTCs) have been established for Ranger, Jabiluka and Nabarlek. The MTC meetings provide an effective forum for stakeholders, including SSD staff, to discuss technical environmental management issues, especially in connection with the assessment of applications and reports submitted by mining companies for approval under Northern Territory and Commonwealth legislation. As such, each Ranger and Jabiluka MTC is made up of representatives from DME (which provides the Chair), SSD, NLC, GAC and Energy Resources of Australia (ERA). Representatives from the Australian Government Department of Resources, Energy and Tourism (RET) also participate in the Ranger and Jabiluka MTCs. Other organisations or experts may be co-opted from time to time as required to assist MTC members. The Nabarlek MTC is made up of representatives from DME, NLC, SSD and the relevant mining company (currently Uranium Equities Limited).

### 3.1.2 Audits and inspections

The Supervising Scientist, in consultation with the applicable MTC members, has developed and implemented a program of environmental audits and inspections at the Ranger mine, the Jabiluka Mineral Lease and the Nabarlek mine. SSD staff also participate in audits of exploration operations throughout the ARR.

Routine Periodic Inspections (RPIs) take place monthly at Ranger, being the only operating mine in the region, and quarterly at Jabiluka, which is currently in long-term care and maintenance. The RPIs are intended to provide a snapshot of the adequacy of environmental management activities on site as well as an opportunity for the inspection team to discuss current environmental management issues with staff on site. The discussions that occur during RPIs may include addressing any unplanned events or reportable incidents and any associated follow-up actions. The inspection team is made up of representatives from the SSD, DME, NLC and GAC.

The El Sherana Airstrip radiological containment facility at South Alligator Valley is also inspected at least once annually by SSD in conjunction with Parks Australia.

Environmental audits are conducted by a team of qualified audit staff from SSD, DME and the NLC and are undertaken in accordance with ISO Standard 19011:2003 (*Guidelines for quality and/or environmental management systems auditing*) and are consistent with current best practice methods for environmental assessments.

The annual environmental audits of Ranger and Jabiluka occur each May to assess the performance of each site against commitments taken from selected management plans or approval documents. The final audit report is tabled at the following meeting of the Alligator Rivers Region Advisory Committee (ARRAC). Audit findings are followed up as required through the RPI process. The Nabarlek program is slightly different in that an inspection is carried out early in the dry season to assess the post wet season condition of the area, and provide recommendations that can be addressed during the dry season when access is available. The annual environmental audit is conducted later in the year if required.

The audit outcomes for 2012–13 are described later in this annual report.

### 3.1.3 Assessment of reports, plans and applications

The Authorisations for Ranger and the Jabiluka are issued under the Northern Territory *Mining Management Act 2001.* The Act provides for alterations to the Authorisation to be issued by the Northern Territory Government. The Authorisations require that ERA seeks approval for certain activities from the Northern Territory regulatory authority, through DME, which then considers applications after SSD, NLC and GAC have assessed the proposal and provided feedback. This provides the primary mechanism for the Supervising Scientist's participation in the regulatory processes of the Northern Territory Government and is supported by section 34 of the Act which requires the Northern Territory Government to act in accordance with the advice of the Commonwealth Resources Minister for issues related to uranium mining.

The main reports and plans assessed by the Supervising Scientist during 2012–13 included:

- Ranger Amended Plan of Rehabilitation No 38
- Ranger Mine Water Management Plan
- Ranger Mine and Jabiluka Annual Environmental Reports
- Ranger Mine and Jabiluka Wet Season Reports
- Ranger Mine Annual Tailings Dam Inspection Report
- Ranger Mine and Jabiluka Radiation Protection and Atmospheric Monitoring Program annual report and quarterly data submissions
- Jabiluka Plan of Rehabilitation No 16
- ERA weekly environmental monitoring data and quarterly reports submitted in accordance with the Authorisations
- Applications by ERA for amendments to their Authorisations (refer to 3.2.2.5 and 3.3.2.4).

## 3.2 Ranger

### 3.2.1 Developments

Mining in Pit 3 at Ranger Mine ceased in November 2012, with backfill of the pit from the western stockpile commencing shortly thereafter. The mill produced 4 313 tonnes of uranium oxide ($U_3O_8$) during 2012–13 from 2 487 000 tonnes of ore (Table 3.1). Production statistics for the milling of ore and the production of $U_3O_8$ at Ranger for the past five years are shown in Table 3.2.

**TABLE 3.1 RANGER PRODUCTION ACTIVITY FOR 2012–13 BY QUARTER**

| | 1/07/2012 to 30/09/2012 | 1/10/2012 to 31/12/2012 | 1/01/2013 to 31/03/2013 | 1/04/2013 to 30/06/2013 | Total |
|---|---|---|---|---|---|
| Production (drummed tonnes of $U_3O_8$) | 1239 | 1227 | 897 | 950 | 4313 |
| Ore treated ('000 tonnes) | 666 | 629 | 551 | 641 | 2487 |

**TABLE 3.2 RANGER PRODUCTION ACTIVITY FOR 2008–09 TO 2012–13**

| | 2008–09 | 2009–10 | 2010–11 | 2011–12 | 2012–13 |
|---|---|---|---|---|---|
| Production (drummed tonnes of $U_3O_8$) | 5678 | 4222 | 2679 | 3282 | 4313 |
| Ore treated ('000 tonnes) | 2042 | 2283 | 1305 | 2404 | 2487 |

#### 3.2.1.1 On-site activities

*Ranger exploration decline project*

In April 2009, ERA submitted a referral for the proposed construction of an exploration decline to provide exploration access to mineralisation in the Ranger 3 Deeps area. This proposal was deemed not to be a controlled action therefore not requiring further assessment under the EPBC Act. The Ranger MTC considered an application from ERA for construction of the decline. Satisfied that all aspects of this application had been adequately addressed by ERA, SSD advised the Northern Territory Government of its support for the approval of this application on 30 June 2011. Following completion of the box-cut and portal, construction of the exploration decline commenced on 1 May 2012. SSD, in conjunction with DME, NLC and GAC, inspected the construction works during the May 2013 environmental audit. Exploration drilling from the decline commenced on 26 May 2013 and, at the end of the reporting period, the decline was 1040 m in length.

*Ranger exploration decline phase 2*

An application to construct a second phase of the exploration decline was approved on 4 June 2013. Phase 2 will include a single vent raise and extension of the decline by approximately 1000 m and a cross cut through the ore body to obtain a bulk sample for metallurgical test work. ERA has stated that the ore obtained from the bulk sample will not be processed through the Ranger Mill, and will be set aside for return to the decline should the Ranger 3 Deeps underground mine not progress.

*Ranger 3 Deeps underground mine*

On 16 January 2013, ERA submitted a referral under the EPBC Act for the development the Ranger 3 Deeps underground mine to be constructed on the site of the existing Ranger uranium mine.

The referral was open for public comment for a period of ten business days until 31 January 2013.

The Australian Government Delegate determined that the proposal would be assessed at the EIS level on 13 March 2013. At the end of the reporting period, the EIS guidelines were under development pending release for public comment.

*Tailings Storage Facility wall raise to 60.5 mRL*

On 1 June 2012, ERA presented stakeholders with an application to construct a centre-line lift on the Tailings Storage Facility (TSF) to raise the height of the wall by 2.2 m from 58.3 mRL to 60.5 mRL during the 2012 dry season. In response to this application, SSD commissioned an independent geotechnical review of the design which subsequently confirmed the design was in accordance with current standards of best practice. The lift was completed and the dam crest certified at 60.5 mRL in November 2012.

*Tailings Storage Facility MOL raise*

An application to raise the maximum operating level (MOL) of the TSF to 59.2 mRL for the dry season and 57.9 mRL for the wet season was approved in January 2013 following completion of the 60.5 mRL lift. The wet season MOL is set to provide capacity to contain a 120 hr probable maximum precipitation (PMP) event of 2590 mm, while the dry season MOL will provide capacity to contain a 6 hour PMP event of 1250 mm. ERA may apply to raise the wet season MOL by an amount proportional to the installed contingency transfer capacity to Pit 3. The MOL shall not be increased above 59.2 mRL regardless of pumping capacity.

SSD reviewed updated three-dimensional groundwater flow and solute transport modelling provided as part of ERA's application to raise the TSF walls and was satisfied that the proposed increase in the MOL will not produce increases in seepage that would adversely impact on the downstream environment of Kakadu National Park.

*Retention Ponds 5 and 6*

As part of ongoing improvements to on site water management, ERA completed the construction a new retention pond, Retention Pond 6 (RP6), to provide increased capacity for pond water storage on site and planned transfer of Pit 3 from the pond water system to the process water system. The pond is designed to hold approximately 1000 ML and is lined with two x 2 mm High Density Polyethylene (HDPE) liners with leak detection, overlaying a compacted clay base. Water will be transferred from Retention Pond 2 (RP2) via dedicated HDPE transfer lines and the pond has contingency overflow capacities back to the pond water system.

ERA has advised its intent to construct a further 1000 ML pond (RP5), but is yet to submit a construction application to the Supervising Authority.

*Brine concentrator*

As part of its strategy to manage and reduce the process water inventory on site, ERA has commenced construction of a brine concentrator on site to treat process water. The brine concentrator will be located at the site of the now-demolished acid plant adjacent to the power station. The brine concentrator has started early-stage commissioning and will have the capacity to treat 1.83 GL of process water per year. The release of treated process water (distillate) from the site will be contingent on approval of an application from ERA, further ecotoxicological testing and assessment by the MTC. SSD has previously undertaken a range of ecotoxicological tests on distillate produced from a brine concentrator pilot plant campaign that was run at Rio Tinto's research centre in Melbourne using process water transported by tanker from the mine.

*Pit 3 backfill*

Mining in Pit 3 was completed in November 2012 and backfilling of the pit from the Western Stockpile commenced shortly thereafter. At the end of the reporting period, approximately 15 million tonnes of material had been returned to the pit, approximately half of the material required to form a level base for tailings deposition.

*Pit 3 cracking and levee*

In September 2012, ERA identified a number of cracks in the wall of Pit 3 with the potential to cause some structural instability during the wet season.

In January 2013, ERA completed the construction of an earthen levee between Magela Creek and a section of the mine access road to prevent the ingress of surface water into these cracks during periods of high flow in Magela Creek, thereby reducing the risk of wall failure.

Pit backfill has now buttressed the toe of the wall and movement in the area of the cracks has all but ceased. On 11 December 2012, a 7.3 magnitude earthquake occurred 600km north of Darwin and was clearly felt in both Darwin and Jabiru. The pit wall monitoring showed no movement as a result of this event.

*Pit 1 Preload*

ERA applied to the Ranger MTC in May 2013 to place a 2.5 m thick layer of rock over the tailings within Pit 1. This loading will activate the wicks installed in 2012 and accelerate the dewatering of the tailings. The information gained from this project will provide valuable data for the validation of tailings consolidation and seepage modelling.

## 3.2.2 On-site environmental management

### 3.2.2.1 Water management

All water on-site is managed in accordance with the Water Management Plan (WMP) which is updated annually and subject to assessment by the MTC before approval. The 2012–13 WMP was submitted for approval by ERA on 27 September 2012. SSD endorsed the plan on 28 March 2013 and the document was formally approved by DME on 27 April 2013. The plan describes the systems for routine and contingency management of the three categories of water on site: process, pond and potable.

As shown in Figure 3.1, the 2012–13 wet season was a below average rainfall year with a total of 1238 mm recorded at Jabiru Airport to 8 July 2013 (annual average 1559 mm). Despite the below average rainfall recorded this year, water management—especially that of process water—remains a critical issue at Ranger.

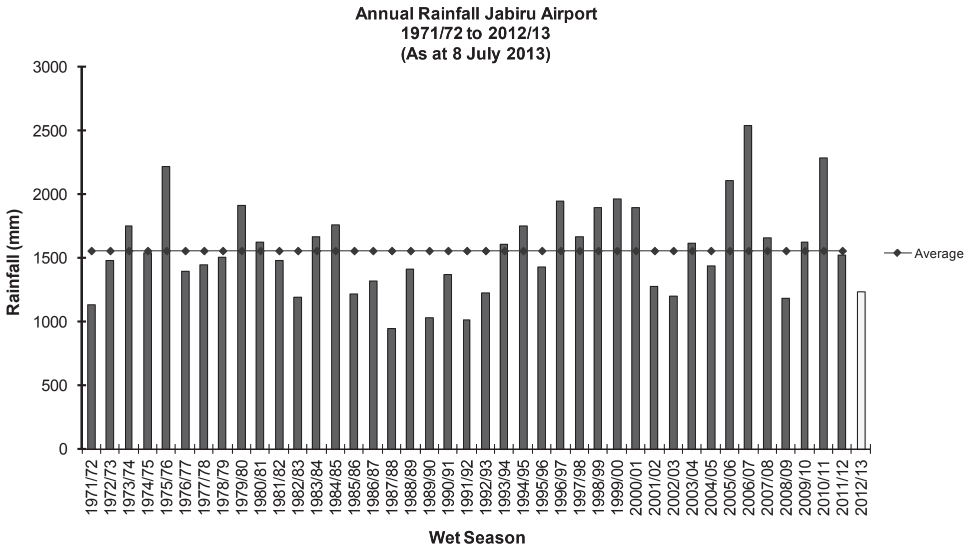



**Figure 3.1** Annual rainfall Jabiru Airport 1971–72 to 2012–13 (data from Bureau of Meteorology)

*Process water system*

Under the Commonwealth Environmental Requirements, water that is in direct contact with uranium ore during processing (process water) must be maintained within a closed system. It may only be released by evaporation or after treatment in a manner and to a quality approved by the Supervising Scientist. Process water is currently stored in the TSF and in Pit 1. There were no releases of process water to the surrounding environment during the reporting period.

As ERA does not currently have the capacity to treat and release process water on site, all process water is stored in Pit 1 and the TSF. As discussed in section 3.2.1.1 above, ERA is currently constructing a brine concentrator on the site to treat process water at a rate of 1.83 GL per year. The brine concentrator is expected to be operational in the second half of 2013.

As at 30 June 2013, the process water inventory was 8912 ML, of which 8891 ML was stored in the TSF. This represents a decrease of 1581 ML over the previous year's total of 10 493 ML due in large part to the below average 2012–13 wet season.

*Pond water system*

The pond water system contains water that has been in contact with stockpiled mineralised material and operational areas of the site, other than those contained within the process water system. Water is managed within this system on the basis of quality. The pond water system consists primarily of RP6, RP2, RP3 and Pit 3. ERA has previously committed that pond water will not be released without prior treatment through wetland filtration or the onsite microfiltration/reverse osmosis treatment plants. As at the end of the reporting period, 1718 ML was contained within the within the pond water system, representing an increase in the volume stored compared to the same time last year (1032 ML). The increased pond water inventory is due to an increase of water retained in Pit 3 as pumping access is not easily attained during backfill operations and the pit no longer needs to be dried out to access the lower levels for mining.

The first 200 mm of incident rainfall on sheeted stockpiles continues to be diverted into the pond water system. This initial runoff generally contains higher levels of mine-derived solutes due to the leaching of solutes from freshly mined rock that occurs in the early stages of the wet season. The runoff after the first 200 mm of rain is directed into the wetland filter system prior to discharge to the environment.

Due to low wet season rainfall, in March 2013 ERA raised concerns that the pond water inventory may be insufficient to last the 2013 dry season and requested stakeholder agreement to the abstraction of water from Magela Creek. Stakeholders agreed on the condition that abstraction would cease if creek flow fell below 5 $m^3$/sec. Abstraction occurred between 23 and 27 March during which time ERA abstracted 17.7 ML from Magela Creek to RP1. This was then followed by a significant rainfall event on 30 and 31 March which delivered over 200 mm and ensured that no further abstraction from Magela Creek would be required for the 2012–13 wet season.

*Methods of disposal of pond water and managed release water*

Passive release water

Rainfall runoff discharges from the Ranger site during the wet season primarily via Corridor Creek and Coonjimba Creek (with lesser amounts via Gulungul Creek and minor amounts via overland flow direct to Magela Creek). RP1 and the Corridor Creek wetland filter act as sediment traps and solute polishing systems prior to outflow from the site. Due to reduced performance, ERA has ceased utilisation of the RP1 wetland filter to polish pond water.

The Corridor Creek wetland filter receives runoff from specially prepared sheeted areas of low grade ore and waste rock stockpiles. The surfaces of these stockpile areas are compacted to reduce infiltration and hence minimise contribution of additional water via seepage to the RP2 pond water system.

An interception trench was installed around the western and northern perimeter of the western stockpile in 2010 to capture poor quality seepage that was previously reporting to RP1, and to redirect stockpile runoff away from RP1. This measure, combined with input of pond water permeate into RP1, has resulted in a substantial improvement to water quality in RP1 over the past three years. Water is passively released from RP1 via a sluice gate when the water level in RP1 exceeds the height of the spillway.

In Corridor Creek, passive release of waters originating from upstream of GC2 occurred throughout the 2012–13 wet season.

#### Managed release water

About 8.4 ML of RP1 water was discharged via siphons/pumping on 1 April 2013 following the single significant rainfall event during the 2012–13 wet season to reduce the overall pond water inventory during periods of higher flow in Magela Creek. During this rainfall event, 170 ML of RP1 water passively discharged over the weir into Coonjimba Creek.

ERA manually controls the discharge of runoff from areas adjacent to Pit 3 via four sluice gates along the Ranger access road. Release from these gates occurred on two occasions during the 2012–13 wet season; January and April 2013. A total volume of approximately 1.4 ML of water was released via the Pit 3 sluice gates.

ERA was again granted interim approval through the Water Management Plan for the discharge of RP1 water to Magela Creek from the MG001 site (see Map 2 for location) over the 2012–13 wet season. Discharge is managed to ensure electrical conductivity within Magela Creek is maintained within the specified limits. Controlled discharge occurred on one occasion from 1 to 2 April 2013 during high flow conditions in Magela Creek. A total volume of approximately 14 ML of RP1 water was released via MG001.

#### Pond water treatment

Pond water is treated via three microfiltration/reverse osmosis water treatment plants (WTP), with WTP1 and WTP2 each having a 7 ML/day capacity and WTP3 an 11 ML/day capacity.

All three water treatment plants were in operation during the reporting period. Volumes of water treated and permeate produced are reported in Table 3.3.

**TABLE 3.3 POND WATER TREATMENT PLANT (WTP) VOLUMES**

| WTP | Volume treated (ML) | Permeate produced (ML) |
|---|---|---|
| 1 | 483 | 330 |
| 2 | 504 | 360 |
| 3 | 107 | 73 |

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

Land application areas

The locations of land application areas (or irrigation areas) at the Ranger mine are shown on Map 2. Direct irrigation of RP2 water ceased from 2009. All water disposed of via the land application areas is now treated or polished through a wetland filter prior to irrigation.

All land application areas, other than the Magela land application area which was taken out of service for rehabilitation trials, were utilised during the 2012 dry season with a total volume of 114.5 ML irrigated. Irrigation had not commenced for the 2013 dry season prior to the end of the reporting period. Volumes of water disposed of to each irrigation area are shown in Table 3.4.

**TABLE 3.4 IRRIGATION VOLUMES BY LOCATION (ML)**

| RP1 LAA | Djalkmarra LAA | Jabiru East LAA | RP1 Extension LAA | Corridor Creek LAA |
|---|---|---|---|---|
| 11.1 | 0.2 | 28.2 | 8.9 | 66.1 |

### 3.2.2.2 Tailings and waste management

*Tailings*

From August 1996 to December 2008 no process residue from the milling of ore was deposited into the TSF, with Pit 1 being the sole receptor. Over this period, 20 $Mm^3$ of tailings were deposited in Pit 1 including 1.8 $Mm^3$ transferred from the TSF by dredging. Transfer of tailings into Pit 1 ceased in December 2008, when tailings reached the maximum permitted level of 12 mRL and deposition of tailings in the TSF resumed. Tailings are discharged to the TSF via a floating discharge pipe that is moved regularly to achieve an even deposition across the footprint of the dam.

ERA suspended processing and ceased all mining-related inputs to the TSF between January and June 2011 to ensure the maximum operating level of process water in the TSF did not exceed the then MOL of 53 mRL as a result of rainfall input.

ERA continued to progress plans for the closure of Pit 1 during the 2012–13 reporting period. Dewatering of the tailings surface and the installation of 7499 wicks to a maximum depth of 44 m to facilitate tailings consolidation in Pit 1 was completed in October 2012.

The average density of tailings in Pit 1 at June 2013 was 1.37 $t/m^3$, which exceeds the minimum target density of 1.2 $t/m^3$. The average density of tailings in the TSF at the end of reporting period was 1.0 $t/m^3$.

### 3.2.2.3 Audit and Routine Periodic Inspections (RPIs)

Eleven inspections and one audit were undertaken at Ranger during the 2012–13 reporting period. The grading system used in the audit, shown in Table 3.5, is the same as that used by DME. Use of this ranking system ensures the outcomes of the Ranger auditing process are consistent with that for other mines in the Northern Territory.

| TABLE 3.5 GRADING SYSTEM | |
|---|---|
| Category 1 Non-Conformance (CAT 1) | A category 1 non-conformance refers to a situation where an identified activity is not in compliance with the Authorisation, approval document or applicable legislation and could result in a high risk or is a persistent Category 2 non-conformance. |
| Category 2 Non-Conformance (CAT 2) | A category 2 non-conformance relates to an isolated lapse of control or an identified activity that is not in compliance with the Authorisation, approval document or applicable legislation that could result in a low or moderate risk. |
| Conditional (C) | This includes items that have been identified during planning that meet the established criteria and have commenced but have yet to be completed. |
| Acceptable (A) | This includes items that have been identified during planning that meet the established criteria and have been completed. |
| Not Verified (NV) | This is where compliance with the item has not been assessed. This may also include items that have been identified during planning but have yet to commence. |
| Observation (O) | An area that has notably improved or has the potential to be improved, or is outside the scope of the audit but is notable. |

Findings from the May 2012 environmental audit were followed up through the RPI process over the 2012–13 reporting period. The 2013 environmental audit of the Ranger mine was undertaken in May 2013. RPIs were carried out for each month of the 2012–13 reporting year with the exception of May. Table 3.6 shows the focus areas for the audit and RPIs for the year.

*Audit outcomes*

#### Closeout of findings from the May 2012 environmental audit

The May 2012 annual environmental audit delivered six conditional findings as listed in the 2011–12 Supervising Scientist Annual Report (see Table 3.5 for definitions). These findings were followed up via the monthly RPI process with all findings closed out prior to the 2013 annual audit.

#### May 2013 environmental audit

The 2013 environmental audit of Ranger mine was held on 13–16 May 2013. The audit team was made up of representatives from the NLC, DME, GAC and SSD. The following documents were the subject of the 2013 audit:

- Ranger Water Management Plan 2012–2013
- R3D Exploration Decline Application
- R3D Water Management Plan
- R3D Radiation Management Plan

109 commitments were audited against the grading system shown in Table 3.5.

**TABLE 3.6 AUDIT AND RPI**

| Date | Foci |
|---|---|
| 19 July 2012 | Ranger 3 Deeps (R3D) exploration decline box-cut, Pit 1 wick installation exploration drilling sites, RP5, RP6 and TSF wall raise. |
| 16 August 2012 | Exploration decline, TSF raise, RP6, tailings corridor. |
| 20 September 2012 | Northern RPA exploration drilling, waste hydrocarbon storage, clarifier tank, tailings dam lift, RP6. |
| 18 October 2012 | Exploration decline radiation protection, wet season preparation (various sumps and pumps). |
| 15 November 2012 | Pit 3 levee, RP5, brine concentrator, exploration decline. |
| 13 December 2012 | Magela Land Application Area, Pit 3 Levee, Pit 3 Backfill, Brine Concentrator, Skylab stockpile sheeting, Bulk Diesel Facility. |
| 17 January 2013 | Exploration decline, brine concentrator, Pit 3 backfill, skylab stockpile sheeting, Pit 3 levee, RP6 and TSF. |
| 21 February 2013 | Pit 3 levee, WTP1 brines pipeline, acid tanks and bund. |
| 21 March 2013 | Brine concentrator, brine concentrator pipelines hydrostatic testing incident, Pit 3, MG001 boat ramp for Magela Creek abstraction point, trial landform. |
| 18 April 2013 | Exploration decline vent raise location, Pit 3 backfill, Pit 3 levee and borrow pit, Corridor Road brine transfer line, GCBR/RP5, TSF and RP6. |
| 13–16 May 2013 | Audit: Ranger Water Management Plan 2012-2013; R3D exploration decline application; R3D Radiation Management Plan; R3D Water Management Plan. |
| 13 June 2013 | CCD7 tailings slurry release, Pit 3 backfill, trial landform, exploration core store. |

One category-2 non-conformance was found related to the timeliness of reporting of water quality guideline trigger value exceedances.

The audit team provided a further 12 observations throughout the audit which were reported to ERA in the closing meeting and via an audit report. All other findings were ranked as acceptable or not verified. SSD will continue to follow up on all identified issues and ensure the close-out of corrective actions through the RPI process.

#### 3.2.2.4 Minesite Technical Committee

The Ranger Minesite Technical Committee met six times during 2012–13. Dates of meetings and issues discussed are shown in Table 3.7. Significant agenda items discussed at MTCs included updates from ERA on site activities including water management and inventories, exploration decline and brine concentrator projects, TSF raise, updates from the Ranger Closure Criteria Working Group, the findings of the Independent Surface Water Working Group, Pit 3 levee, Pit 3 backfill and Pit 1 preload.

**TABLE 3.7 RANGER MINESITE TECHNICAL COMMITTEE MEETINGS**

| Date | Significant agenda items in addition to standing items |
|---|---|
| 20 July 2012 | TSF MOL, TSF lift, water quality reporting, Ranger exploration, Ranger MMP, various reports, TSF inspection, RP5 and RP6, Mg pulse exposure work, brine treatment. |
| 5 October 2012 | TSF MOL, Ranger exploration, Ranger MMP, Ranger Water Management Plan, Ranger Wet Season Report, mine closure, RP5 and RP6, Pit 3 levee. |
| 7 December 2012 | TSF MOL, ISWWG, TSF MOL, Ranger Water Management Plan, Ranger Wet Season Report, mine closure, Pit 3 levee, SSD monitoring program, TSF contingency pumping system, brine treatment. |
| 8 February 2013 | TSF MOL, ISWWG, Ranger Water Management Plan, Ranger Wet Season Report, Ranger Environment Report, Annual Plan of Rehabilitation, mine closure, brine treatment, Mg pulse exposure framework, TSF contingency pumping system. |
| 15 March 2013 | Pit 3 backfill, Pit 1 preload, ISWWG, brine treatment, TSF contingency pumping system, Ranger Water Management Plan, Ranger Wet Season Report, Ranger Environment Report, Annual Plan of Rehabilitation, mine closure, abstraction from Magela Creek. |
| 17 May 2013 | ISWWG recommendations, mine closure planning, abstraction from Magela Creek, phase 2 exploration decline application, 2013 surface exploration program, Pit 1 pre-load notification, Ranger wet season reporting. |

#### 3.2.2.5 Authorisations and approvals

There were three changes to the Ranger Authorisation during the reporting period. The current version of the Authorisation (0108-16) was issued on 18 June 2013 and included revised requirements for water abstraction from Magela Creek. Previous versions were altered to vary the TSF MOL as discussed above in Section 3.2.1.1.

#### 3.2.2.6 Incidents

*Background to incident investigation*

Since 2000, ERA has undertaken to provide stakeholders with a comprehensive list of environmental incidents reported at its Ranger and Jabiluka operations on a regular basis. The regular monthly environmental incident report is additional to reports made to meet the statutory requirements for incident reporting. This regime of reporting all recorded environmental incidents is undertaken voluntarily by ERA in response to concerns expressed by stakeholders about the establishment of suitable thresholds of incident severity for reporting.

Immediately upon receipt of notification of any incident, SSD assesses the circumstances of the situation and a senior officer makes a decision on the appropriate level of response. Dependent on the assessment, this response will range from implementation of an immediate independent investigation through to seeking further information from the mine operator before making such a decision. In those cases where immediate action is not considered to be required, the situation is again reviewed on receipt of a formal incident investigation report from the operator.

Prior to each RPI (see section 3.1.2), the inspection team reviews the previous month's environmental incident report summary (EIRS) and any open issues. Where an incident is considered to have any potential environmental significance or represents a repetition of a class of occurrences, an on-site review of the circumstances is scheduled as a part of the routine inspection agenda.

SSD determined that none of the incidents that occurred during the reporting period were of a serious enough nature to warrant a separate independent investigation. However, the incidents below were followed up through the RPIs to inspect the locations of the incidents and to gain further information and understanding of remedial actions taken by ERA to prevent future recurrence of similar incidents.

*Breach of vehicle card reader procedure*

ERA advised that, on Wednesday 11 July 2012, a breach of procedure occurred where a vehicle card reader was removed from a Landcruiser wagon and transferred to a truck. The transfer occurred at an off-site location. The truck accessed Ranger mine site and shortly later attempted to exit site. The gatehouse operators then identified that the vehicle card reader had been transferred to the truck. The vehicle card reader system was developed and implemented with the primary purpose to prevent controlled vehicles from exiting site. For vehicles entering site, the boom gate is activated automatically for vehicles with an authorised vehicle card reader accompanied by a person holding a current authorised ERA Ranger Mine pass. An additional suite of controls apply for vehicles exiting site. These controls succeeded in detecting that the card reader had not been legitimately installed in the truck. No controlled vehicles were involved in this incident.

*Return process water pipeline leak*

ERA advised that, during a scheduled tails line inspection on Saturday 28 July 2012, a small leak was detected in the process water return line along Corridor Road. Following the leak discovery, the process water return line was shut down and a successful repair to the pipeline was completed. The leak impacted an area of soil approx 25 $m^2$ to a depth of approx 30 cm and was contained within the pipeline culvert area. Investigation showed that the leak was the result of a hole created by termites. The area was subsequently professionally treated with termiticide to prevent any further termite attacks.

*Water treatment plant brine leak*

ERA advised that, on Saturday 19 January 2013, the WTP 1 brine discharge line was observed leaking out of the ground near the WTP. The leak was within the Corridor Road containment bund which reports to Pit 1. The pipeline was isolated immediately and the remaining water in the pipeline was drained back to the WTP concrete bund. An estimated 5000 L of brine leaked into the containment bund with an EC of 4950 µS/cm. All of the spill was contained within the bunded area.

*CCD7 feed pump failure*

ERA advised that, on Wednesday 5 June 2013 at approximately 6pm, the discharge spool on CCD7 feed pump failed causing approximately 200 L of tailings slurry to spray outside the bunded area. An earthen bund was created to contain and cover the material which was then scraped up and disposed of in Pit 1. No material entered any drains. A radiation survey was conducted in the area following the clean-up and no readings above background were measured.

The rubber lining on the spool initially failed leading to metal corrosion in January 2013. The rubber lining was repaired and the metal plate patched at that time. This section failed again and the plate was repatched on 28 May 2013. At the RPI on 13 June 2013, process water was observed leaking through a 3 cm hole in the discharge feedbox. The process water was diverted out of the discharge feedbox and contained within the bund. The item will remain on the RPI action list until the spool has been completely refurbished or replaced and the RPI team are satisfied the incident will not reoccur.

## 3.2.3 Off-site environmental protection

### 3.2.3.1 Surface water quality

Under the Authorisation, ERA is required to monitor and report on water quality in Magela and Gulungul Creeks adjacent to the Ranger mine. Specific water quality objectives must be achieved in Magela Creek.

The Authorisation specifies the sites, the frequency of sampling and the analytes to be reported. Each week during the wet season ERA reports the water quality at key sites, including Magela and Gulungul Creeks upstream and downstream of the mine, to the major stakeholders (the Supervising Scientist, DME, NLC and GAC). A detailed interpretation of water quality across the site is provided at the end of each wet season in the ERA Ranger Annual Wet Season Report.

In addition to ERA's monitoring program, 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. Key results are presented in time-series charts throughout the wet season on the internet at www.environment.gov.au/ssd/monitoring. The highlights of the monitoring results from the 2012–13 wet season are summarised below.

*Chemical and physical monitoring of Magela Creek*

Since the 2010–11 wet season, SSD has used continuous monitoring of EC, turbidity and water temperature coupled with event-based automatic sampling as its primary water quality monitoring method. In comparison to the redundant weekly grab sampling method, the continuous monitoring method has substantially enhanced SSD's ability to independently detect changes in water quality through time. Manual grab samples are still collected during routine site visits for the purposes of quality control and for analysis of radium. Map 2 shows the location of the upstream (MGUGT) and downstream (MCDW) monitoring sites and key Ranger minesite features.

Flow was first recorded at the Magela Creek upstream and downstream monitoring stations on 7 January 2013. Due to the below average rainfall this wet season (Figure 3.1) the Magela Creek flow remained very low (<25 $m^3/s$) with the exception of a flood event occurring on the 31 March 2013.

On 17 January 2013, a localised high intensity rainfall event in the vicinity of the downstream monitoring station (81.8 mm at Jabiru airport and 40.4 mm at MG009) resulted in a rapid increase in flow at MCDW peaking at 14 $m^3/sec$, in turn decreasing EC (Figure 3.2) and significantly increasing turbidity (Figure 3.3). It is not likely that the Pit 3 levee contributed to this turbidity event as ERA reported only 14 mm of rainfall was recorded at Pit 3. Water quality parameters returned to previous levels within a few hours. The effects of this rainfall event were also observed at both the upstream and downstream monitoring sites in Gulungul Creek (see below).

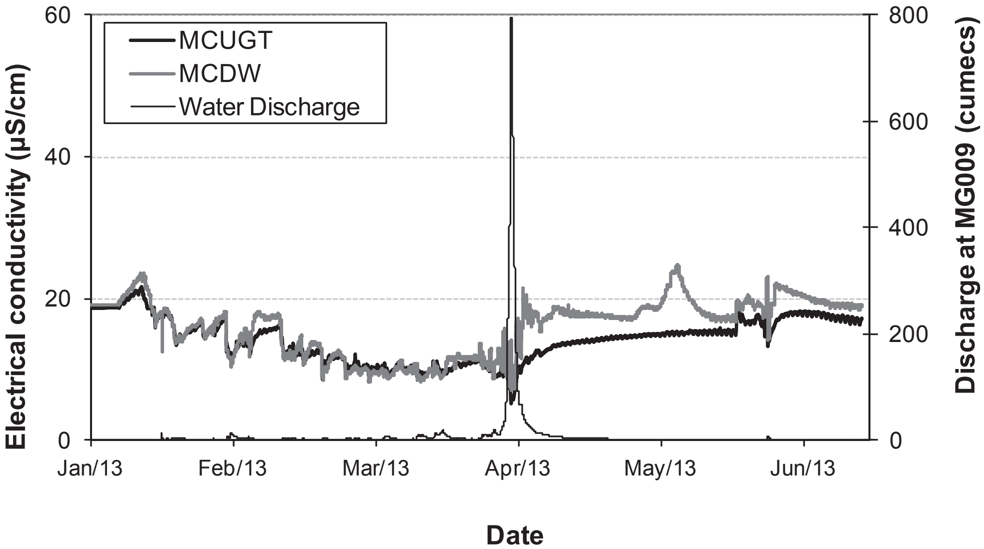



**Figure 3.2** Continuous electrical conductivity and discharge in Magela Creek between January and June 2013

On 30 and 31 March 2013, a low pressure system resulted in heavy rainfall over the Arnhem Land region. Jabiru Airport recorded total rainfall of 240 mm over the two days and Magela Creek flow quickly rose and peaked at 800 $m^3/s$. During this period water from RP1 with an EC of approximately 300 µS/cm was released into Coonjimba Billabong, resulting in slightly increased EC levels at MCDW during the latter part of the flood event, as the creek flow receded and the water in the billabong discharged into the creek. However, due to the large dilution rates during this rainfall event, the EC did not exceed the focus trigger level of 21 µS/cm.

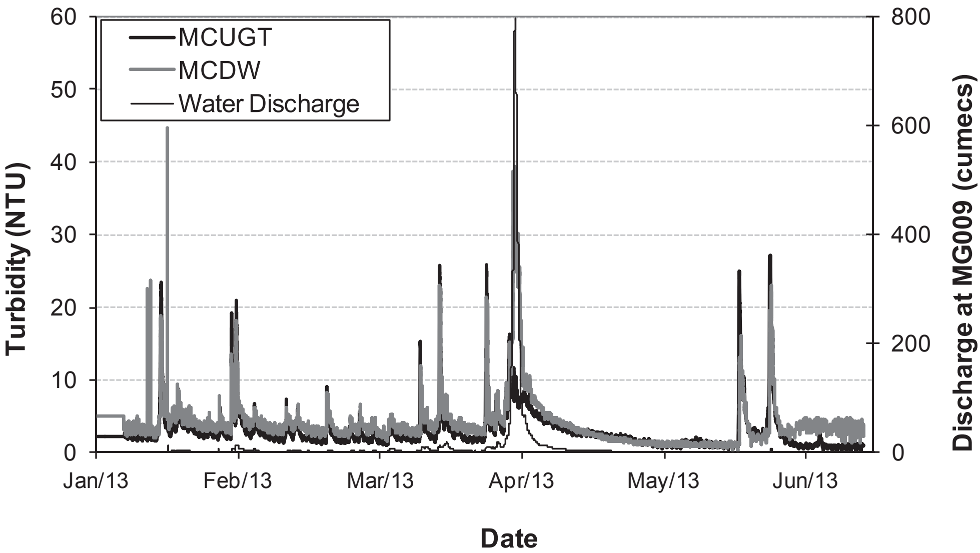



**Figure 3.3** Continuous turbidity and discharge in Magela Creek between January and June 2013

During early May the minesite released pond water treatment plant permeate (good quality water) into the Corridor Creek system. This input resulted in the outflow of water from Georgetown Billabong into Magela Creek. As the billabong waters typically have a higher EC than the creek waters during the dry season due to solute inputs from Corridor Creek and evapoconcentration, the outflow from Georgetown Billabong was detected at MCDW via an increase in EC to 25 µS/cm on 5 May 2013. This EC was just above the Focus trigger value of 21 µS/cm. The minesite stopped the discharge of permeate into Corridor Creek and in turn Georgetown Billabong ceased flowing into Magela Creek and a corresponding decrease in EC at MCDW was observed. A number of EC fluctuations were observed during May and June as a result of discrete rainfall events combined with very low flow in the creek.

During the wet season, the maximum total uranium concentration measured downstream from the Ranger mine was 0.05 µg/L. This value is approximately 1% of the local ecotoxicologically-derived limit of 6 µg/L for protection of aquatic ecosystems, and approximately 0.25% of the 20 µg/L guideline for potable water (Figure 3.4).

The maximum manganese concentration of 9.9 µg/L occurred in early April following the large rainfall event (Figure 3.5). This value is below the action trigger value of 11 µg/L for manganese. However, surface water flows on this date were less than 1 cumecs, noting that the manganese guideline trigger value only applies when surface water flows are greater than 5 cumecs.

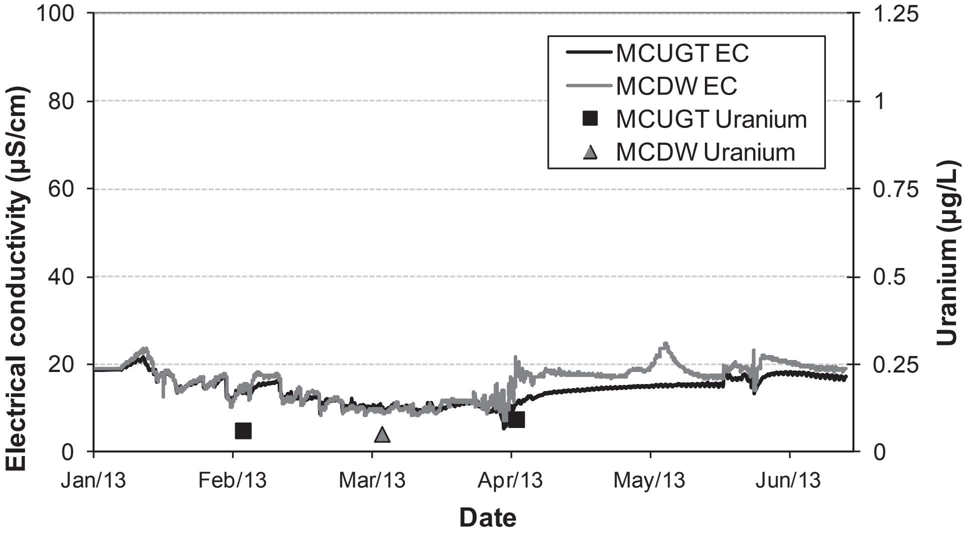



**Figure 3.4** Total uranium concentrations in triggered samples and continuous electrical conductivity in Magela Creek between January and June 2013

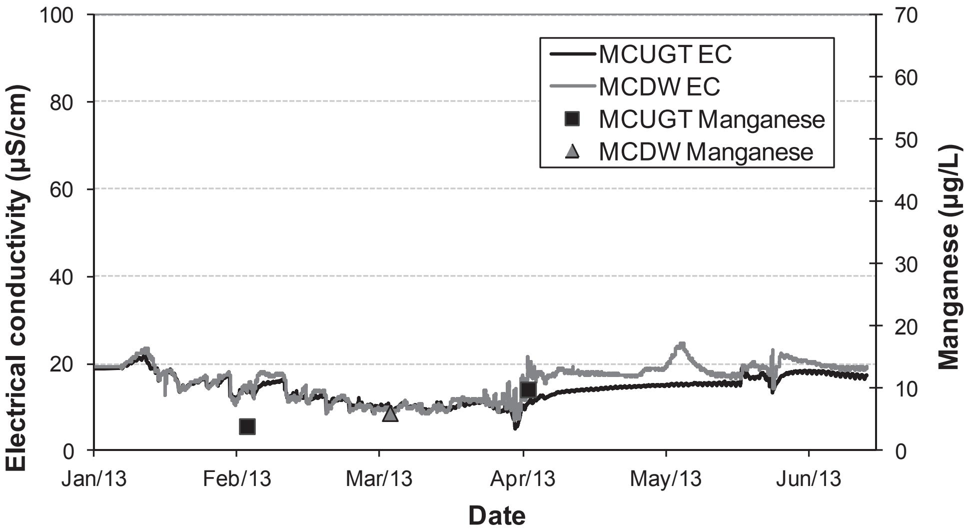



**Figure 3.5** Total manganese concentrations in triggered samples and continuous electrical conductivity in Magela Creek between January and June 2013

Magnesium and sulfate concentrations measured during 2012–13 were low reflecting the low mine site inputs to the creek this season (Figures 3.6 & 3.7). Automatic samples were not triggered for any EC peaks during the 2012–13 wet season as the EC did not exceed the 42 µS/cm (corresponding to 3 mg/L magnesium) guideline.

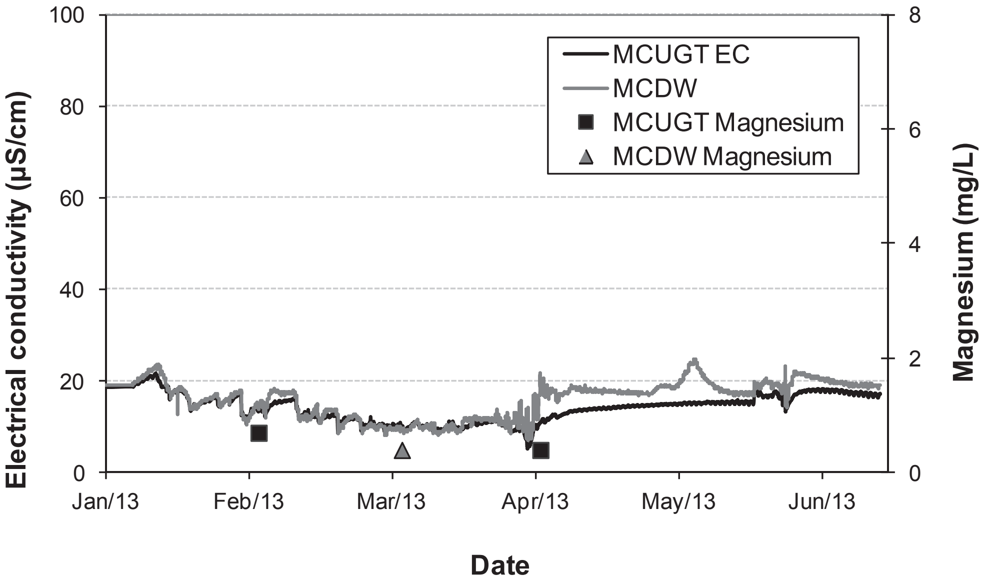



**Figure 3.6** Total magnesium concentrations in triggered samples and continuous electrical conductivity in Magela Creek between January and June 2013

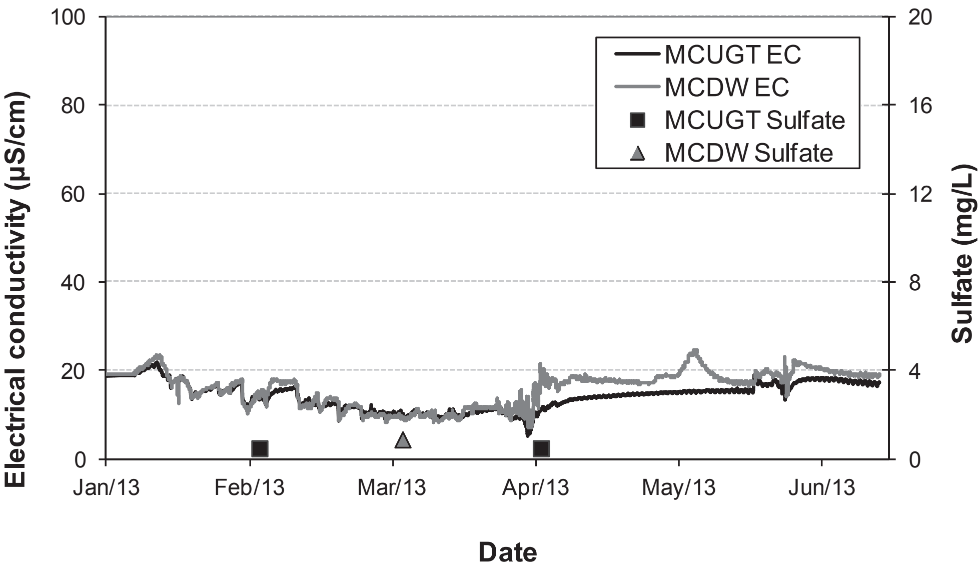



**Figure 3.7** Total sulfate concentrations in triggered samples and continuous electrical conductivity in Magela Creek between January and June 2013

Continuous monitoring continued until 12 June 2013 when the multi-probes were no longer submersed and could not be lowered any further. Cease to flow in Magela Creek was agreed by stakeholders on 1 July 2013.

Overall, the water quality measured in Magela Creek for the 2012–13 wet season showed lower EC at the downstream monitoring site compared to previous wet seasons due to very low rainfall, which resulted in reduced surface run-off and low creek flow conditions plus reduced volume of managed released waters from the minesite. The results indicate that, based on water quality, the aquatic environment in the creek has remained protected from mining activities (Figure 3.8).

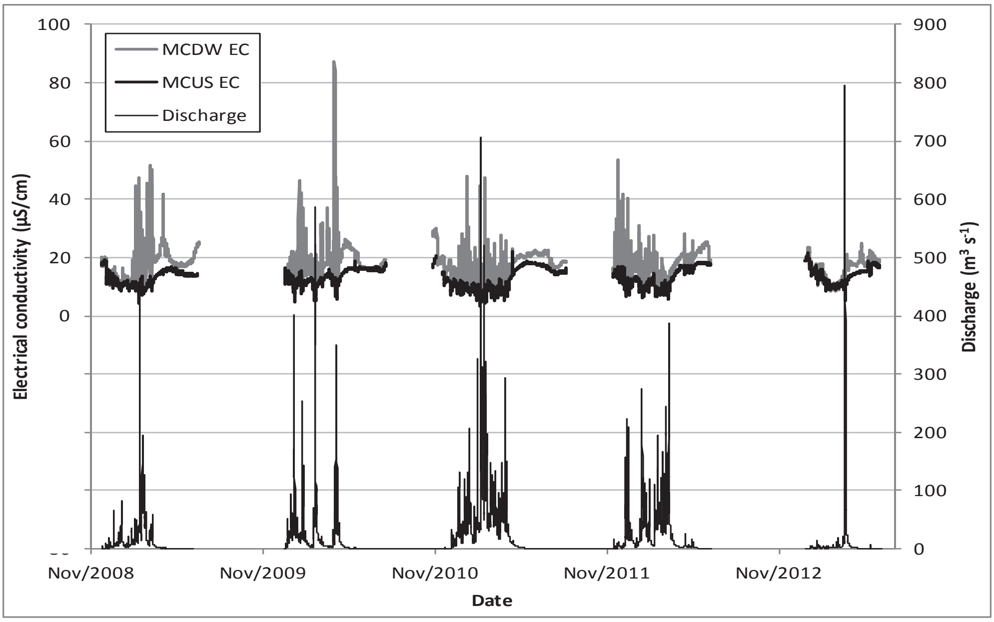



**Figure 3.8** Continuous electrical conductivity and discharge (lower trace) in Magela Creek for each wet season between November 2008 and June 2013 (values averaged over a 90 minute period of measurement)

Radium in Magela Creek

Surface water samples are collected fortnightly from Magela Creek upstream and downstream of the Ranger mine. The fortnightly samples are combined to give monthly composite samples. Total radium-226 ($^{226}Ra$) is measured in these samples and results for the 2012–13 wet season can be compared with previous data ranging back to the 2001–02 wet season (Figure 3.9).

The data from monthly sample composites show that the levels of $^{226}Ra$ are very low in Magela Creek, both upstream and downstream of the Ranger mine. An anomalous $^{226}Ra$ activity concentration of 8.8 mBq/L measured in a sample collected from the control site upstream of Ranger in 2005 was probably due to a higher contribution of $^{226}Ra$-rich soil or finer sediments that are present naturally in Magela Creek. This has previously been discussed in the 2004–05 Supervising Scientist Annual Report.

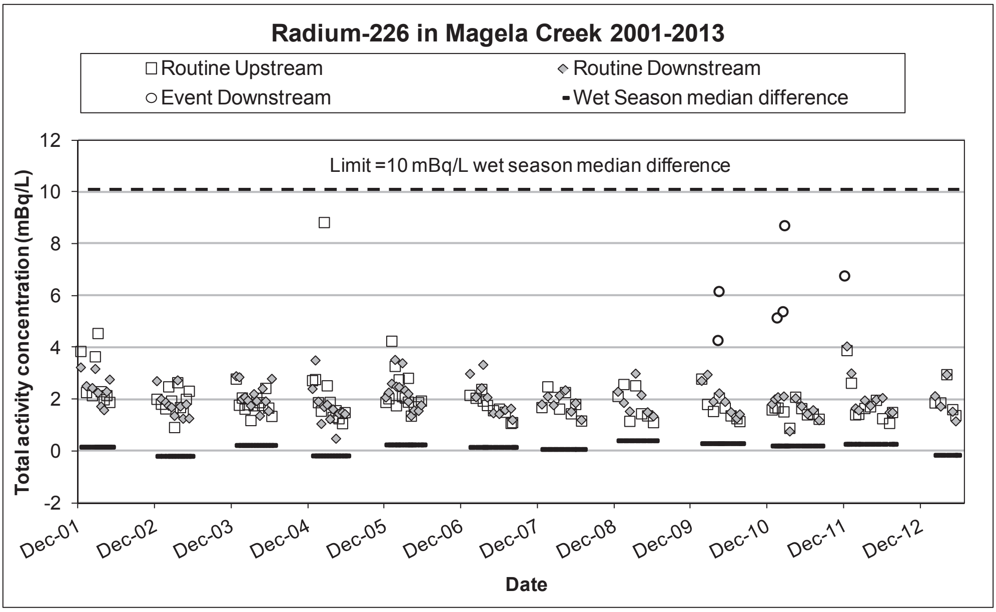



**Figure 3.9** Radium-226 in Magela Creek 2001–2013

The limit value for total $^{226}$Ra activity concentrations in Magela Creek has been defined for human radiological protection purposes, and is based on the median difference between upstream and downstream $^{226}$Ra activity concentrations over one entire wet season. The median of the upstream $^{226}$Ra data collected over the current wet season is subtracted from the median of the downstream data. This difference value, called the 'wet season median difference', quantifies any increase at the downstream site, and should not exceed 10 mBq/L.

A wet season median difference of 10 mBq/L would result in a mine origin ingestion dose from $^{226}$Ra bioaccumulated in mussels of about 0.3 mSv, if 2 kg of mussels were ingested by a 10 year old child. Wet season median differences (shown by the horizontal lines in Figure 3.9) from 2001 to 2013 are close to zero, indicating that the majority of $^{226}$Ra is coming from natural sources of Ra located in the catchment upstream of the mine. The wet season median difference for the entire monitoring period (2001–2013) is only 0.1 mBq/L.

Since 2010, $^{226}$Ra analyses of a composite of samples collected by autosampler during individual EC-triggered events have also been performed. The results are shown in Figure 3.9, together with the results from the routine radium analyses. The EC-triggered event data are not included in the calculation of the wet season median difference, because these EC events are short-lived and their impact on seasonal $^{226}$Ra loads is very small.

There were no EC-triggered event samples collected during the 2012–13 wet season. The wet season median difference for the 2012–13 wet season is -0.1 mBq/L indicating a greater median value for the upstream monitoring site than for the downstream monitoring site.

*Chemical and physical monitoring of Gulungul Creek*

Flow was first recorded at the Gulungul Creek upstream and downstream monitoring stations on 23 December 2013. Flow remained very low due to below average rainfall this wet season.

On 17 January 2013 Jabiru airport recorded a rainfall event of 81.8 mm. This appeared to have been a localised rainfall event resulting in increased EC and increased turbidity at both the upstream and downstream monitoring sites. Water quality parameters returned to previous levels within a few hours.

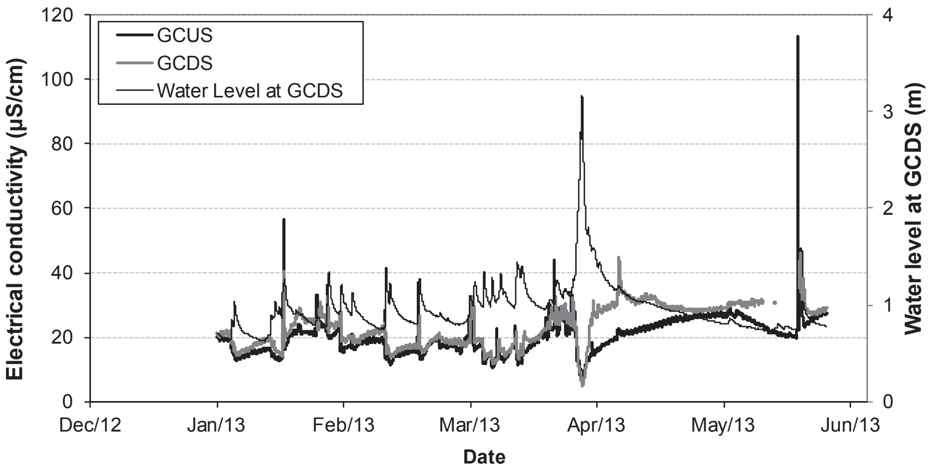



**Figure 3.10** Electrical conductivity and water level in Gulungul Creek between December 2012 and June 2013

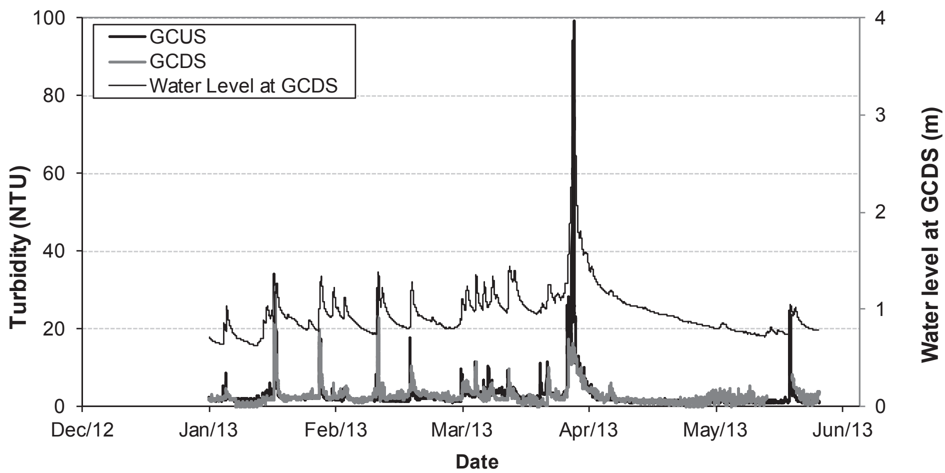



**Figure 3.11** Turbidity and water level in Gulungul Creek between December 2012 and June 2013

Continued low rainfall conditions resulted in low flow levels in the creek through most of February. The frequency of rainfall events increased in March which increased the flow levels in Gulungul Creek.

On 30 and 31 March 2013 a low pressure system resulted in significant rainfall over Arnhem Land. Jabiru Airport recorded total rainfall of 240 mm over the two days. Flow within Gulungul Creek quickly rose, with a corresponding decline in EC due to dilution with low salinity rainfall. EC increased in early April as flow levels decreased.

On 9 April 2013 an increase in EC coincided with a localised rainfall event. The EC at the downstream monitoring site peaked at 45 µS/cm and remained above 42 µS/cm for a period of 5 hours. Under the SSD ecotoxicology electrical conductivity-magnesium pulse framework, a 5 hour pulse duration would have an EC limit value of 581 µS/cm, thus with a peak of 45 µS/cm the downstream aquatic ecosystem was very unlikely to have been impacted by this event.

From mid April, recessional flow conditions became established within Gulungul Creek with sustained low flows and slowly rising and converging EC at upstream and downstream monitoring sites. During early to mid May, the monitoring multi-probe sensor at GCDS was no longer submersed due to very low flow levels.

A localised rainfall event in the upper Gulungul Creek catchment on 22 May 2013 flushed solutes into the creek resulting in a non-mine derived EC peak of 113 µS/cm at the upstream monitoring site, GCUS. These solutes were washed down the creek and progressively diluted, producing EC peaks of 76 and 46 µS/cm at GCMID and GCDS monitoring sites (Figure 3.12). The EC at the downstream monitoring site remained above 42 µS/cm for a period of 3.3 hours. Under the SSD ecotoxicology electrical conductivity-magnesium pulse framework, a 3.3 hour pulse duration would have an EC limit value of 1140 µS/cm, thus with a peak of 46 µS/cm, the downstream aquatic ecosystem was very unlikely to have been impacted by this natural event.

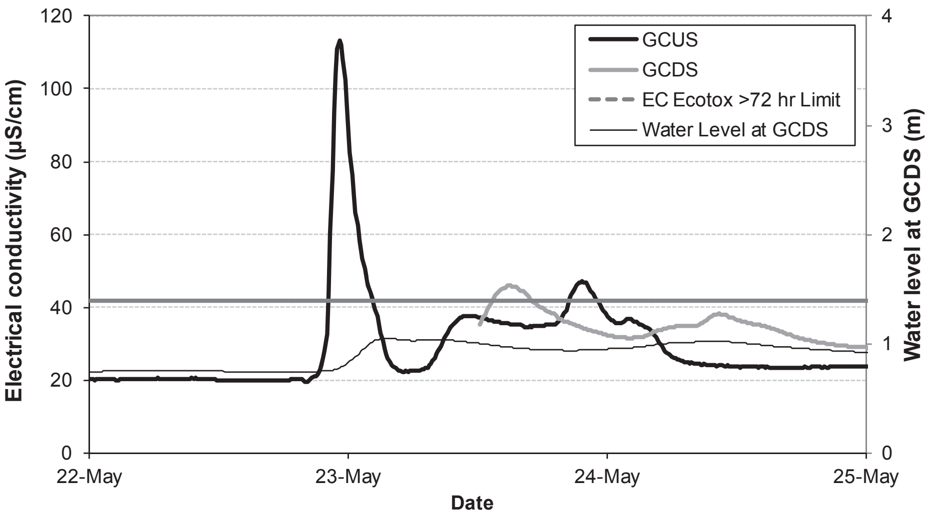



**Figure 3.12** Electrical conductivity and water level in Gulungul Creek during 22–25 May 2013

Continuous monitoring continued until 29 May 2013 when the multi-probes were no longer submersed and could not be lowered any further. Cease to flow in Gulungul Creek was agreed by stakeholders on 18 June 2013.

During the 2012–13 wet season, the maximum total uranium concentration of 0.45 µg/L (Figure 3.13) was measured at GCUS upstream from the Ranger mine. Manganese concentrations were also greatest at the upstream monitoring site (GCUS) with a maximum concentration of 22 µg/L recorded on 11 February 2013 (Figure 3.14).

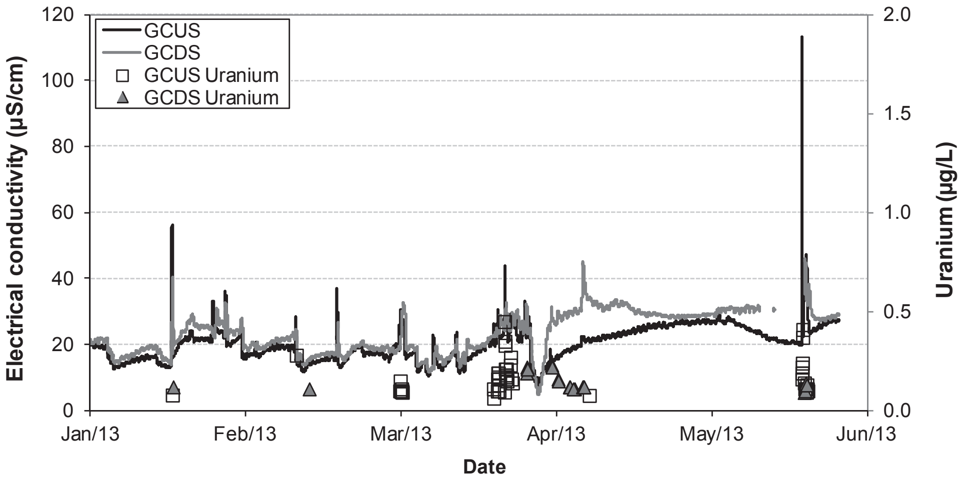



**Figure 3.13** Electrical conductivity and total uranium concentrations in Gulungul Creek between December 2012 and June 2013

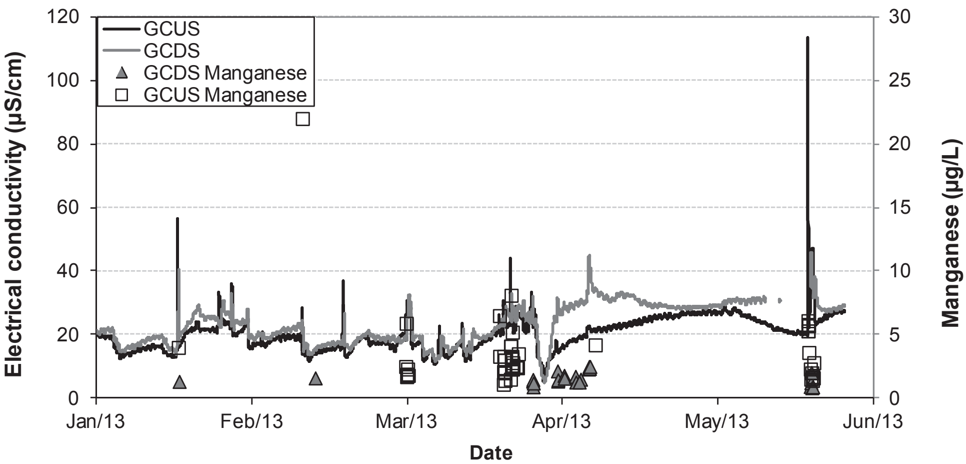



**Figure 3.14** Electrical conductivity and total manganese concentrations in Gulungul Creek between December 2012 and June 2013

Magnesium concentrations closely followed the EC continuous monitoring trace (Figure 3.15). The highest recorded concentrations occurred at GCUS monitoring site, upstream of the minesite with a peak of 9.3 mg/L on 22 May 2013. At the downstream monitoring site the concentrations of magnesium remained below 2.6 mg/L throughout the wet season.

Sulfate concentrations were generally low. The highest concentrations of 5 mg/L were observed at GCDS on 9 April 2013 (Figure 3.16).

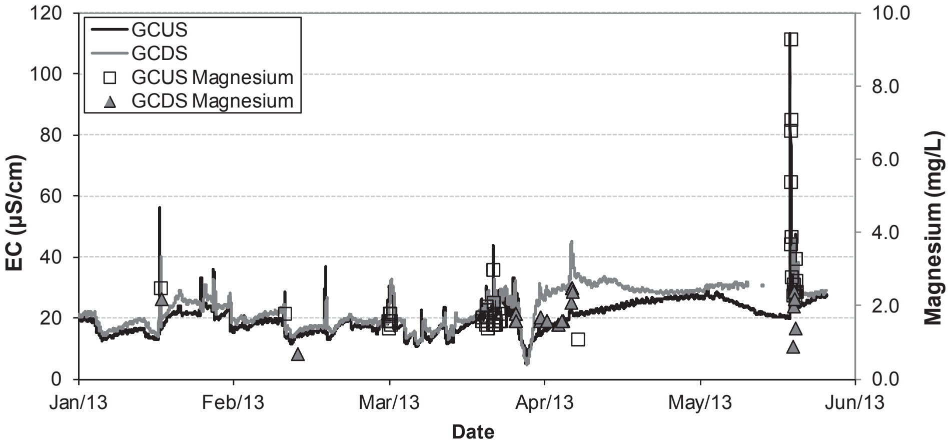



**Figure 3.15** Electrical conductivity and total magnesium concentrations in Gulungul Creek between December 2012 and June 2013

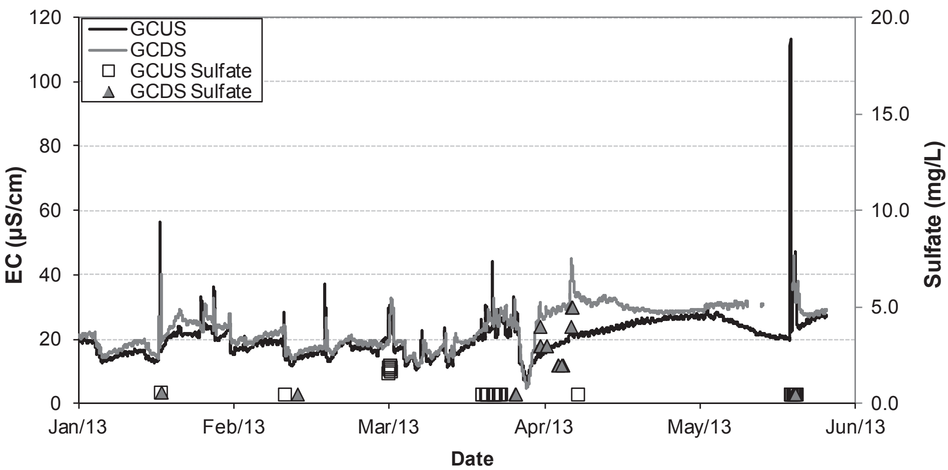



**Figure 3.16** Electrical conductivity and total sulfate concentrations in Gulungul Creek between December 2012 and June 2013

Overall, the water quality measured in Gulungul Creek for the 2012–13 wet season showed greater fluctuation in EC at the upstream monitoring site compared to previous wet seasons. This was due to very low overall rainfall and the effects from small scale rain events within the Gulungul catchment area, which resulted in localised surface runoff and influx of solutes into the creek. The results for the downstream monitoring site are comparable to previous years and indicate that, based on water quality, the aquatic environment in the creek has remained protected from mining activities (Figure 3.17).

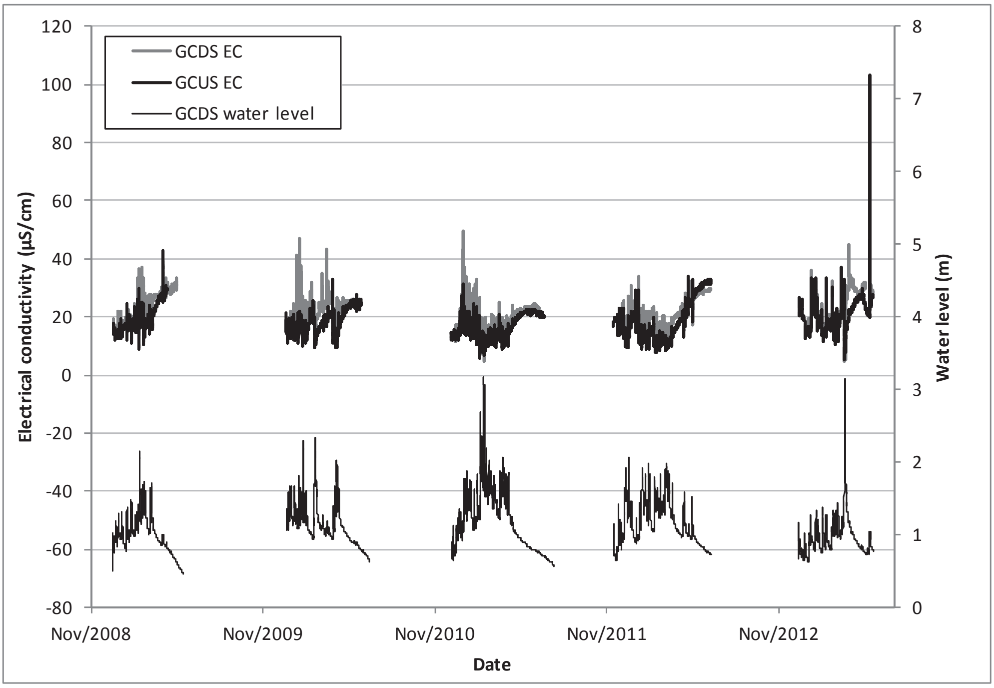



**Figure 3.17** Electrical conductivity measurements and discharge (lower trace) in Gulungul Creek between November 2008 and July 2013 (values averaged over a 1 hour period of measurement)

### 3.2.3.2 Biological monitoring in Magela Creek

Research conducted by ***eriss*** since 1987 has been used to develop biological techniques to monitor and assess the potential effects of uranium mining on aquatic ecosystems downstream of Ranger mine. Two broad approaches are used: (1) early detection and (2) assessment of overall ecosystem-level responses at the end of the wet season.

*Early detection* of effects in Magela Creek is performed using two techniques: (i) in situ toxicity monitoring for detection at a weekly timescale of effects arising from inputs of mine waters during the wet season, and (ii) bioaccumulation, used to measure over a seasonal timescale a potential developing issue with mine-derived solutes (metals and radionuclides) measured in aquatic biota.

For *ecosystem-level responses*, benthic macroinvertebrate and fish community data from late wet season sampling in Magela and Gulungul Creek sites are compared with historical data and data from control sites in streams unaffected by contemporary mining.

The findings from toxicity monitoring, bioaccumulation, and fish and macroinvertebrate community studies conducted during the 2012–13 reporting period are summarised below.

*In situ toxicity monitoring*

In this form of monitoring, effects on receiving waters of water dispersed from the Ranger minesite are evaluated using responses of aquatic animals exposed in situ to creek water. The response measured is reproduction (egg production) by the freshwater snail, *Amerianna cumingi*. Each test runs over a four day (96 hr) exposure period. In such chronic exposure situations, this species has been shown to be among the most sensitive, to both uranium and magnesium, of SSD's suite of six local species as determined using standardised laboratory toxicity test protocols.

For the 1990–91 to 2007–08 wet seasons, toxicity monitoring was carried out using the 'creekside' methodology (Figure 3.18A). This involved pumping a continuous flow of water from the adjacent Magela Creek through tanks containing test animals located under a shelter on the creek bank. In the 2006–07 wet season, an in situ testing method commenced, in which test animals are placed in floating (flow-through) containers located in the creek itself (see section 3.2 of the 2007–08 Supervising Scientist Annual Report for details). Thus for the 2006–07 and 2007–08 wet seasons, creekside and in situ testing were conducted in parallel, to evaluate the effectiveness of the in situ method. For current data analyses, creekside data up to and including the 2005–06 wet season and in situ data from the 2006–07 wet season onward (Figure 3.18) are combined. The most recent refinement to this program has been the extension of toxicity monitoring to Gulungul Creek, with testing commencing in the 2009–10 wet season (Figure 3.18 B).

The first of eight tests in Magela Creek commenced on 10 January 2013, six days after the establishment of continuous flow in the creek. The following week, on 17 January 2013 the first of the seven Gulungul tests commenced. A combined total of 15 tests were completed over 15 weeks, alternating weekly between both creeks. The final test was completed in Magela Creek on 22 April 2013. For the fifth and sixth Gulungul Creek tests, data arising from one of the two duplicate floating containers deployed at the upstream site were deemed invalid due to container misalignment and subsequent restricted through-flow of creek waters. As such, results from the remaining duplicate only were used for subsequent statistical analyses for these two tests. Upstream and downstream egg production and difference values for both creeks are displayed in Figure 3.18B.

A marked increase in the mean number of eggs produced during each test for both sites of Magela and Gulungul Creeks was observed over the 2012–13 wet season (Figure 3.18B). Similar high egg production had previously only been observed in the first three tests of the 2006–07 wet season (Figure 3.18B). A significant factor contributing to this increase in egg production appears to be a new and more effective culturing regime for the snails at the laboratory aquaculture facility. The potential influence of snail husbandry on egg production and wet season toxicity monitoring results is discussed below and in more detail in section 4.4 of this report.

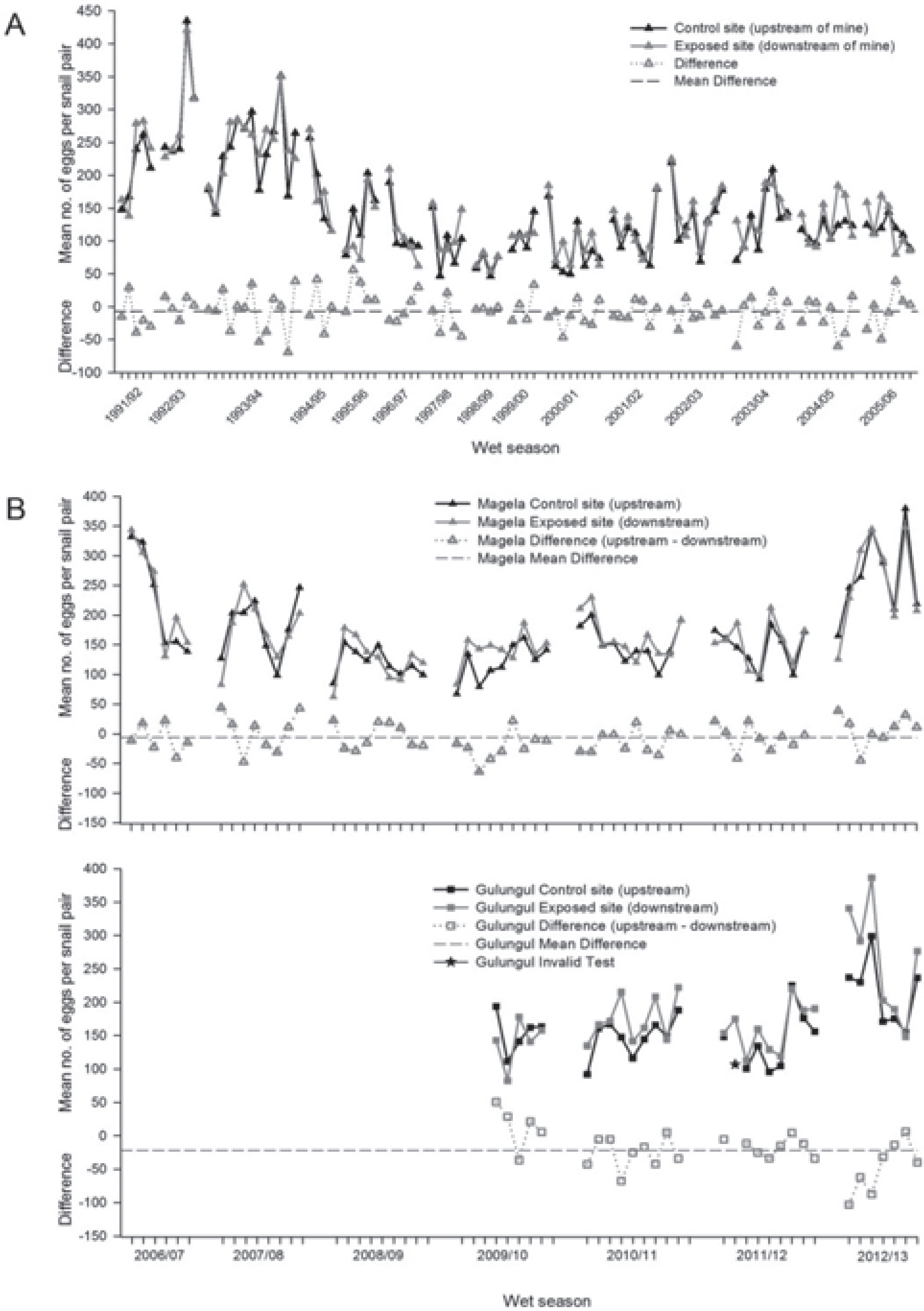



**Figure 3.18** Time-series of snail egg production data from toxicity monitoring tests conducted in Magela Creek using A: creekside tests, and B: in situ tests with Gulungul tests commencing in 2009–10.

#### Analysis of results

After each wet season, toxicity monitoring results for the tests are analysed, with differences in egg numbers (the 'response' variable) between the upstream (control) and downstream (exposed) sites tested for statistical change between the wet season just completed and previous wet seasons. This Before-After Control-Impact Paired (BACIP) design, with Analysis of Variance (ANOVA) testing, is described further in the Supervising Scientist's annual report for 2007–2008 (section 3.2.3).

### Magela Creek

The positive mean difference value for the eight 2012–13 wet season tests, of 7.51, indicates higher upstream egg production than downstream, contrasts with the historical trend of greater downstream egg production (mean difference value across all wet seasons of -8.04). The only previous period for which a positive mean difference value was observed was for the 1995–96 wet season. ANOVA results for the 2012–13 wet season, together with results from previous wet season scenarios, are displayed in Table 3.8. The significant differences observed in previous years, associated with particularly high egg production at the downstream site relative to the upstream site in the 2009–10 wet season, and to a lesser extent the 2010–11 wet season (Figure 3.18), are discussed in the respective Supervising Scientist annual reports. No significant difference was observed between the difference values derived from the 2012–13 wet season and those from previous wet seasons, though the low ANOVA significance value (near the 5% level, p = 0.083) highlights the unusually higher upstream egg production compared to downstream observed in this year (Table 3.8).

**TABLE 3.8 RESULTS OF ANOVA TESTING COMPARING MAGELA UPSTREAM-DOWNSTREAM DIFFERENCE VALUES FOR MEAN SNAIL EGG NUMBER FOR DIFFERENT 'BEFORE VERSUS AFTER' WET SEASON SCENARIOS**

| Before | After | Probability value (*P*) | Significance |
|---|---|---|---|
| All previous seasons | 2009–10 | 0.043 | at 5% level |
| All previous and following seasons | 2009–10 | 0.040 | at 5% level |
| All previous seasons | 2010–11 | 0.436 | NS |
| All previous seasons | 2010–11 + 2009–10 | 0.043 | at 5% level |
| All previous and following seasons | 2010–11 + 2009–10 | 0.025 | at 5% level |
| All previous seasons | 2011–12 | 0.916 | NS |
| All previous seasons | 2012–13 | 0.083 | NS |

NS = not significant

**Gulungul Creek**

The mean difference value across all Gulungul Creek tests for 2012–13, of -47.4, continues the trend of greater egg production downstream reported in previous years. Notable for this wet season were the particularly high egg numbers observed downstream in the first three tests compared to numbers upstream, giving rise to difference values much lower than previously recorded (Figure 3.18B). While the wet season mean difference value is much lower than the running mean of -13.47, ANOVA testing found no significant difference between the 2012–13 difference values and those recorded in previous wet seasons ($p = 0.228$).

Apart from the primary Before/After factor and associated hypothesis, the particular two-factor ANOVA model used for toxicity monitoring also allows variation amongst years (or wet seasons) and among tests within a wet season to be estimated separately. The second 'Season' factor can be used to determine whether, within the Before and After periods, any set of difference values for a wet season are significantly different. For Gulungul Creek after both the 2011–12 and 2012–13 wet seasons, the season factor has been significant ($p = 0.005$ and 0.048 respectively), compared to Magela Creek where this factor has never been significant. A significant season factor does not in itself imply potential mine-related impact; in this (Gulungul) case, it highlights the high inter-annual variation observed in seasonal difference values, as shown in Figure 3.18B and as reported in the previous Supervising Scientist annual report (2011–2012).

Conclusions

In the Supervising Scientist's annual reports for 2009–2010 and 2010–2011 (section 3.4 of both reports), the influence of water temperature and electrical conductivity on the snail egg laying response was described. In section 4.4 of the current report, these same water quality variables, together with snail husbandry conditions, are considered in the context of explaining the lower (compared to upstream) egg production observed in Magela Creek downstream of Ranger, as well as the particularly high egg production observed in the first three tests in Gulungul Creek downstream of Ranger, in the 2012–13 wet season.

The analysis presented in section 4.4 highlights the different water temperature regimes prevailing in both creeks over the 2012–13 wet season: median water temperatures were typically between 30 and 32°C in Magela Creek but lower, between 27 and 30°C, in Gulungul Creek (Figure 3.18). For these respective water temperature ranges, decreases and increases in snail egg production have been observed with increasing electrical conductivity (EC) over the range 10–30 µS/cm (see section 3.4 of the Supervising Scientist's annual report, 2011–2012). In both creeks, median water temperature was higher at the downstream monitoring sites across all tests. Thus, and in general, the lower Magela, but higher Gulungul, downstream egg production, compared to respective upstream sites, reflects the inhibitory and enhanced effects respectively, associated with the different water temperature regimes in each of the creeks (section 4.4).

For only one toxicity monitoring test (the last Gulungul test, Figure 3.18) the median EC value was greater than 25 µS/cm, indicating for both creeks and across the 2012–13 wet season very limited mine water inputs (see section 3.2.3.1). Thus, the toxicity monitoring results for 2012–13 reflect patterns associated with natural water quality (water temperature, EC) conditions in both creeks. There was no evidence of mine-related effects upon snail egg production over the wet season.

*Bioaccumulation in freshwater mussels*

Some metals and radionuclides bioaccumulate in aquatic biota, in particular freshwater mussels of Magela Creek and tributaries. Therefore, it is essential to check that food items collected from Magela Creek are fit for human consumption and that concentrations of metals and radionuclides in organism tissues attributable to Ranger mine remain within acceptable levels. Enhanced body burdens of mine-derived solutes could also potentially reach limits that may harm the organisms themselves, and therefore any elevation in tissue concentrations can provide useful early warning of bioavailability of these constituents. Hence, the bioaccumulation monitoring program serves an ecosystem protection role in addition to the human health aspect.

Local Aboriginal people harvest fish and mussels from Mudginberri Billabong, 12 km downstream of the Ranger mine (Map 3). Routine monitoring of the levels of radionuclides and some metals in these food items commenced in 2000. Monitoring had not shown any issues of potential concern with regards to bioaccumulation in fish. Hence, the focus of the bioaccumulation monitoring program has been directed at mussel tissue analysis, while the two-yearly fish sampling program was discontinued in 2007. Up until 2008, mussels were collected annually from two sites: Mudginberri Billabong (the potentially impacted site) and Sandy Billabong (the control site in a different catchment, sampled from 2002 onwards). The results showed that radionuclide burdens in mussels from Mudginberri Billabong were generally about twice that observed in the control site Sandy Billabong. Two research projects reported in previous Supervising Scientist annual reports concluded that this difference was due to natural catchment influences and differences in water chemistry, rather than mining-related inputs to Magela Creek. Thus, the scope of the monitoring program for mussel bioaccumulation was reduced from 2009 onwards. It now involves the annual collection and analysis of a bulk mussel sample from Mudginberri Billabong, rather than analysing separate age-classed mussels from both Mudginberri and Sandy Billabongs. This is done primarily to provide reassurance that the consumption of mussels does not present a radiological risk to the public. Every three years, starting with the October 2011 collection (reported in the 2011–2012 Supervising Scientist annual report), a detailed study (analysis of aged mussels from Mudginberri and Sandy Billabongs) is conducted and results compared with those from previous years.

Mussel, sediment and water samples were collected in October 2012 from Mudginberri Billabong. While the routine sampling schedule required just the analysis of a bulk sample, for this year, mussels were aged and individual age groups analysed for $^{226}$Ra and $^{210}$Pb via gamma spectrometry, uranium via inductively coupled plasma mass spectrometry (ICPMS) and $^{210}$Po via alpha spectrometry, to investigate the uptake of $^{210}$Po in mussels in more detail and the contribution of $^{210}$Po to radiological dose from the ingestion of mussels.

Uranium in freshwater mussels

Uranium concentrations in mussels and water samples collected concurrently from Mudginberri Billabong and Sandy Billabong (control site) over the years are shown in Figure 3.19.

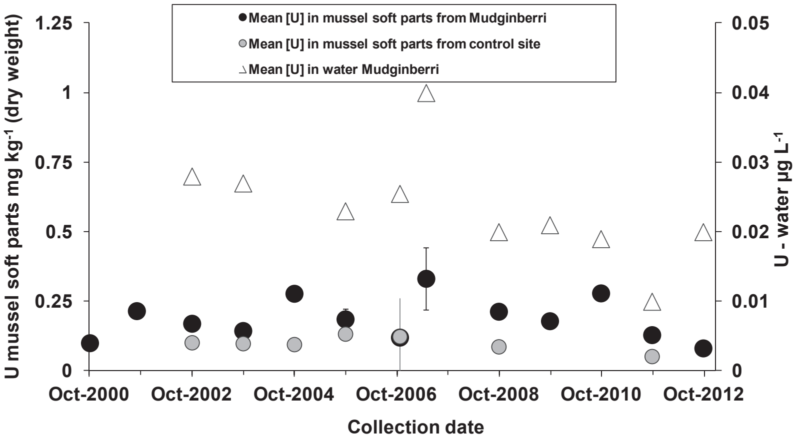



**Figure 3.19** Mean concentrations of uranium (U) measured in mussel soft-parts and water samples collected from Mudginberri and Sandy Billabongs since 2000.

The concentrations of uranium in mussels from Mudginberri Billabong are very similar from 2000 onwards, with no evidence of an increasing trend in concentration over time. Essentially constant and low levels were also observed between 1989 and 1995 (see the respective annual reports). Notwithstanding some bioaccumulation with age, uranium in mussels is reported to have a short biological half-life, a conclusion that is supported by current data. The low and constant uranium concentrations up to the last sample taken in October 2012 indicate absence of any mining influence.

$^{226}$Ra, $^{210}$Pb and $^{210}$Po in mussels

$^{226}$Ra and $^{210}$Pb activity concentrations in mussels collected from Mudginberri and Sandy Billabongs in 2012 are compared with the average activity concentrations measured in previous years in Figure 3.20.

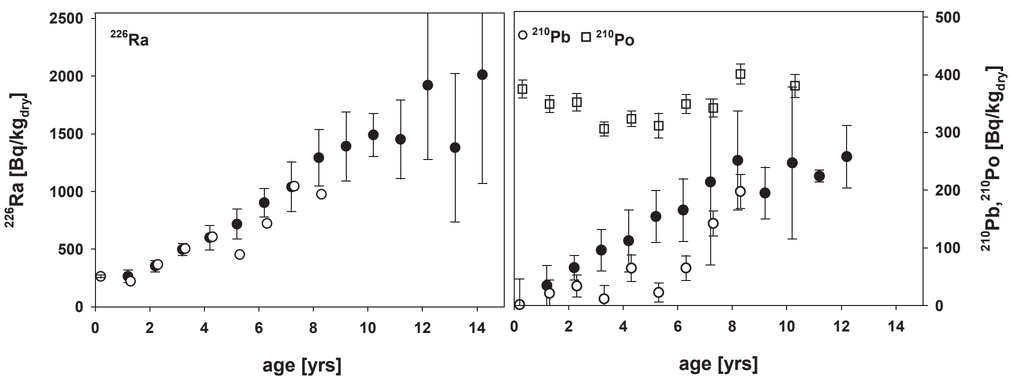



**Figure 3.20** $^{226}$Ra, $^{210}$Pb and $^{210}$Po activity concentrations measured in dry mussel flesh from Mudginberri Billabong plotted against mussel age. Averages of previous end of dry season collections (2000–2011) are shown as solid symbols, open symbols show the results from the 2012 collection.

The graphs show that $^{226}Ra$ and $^{210}Pb$ activity concentrations in aged mussels are similar to the average from previous collections, although $^{210}Pb$ activity concentrations are somewhat lower. The lower values are most likely associated with small differences in sampling location. As an insufficient number of mussels could be collected at the routine sampling site along the (eastern) bank opposite the Mudginberri boat ramp, some mussels were collected from a sandbank at the billabong inlet where $^{210}Pb$ activity concentrations in mussel flesh have previously been shown to be lower (Figure 3.21).

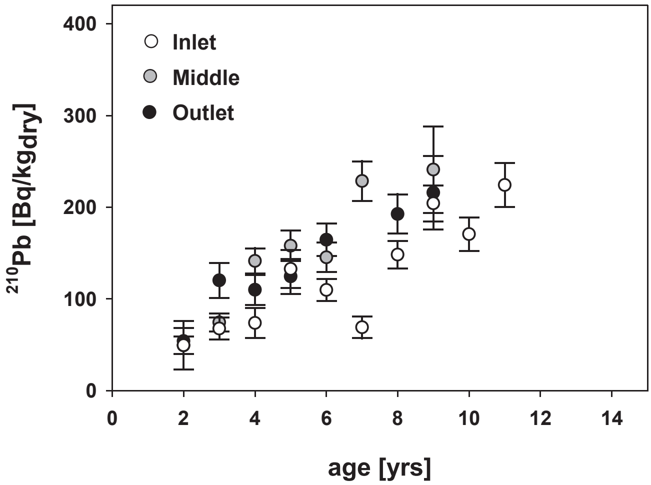



**Figure 3.21** $^{210}Pb$ activity concentrations measured in dry mussel flesh from Mudginberri Billabong in 2008 at the billabong inlet, middle and outlet, plotted against mussel age.

$^{210}Po$ activity concentrations in aged mussels from Mudginberri Billabong were between 300 and 400 Bq·kg$^{-1}$ dry weight in 2012; concentrations arise from both direct uptake of $^{210}Po$ from the water column and ingrowth from its radioactive parent $^{210}Pb$. There is no apparent increase in $^{210}Po$ activity concentration in one to10 year old mussels, consistent with its short physical half life of 138 days. The higher $^{210}Po$ activity concentration compared to $^{210}Pb$ indicates higher accumulation of $^{210}Po$ from the water column compared to $^{210}Pb$. This has been previously observed in the Alligator Rivers Region and elsewhere. Implications for the ingestion dose assessment are reported in section 3.6.2.2 (*Ingestion pathway*).

*Monitoring using macroinvertebrate community structure*

Macroinvertebrate communities have been sampled from a number of sites in Magela Creek at the end of significant wet season flows, each year from 1988 to the present. The design and methodology have been refined over this period (changes are described in the 2003–04 Supervising Scientist annual report, section 2.2.3). The present design is a balanced one comprising upstream and downstream sites at two 'exposed' streams (Gulungul and Magela Creeks) and two control streams (Burdulba and Nourlangie Creeks).

Samples are collected from each site at the end of each wet season (between April and May). For each sampling occasion and for each pair of sites for a particular stream, dissimilarity indices are calculated. These indices are a measure of the extent to which macroinvertebrate communities of the two sites differ from one another. A value of 'zero%' indicates macroinvertebrate communities identical in structure while a value of '100%' indicates totally dissimilar communities, sharing no common taxa.

Disturbed sites may be associated with significantly higher dissimilarity values compared with undisturbed sites. Compilation of the full macroinvertebrate dataset from 1988 to 2012, and data from the paired sites in the two 'exposed' streams, Magela and Gulungul Creeks, for 2013, have been completed with results shown in Figure 3.22. 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 statistical analysis, dissimilarity values for each of the five possible, randomly-paired, upstream and downstream replicates within each stream are derived. These replicate dissimilarity values may then be used to test whether or not macroinvertebrate community structure has altered significantly at the exposed sites for the wet season of interest. For this multi-factor ANOVA, only data gathered since 1998 have been used (data gathered prior to this time were based upon different and less rigorous sampling and sample processing methods, and/or absence of sampling in three of the four streams).

At the time of preparing this annual report and as noted above, only samples from Magela and Gulungul Creeks from the 2012–13 wet season were available for analysis. Without comparable data from the two control streams, it is not possible to run the full ANOVA testing for 2013. Instead, a modified ANOVA model was run using the factors Before/After (BA; fixed), Year (nested within BA; random) and Stream (upstream vs downstream paired dissimilarities; random) examining just the exposed creeks, Magela and Gulungul, to determine if any change in these streams has occurred. The ANOVA showed no significant change from the before (pre 2012–13) to after (2012–13) 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).

These results confirm that the dissimilarity values for 2013 for both Magela and Gulungul Creeks do not differ from previous years. While the Year*Stream interaction is significant in the same analysis ($p = 0.008$), this simply indicates that dissimilarity values for the two streams show natural differences through time (also evident in the control streams). This variation over time is evident in Figure 3.22, particularly for recent years in Gulungul Creek, and is further considered below.

In ***eriss***'s Annual Research Summary for 2010–11, a sharp rise in dissimilarity for Gulungul Creek following the 2010–11 wet season was reported[1] (see 2011 Gulungul dissimilarity value in Figure 3.22). Accompanying multivariate analyses showed that the upstream Gulungul site in 2011 was significantly different from the before (pre 2010–11) to after (2010–11) periods and that was related to an unusually higher proportion of taxa with a preference for high velocity waters (ie so-termed 'flow-dependent' taxa). The magnitude of paired-site dissimilarity for Gulungul Creek in 2013 has declined from its peak in 2011, and is now back to similar values to those recorded prior to 2011 (Figure 3.22). This shift back to

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1 Humphrey CL, Chandler L, Camilleri C & Hanley J 2012. Monitoring using macroinvertebrate community structure. In ***eriss*** *research summary 2010–2011*. eds Jones DR & Webb A, Supervising Scientist Report 203, Supervising Scientist, Darwin NT, 88–92.

pre-2011 dissimilarity corresponds with a decline (from 2011) in the abundances of particular flow-dependant taxa at the upstream site (data not shown here), corresponding with the low rainfall (Figure 3.1) received in the 2012–13 wet season.

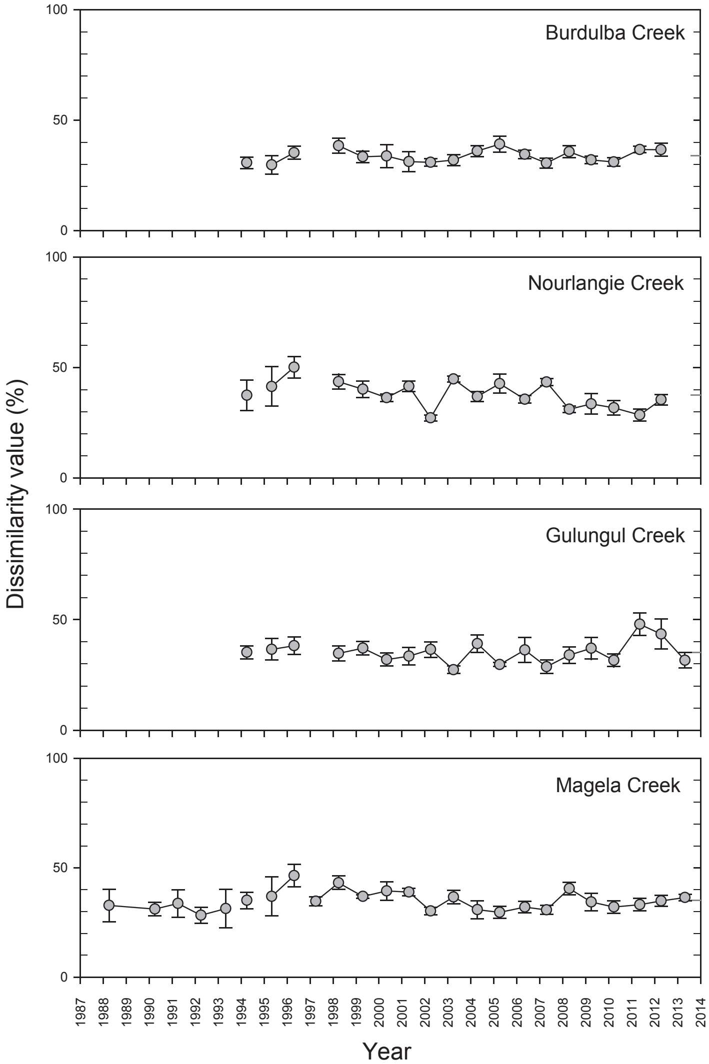


**Figure 3.22** Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger mine for the period 1988 to 2013. The dashed vertical lines delineate periods for which a different 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 3.23 depicts the multivariate ordination derived using replicate within-site macroinvertebrate data. Data points are displayed in terms of the sites sampled in Magela and Gulungul Creeks downstream of Ranger for each year of study (to 2013), relative to Magela and Gulungul Creek upstream (control) sites for 2013, and all other control sites sampled up to 2012 (Magela and Gulungul upstream sites, all sites in Burdulba and Nourlangie). Samples close to one another in the ordination indicate a similar community structure.

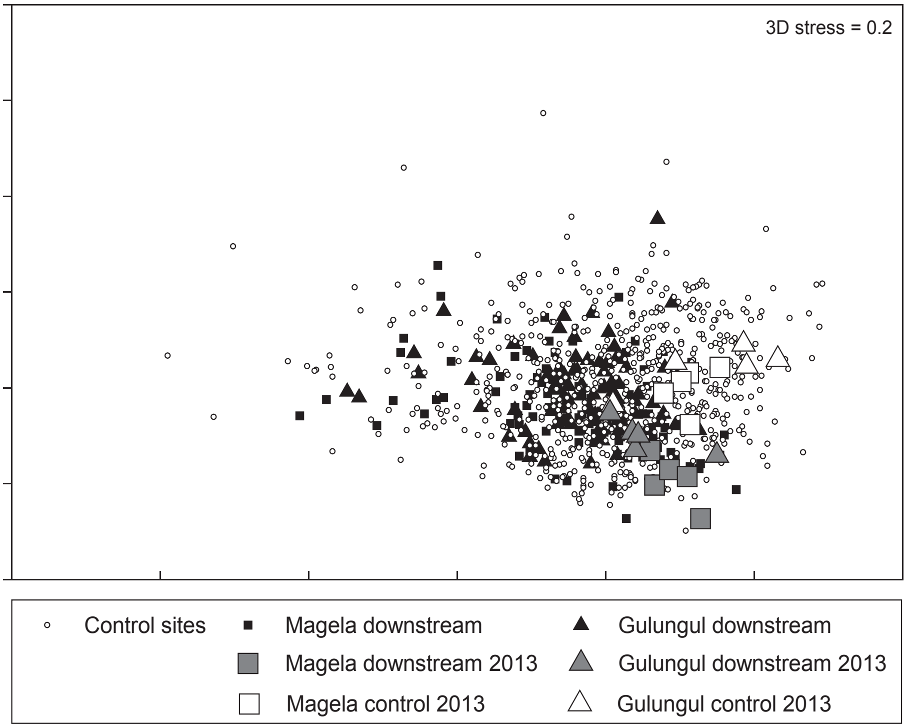


**Figure 3.23** Ordination plot (axis 1 and 2) of macroinvertebrate community structure data from sites sampled in several streams in the vicinity of Ranger mine for the period 1988 to 2013. Data from Magela and Gulungul Creeks for 2013 are indicated by the enlarged symbols.

Data points associated with the 2013 Gulungul and Magela downstream sites are generally interspersed among the points representing the control sites, indicating that these 'exposed' sites have macroinvertebrate communities that are similar to those occurring at control sites. This was confirmed by PERMANOVA (PERmutational Multivariate Analysis Of Variance) testing on the individual sites (compared to paired site dissimilarity for the ANOVA above) of the exposed streams (Magela and Gulungul) which showed no significant difference between the downstream data from 2013 with downstream data from previous years, and no significant difference between the upstream data from 2013 with upstream data from previous years.

Collectively, these graphical and statistical results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2013 have not adversely affected macroinvertebrate communities.

*Monitoring using fish community structure*

Assessment of fish communities in billabongs is conducted between late April and July each sampling year, the precise time of the monitoring being dependent on flow regime, using non-destructive sampling methods at 'exposed' and 'control' locations. Two billabong types are sampled: deep channel billabongs every year and shallow lowland (mostly backflow) billabongs dominated by aquatic plants every two years. Details of the sampling methods and sites were provided in the 2003–04 Supervising Scientist annual report (section 2.2.3).

These programs were reviewed in October 2006 and the refinements to their design are detailed in Supervising Scientist annual reports 2007 and 2008 (section 2.2.3).

For both deep channel and shallow lowland billabongs, comparisons are made between a directly-exposed billabong in the Magela Creek catchment downstream of the Ranger mine versus control billabongs from an independent catchment (Nourlangie Creek and Wirnmuyurr Creek). The extent of similarity of fish communities in exposed sites to those in control sites is determined using multivariate dissimilarity indices, calculated for each sampling occasion. The use of dissimilarity indices has been described and defined in the *Monitoring using macroinvertebrate community structure* section above. A significant change or trend in the dissimilarity values over time could imply mining impact.

### Channel billabongs

The similarity of fish communities in Mudginberri Billabong (directly exposed site downstream of Ranger in Magela Creek catchment) to those of Sandy Billabong (control site in the Nourlangie Creek catchment) (see Map 3) is determined using multivariate dissimilarity indices calculated for each annual sampling occasion. A plot of the dissimilarity values from 1994 to 2013 is shown in Figure 3.24.

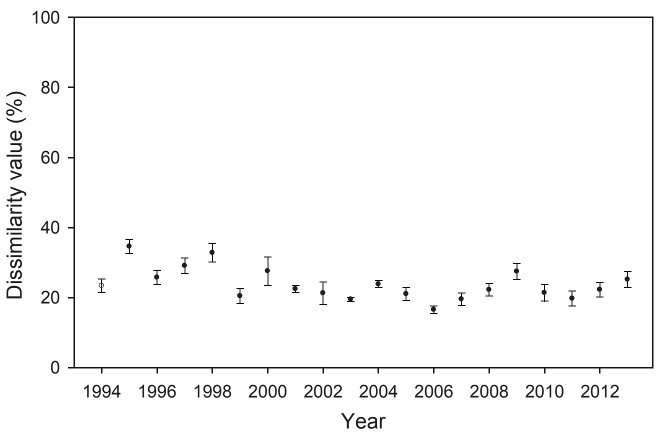


**Figure 3.24** Paired control-exposed dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in Mudginberri ('exposed') and Sandy ('control') Billabongs over time. Values are the mean dissimilarity (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of transect data between the two waterbodies. The dashed line is the mean dissimarity over all years.

The paired-billabong dissimilarity values have been analysed using a two-factor ANOVA (Analysis Of Variance), with Before/After (BA; fixed) and Year (nested within BA; random) as factors. In this analysis the 'BA' factor tests whether values for the year of interest (2013) are consistent with the range of values reported in previous years (1994 to 2012) while the factor 'Year' tests for differences amongst years within the before or after periods. The ANOVA results for 2013 changed only slightly from those reported in Supervising Scientist annual report 2011–2012, showing no significant difference between 2013 and other years (BA factor not significant, $p = 0.771$). This indicates the relationship between Mudginberri and Sandy Billabong fish communities has remained consistent with relationships observed in previous years.

However, as reported in 2012, the variation in fish assemblage dissimilarities between the two billabongs amongst years (tested by factor per year) was significantly different over the 1994 to 2013 period ($p < 0.001$). This variation over time, evident in Figure 3.24, has been demonstrated to be mainly associated with longer term changes in abundance of chequered rainbowfish (*Melanotaenia splendida inornata*) in Magela Creek (Supervising Scientist Annual Report 2003–2004, section 2.2.3). This species is the most common fish species in Magela Creek.

The annual changes in rainbowfish abundance in Magela Creek have been shown in previous Supervising Scientist annual reports to be negatively correlated with magnitude of wet season discharge (specifically wet season total, January total and February total) measured at G821009 in Magela Creek. More recently, rainfall at Jabiru Airport has been used in place of discharge data as it is considered more representative of regional wet season conditions (Supervising Scientist annual report 2011–2012). Inclusion of results from 2013 sampling support those from previous years, with negative relationships observed between rainbowfish abundance in Mudginberri Billabong and total annual rainfall ($p = 0.009$) and for the total rainfall in January ($p = 0.021$) and February ($p = 0.046$). This is particularly evident from the plotted data in Figure 3.25 which highlights the comparatively high rainbowfish abundances recorded in 2013, associated with a below-average wet season rainfall for 2012–13.

The 2013 results continue to support previous suggestions that reduced rainbowfish abundances occur after larger wet season rainfalls as a consequence of the more extensive upstream migration of rainbowfish past Mudginberri Billabong in response to high stream flows. This has the effect of reducing the concentration of fish in the billabong during the recessional flow period. Conversely, years of below average rainfall, such as 2012–13, have the potential to reduce upstream migration of rainbowfish, resulting in above average counts (see Figure 3.25).

Collectively, the analyses described above provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2013 have not adversely affected fish communities in channel billabongs.

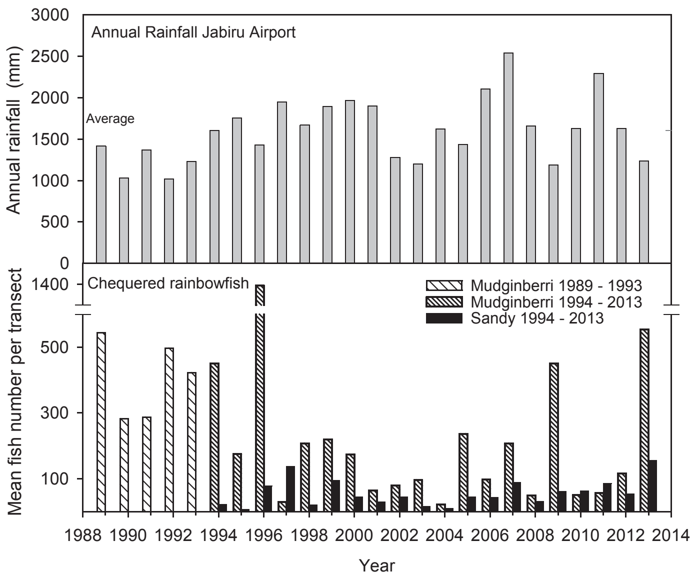


**Figure 3.25** Relative abundance of chequered rainbowfish in Mudginberri and Sandy Billabongs from 1989 to 2013 with associated annual wet season rainfall recorded at Jabiru Airport.

#### Shallow lowland billabongs

Monitoring of fish communities in shallow lowland billabongs is usually conducted every other year, with the exception of 2011 where staff resources were directed to another project (see Supervising Scientist annual report 2010–2011). The last assessment was conducted in 2012 with results reported in Supervising Scientist annual report 2011–2012 (section 2.2.3). The next assessment is due to be conducted between late April and June 2014.

# 3.3 Jabiluka

## 3.3.1 Developments

The site continues to be managed under a long-term care and maintenance regime. There has been no change to the statutory monitoring program undertaken by ERA in Swift Creek (Ngarradj) during the reporting period. SSD continues to monitor downstream water quality.

## 3.3.2 On-site environmental management

### 3.3.2.1 Water Management

The site continues to be maintained as a passive discharge site. On 5 December 2013, ERA submitted an application to discharge IWMP water to Swift Creek (Ngarradj) for the purpose of emptying the IWMP prior to rehabilitation. During the initial decommissioning works at Jabiluka in 2004, the IWMP was cleaned and the water quality since has been close to that of rainwater. Stakeholders approved the application on 21 December 2012. Due to the below average rainfall during the 2012–13 wet season, creek flow was insufficient to enable all the IWMP water to be discharged. ERA submitted a subsequent application on 14 June 2013 to enable land irrigation of the remaining IWMP water. Stakeholders approved this application on 27 June 2013.

### 3.3.2.2 Audit and Routine Periodic Inspections (RPIs)

Four inspections were undertaken at Jabiluka during 2012–13 (Table 3.9). An environmental audit was held in May 2013 and RPIs were held in August and November 2012 and February 2013. An inspection was also conducted in July 2013 to observe the land irrigation of IWMP water and discuss various aspects of the IWMP rehabilitation application.

*Audit outcomes*

#### Closeout of findings from the May 2012 environmental audit

The Category 2 non-conformance recorded during the 2012 audit was due to the late submission of the Annual Amended Plan of Rehabilitation (APR) for the site. At the time of the 2012 audit, ERA had not applied for an extension to the submission date and the plan was overdue. The 2012 report was submitted on 28 June 2012. In 2013, the Jabiluka APR was submitted in a timely manner on 24 April 2013.

The conditional finding from the 2012 audit relates to the ongoing works to finalise rehabilitation of redundant bore holes in Mine Valley and ERA is progressing necessary permits through the Aboriginal Areas Protection Authority (AAPA). The permits were finally granted by AAPA on 28 February 2013. This finding remains conditional pending completion of the works.

**TABLE 3.9 RPI FOCUS DURING THE REPORTING PERIOD**

| Date | Inspection type | Foci |
|---|---|---|
| 18 August 2012 | RPI | Interim water management pond (IWMP) and drop structure, access road, helipad, hardstand and portal area revegetation, vent raise |
| 17 November 2012 | RPI | Interim water management pond (IWMP) and drop structure, access road, hardstand and portal area revegetation, Djarr Djarr |
| 16 February 2013 | RPI | Interim water management pond (IWMP) and drop structure, access road, hardstand and portal area revegetation, Djarr Djarr |
| 16 May 2013 | Audit | IWMP and drop structure, access road, hardstand area revegetation, vent raise, Djarr Djarr |
| 2 July 2013 | Application inspection | IWMP water land irrigation; IWMP rehabilitation application |

Djarr Djarr = former mine worker's camp for Jabiluka

May 2013 environmental audit

The annual environmental audit of Jabiluka was held in May 2013 and tested compliance against 22 specific commitments taken from Authorisation 0140-05. The information collected against each criterion was assessed and given a ranking as per the grading system provided in Table 3.5. The audit process found evidence to grade one criterion as conditional. This finding is a continuation of the 2012 finding related to the outstanding rehabilitation of redundant bore holes in Mine Valley.

#### 3.3.2.3 Minesite Technical Committee

The Jabiluka MTC met six times during 2012–13. Dates of meetings and significant issues discussed are shown in Table 3.10.

#### 3.3.2.4 Authorisations and approvals

No applications to alter the Jabiluka Authorisation 0140-5 were received during the 2012–13 reporting period.

#### 3.3.2.5 Incidents

There were no reported environmental incidents reported for the 2012–13 reporting period.

**TABLE 3.10 JABILUKA MINESITE TECHNICAL COMMITTEE MEETINGS**

| Date | Significant agenda items |
|---|---|
| 20 July 2012 | Annual Plan of Rehabilitation no.15, Djarr Djarr rehabilitation, AAPA clearances for Jabiluka monitoring and rehabilitation works. |
| 5 October 2012 | Removal and dewatering of the IWMP, Jabiluka Wet Season Report, AAPA clearances, Annual Plan of Rehabilitation no.15, Djarr Djarr rehabilitation. |
| 7 December 2012 | Removal and dewatering of the IWMP, Jabiluka Wet Season Report, AAPA clearances, Annual Plan of Rehabilitation no.15. |
| 8 February 2013 | Removal and dewatering of the IWMP, Jabiluka Interpretive Report, AAPA clearances, Annual Plan of Rehabilitation no.15. |
| 15 March 2013 | Removal and dewatering of the IWMP, AAPA clearances, Update of Jabiluka Authorisation. |
| 17 May 2013 | Removal and dewatering for IWMP, Jabiluka Interpretive Report, AAPA clearances, Update of Jabiluka Authorisation, Annual Plan of Rehabilitation no.15. |

## 3.3.3 Off-site environmental protection

### 3.3.3.1 Surface water quality

In accordance with the Jabiluka Authorisation, ERA is required to monitor a range of surface and ground waters on the lease and to demonstrate that the environment remains protected. Specific water quality objectives (criteria thresholds were described in Supervising Scientist Annual Report 2003–04) must be met. Each month during the wet season, ERA reports the water quality in Swift Creek (Ngarradj) to the major stakeholders (SSD, DME and NLC). A detailed interpretation of water quality across the site is provided at the end of each wet season in the ERA Jabiluka annual wet season report (WSR).

In addition to the ERA program, the Supervising Scientist conducts monitoring in Swift Creek (Ngarradj). Jabiluka has been in a long-term care and maintenance phase since late 2003 and poses a low risk to the environment. As a consequence of this low risk and the good data set acquired indicating the environment has been protected, the monitoring program has been systematically scaled down.

The SSD biological monitoring program for Jabiluka ceased in 2004, commensurate with the low risk posed while the site is in long-term care and maintenance mode. Results from six years (1999–2004) of fish community structure studies were reported in Supervising Scientist Annual Report 2003–04 along with results for macroinvertebrate community structures.

Since 2009–10, SSD has collected continuous monitoring data (electrical conductivity and water level) from the downstream statutory compliance site only. ERA collects monthly grab samples from both the upstream and downstream site. Previous grab sample monitoring data can be found on the SSD website at www.environment.gov.au/ssd/monitoring/ngarradj-chem.html and have been reported in previous annual reports.

*Chemical and physical monitoring of Swift Creek (Ngarradj)*

Flow was first recorded at the Swift Creek (Ngarradj) monitoring station on 17 January 2013. Continued low rainfall conditions resulted in low flow levels in the creek through most of February. March experienced an increase in the frequency of rainfall events, which increased the flow levels in Swift Creek (Ngarradj) with a corresponding decrease in EC (Figure 3.26).

A significant rainfall event occurred on 30 and 31 March 2013 with Jabiru Airport recording a total rainfall of 240 mm over the two days. Flow within Ngarradj quickly rose with a corresponding decline in EC. EC subsequently increased through April as flow levels decreased with typical recessional flow conditions becoming established in May and June.

Continuous monitoring continued until 12 June 2013, when the multi-probes were no longer submersed and could not be lowered any further. Cease to flow in Ngarradj was agreed by stakeholders on 19 June 2013.

During the season there were intermittent communications issues between the monitoring station and the server. Data was able to be manually downloaded during site visits with the SSD web page updated as data became available. A modified satellite antenna system has been installed and has rectified the communications issues.

Overall, the water quality measured in Swift Creek (Ngarradj) for the 2012–13 wet season is comparable with previous wet seasons (Figure 3.27) and does not appear to show a detectible effect from the discharge of the IWMP.

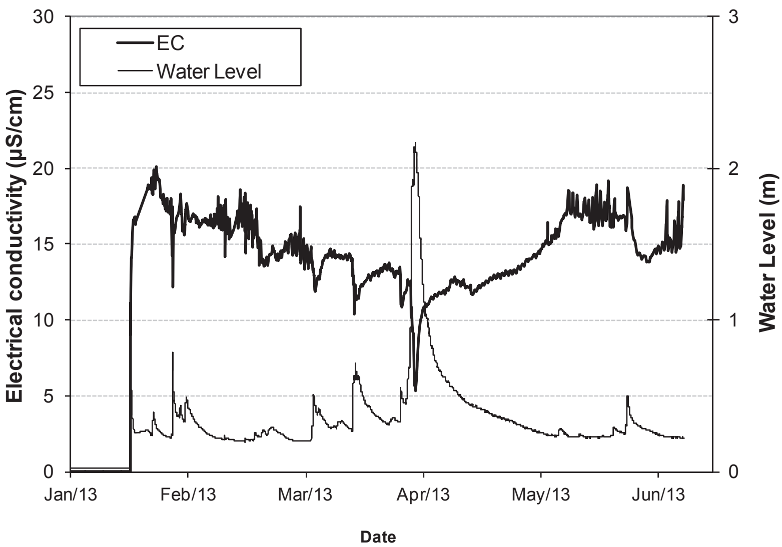


**Figure 3.26** Continuous electrical conductivity in Ngarradj between January and June 2013

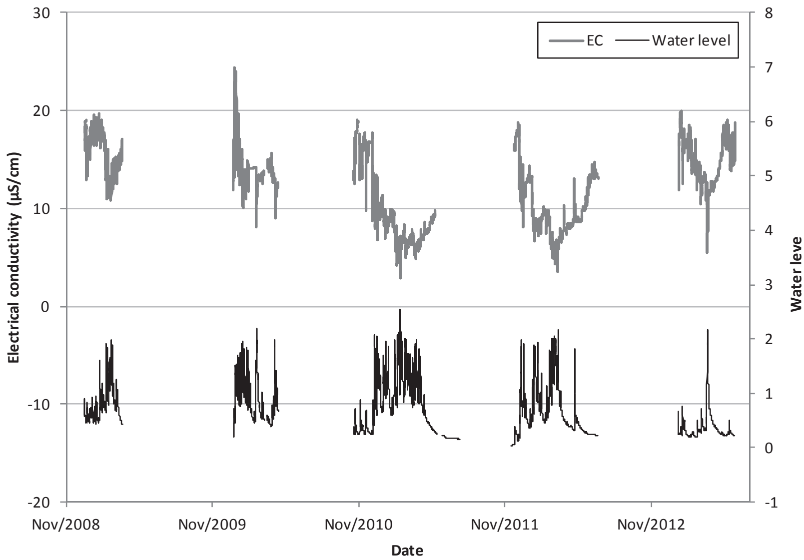


**Figure 3.27** Electrical conductivity measurements at the downstream monitoring station in Swift Screek (Ngarradj) for each wet season between November 2008 and June 2013

## 3.4 Nabarlek

### 3.4.1 Developments

In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd, thereby acquiring the Nabarlek lease (MLN 962). UEL has since developed plans to further explore the lease, clean up the site and continue revegetation and rehabilitation works. Authorisation 0435-01 was granted to UEL on 28 May 2008 allowing exploration and rehabilitation works at Nabarlek to proceed. Since this time, UEL has undertaken significant works to clean up several areas of the site including the old Nabarlek village and re-contouring of the waste rock dump runoff pond. A Mining Management Plan (MMP) for the 2013 dry season exploration works was submitted to DME in March 2013 and is awaiting approval.

#### 3.4.1.1 Minesite Technical Committee (MTC)

The Nabarlek MTC met once during the reporting period. The following items were discussed at a meeting held on 4 July 2012:

- rehabilitation
- exploration
- monitoring
- hydrogeological assessment
- development of closure criteria.

#### 3.4.1.2 Authorisations and approvals

There was no change to the Nabarlek Authorisation during the 2012–13 reporting period.

#### 3.4.1.3 Incidents

There were no environmental incidents reported at Nabarlek during the 2012–13 reporting period.

### 3.4.2 On-site conditions

The site is generally subject to two visits from ***oss*** staff during the year. In addition, ***oss*** may carry out opportunistic site inspections if in the area on other business (eg exploration inspections).

The formal site inspections carried out at Nabarlek each year are:

- post-wet season inspection – the intent of this inspection is to check site stability and erosion following the wet season and to plan works for the coming dry season
- annual audit (pre-wet season) of compliance with the Nabarlek Mining Management Plan.

#### 3.4.2.1 Annual audit

A formal audit was not held during 2012–13 as UEL did not undertake an active exploration drilling program during the 2012 dry season.

#### 3.4.2.2 Inspections

The post wet-season inspection of the Nabarlek site was held on 3 July 2012. Areas inspected included:

- Nabarlek village area
- sewage treatment ponds area
- landfill
- plant area and plant runoff pond
- backfilled pit
- waste rock dump area and waste rock dump runoff pond
- radiologically anomalous area (RAA)
- evaporation ponds.

Stakeholders from SSD, DME, NLC and UEL again visited the minesite on 21 November 2012 to assess progress on drill pad and track rehabilitation. The objective of the site inspection was to verify that rehabilitation of the 55 RC drill sites from the 2011 season has been completed so as to allow UEL to receive a security refund currently held by DME these works.

Twelve drill hole locations and associated drill line tracks were inspected to assess whether there were any issues with drainage (eg erosion, subsidence), revegetation or weeds. Rehabilitation was considered to be acceptable at all sites inspected, with no significant weed infestations observed. Some sites had been affected by wildfire, but this had not impacted plant establishment and diversity. Stakeholders were satisfied with exploration rehabilitation activities and DME granted approval for the reimbursement of $49 850.

#### 3.4.2.3 Radiologically anomalous area (RAA)

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

The issue remains a standing item on the Nabarlek MTC agenda. No works on the RAA were undertaken during this reporting period.

### 3.4.3 Off-site environmental protection

Statutory monitoring of the site is conducted by DME and the operator, UEL. DME carries out surface and groundwater monitoring on and off site, including surface water monitoring downstream of the mine in Kadjirrikamarnda and Cooper Creeks. The results of this monitoring are submitted to ARRAC in the six-monthly Northern Territory Supervising Authority's Environmental Surveillance Monitoring reports.

## 3.5 Other activities in the Alligator Rivers Region

### 3.5.1 Rehabilitation of the South Alligator Valley uranium mines

Background on the remediation of historic uranium mining sites in the South Alligator Valley was provided in the 2008–09 Supervising Scientist Annual Report.

Construction of a new containment facility at the location of the old El Sherana airstrip for the final disposal of historic uranium mining waste was completed over the 2009 dry season by Parks Australia.

***oss*** staff carried out the annual inspection of the containment facility on 30 January 2013 following completion of erosion repair works. Revegetation is progressing well over the old containment areas and previous erosion gullies in parts of the cap have been repaired. An inspection report was provided to Parks Australia.

### 3.5.2 Exploration

***oss*** undertakes a program of site inspections and audits at exploration sites in western Arnhem Land. During the reporting period, SSD led and/or participated in audits of the following exploration sites in Western Arnhem Land:

- Cameco King River Camp and exploration activities
- Alligator Energy Myra Camp and exploration activities
- UXA Resources Limited Nabarlek project.

Each operation was audited against commitments from their approved Mining Management Plan and criteria tested were graded in accordance with the classifications presented in Table 3.5.

#### 3.5.2.1 Cameco King River Camp

The annual environmental audit of Cameco's Arnhem Land project was held in conjunction with DME and NLC on 27–28 August 2012. The audit assessed compliance with Cameco's approved Mine Management Plan for the 2012 dry season campaign and was also used to determine if observations made during the 2011 audit had been incorporated into the operations.

During the audit, SSD, DME and NLC inspected the King River camp as well as current and rehabilitated drill holes in the Angularli project area.

Thirty three commitments were audited against the grading system shown in Table 2.5.

The following 5 conditional findings were determined from the 33 commitments audited:

- implementation of annual internal audit program
- implementation of monthly exploration checklist inspections
- timeliness of drill hole rehabilitation
- frequency of management reviews of the environment, safety and health management policies
- hydrocarbon labelling and storage

In addition, a number of observations were made throughout the audit and reported to Cameco in the closing meeting and in the audit report. All other findings were ranked as acceptable or not verified. SSD will continue to follow up on all identified issues and ensure the close-out of corrective actions during the 2013 audit.

#### 3.5.2.2 Alligator Energy Myra Camp

An environmental audit of Alligator Energy's operations based at Myra Camp was held on 19 September 2012 in conjunction with DME and the NLC. The audit aimed to assess Alligator Energy's compliance with stated commitments in their approved MMP. During the audit the Myra Camp, Two Rocks and Caramal prospects were inspected. Stakeholders noted a continued high standard of environmental controls across the drilling operations and at Myra Camp.

The audit found no non-conformances and produced a number of observations. The audit team were pleased to see improvements to the environmental management of the project as a result of the 2011 stakeholder audit. The audit team were also pleased to see that the considerable works undertaken to stabilise the slope at Caramel had been successful, mitigating possible serious impact on the surrounding environment.

It was also noted that in an effort to improve their operation Alligator Energy has moved to the use of tanks for the storage of drilling fluid rather than in-ground sumps and that drill holes are plugged with expanding foam and concrete to prevent possible water infiltration and resultant erosion which may occur around a concrete plug.

#### 3.5.2.3 UXA Nabarlek project

The annual environmental audit of UXA Resources Ltd Nabarlek project was undertaken on 18 September 2012. The audit team comprised personnel from SSD, DME and NLC. The subject of the audit was the 2012 Mining Management Plan.

The audit team were generally satisfied that UXA complied with the major components of the MMP representing a significant improvement over the 2011 audit. The audit resulted in no significant findings, but a number of observations were made. Generally, the audit team were pleased with the significant progress UXA had made in the development and implementation of key environmental management systems and processes. UXA was encouraged to continue refining their systems; in particular in working with their drill contractor to ensure appropriate environmental standards are upheld.

## 3.6 Radiological issues

### 3.6.1 Background

#### 3.6.1.1 Applicable standards

The radiation dose limit for workers recommended by the International Commission on Radiological Protection (ICRP) and adopted in Australia by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is 100 mSv in a five year period with a maximum of 50 mSv in any one year. In practice this is considered to be an average of 20 mSv per year. The radiation dose limit to the public from a practice such as uranium mining recommended by the ICRP is 1 mSv per year. This limit applies to the sum of all sources and exposure pathways. As outlined in ARPANSA's (2005) 'Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing', it is the operator's and employer's responsibility to 'ensure that the workplace and work procedures are designed, constructed, and operated so as to keep exposures to ionising radiation as low as reasonably achievable'.

This safety guide further recommends to separate radiation workers into designated and non-designated cohorts for monitoring and reporting purposes, where designated workers are those who may be expected to receive a significant occupational radiation dose, nominally above 5 mSv per year. These workers are monitored more intensely than the non-designated workers.

Consequently, there are three levels of radiation dose from other-than-natural sources to distinguish:

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

In addition, the ICRP (2006) recommends the use of dose constraints for the optimisation of radiation protection:

> *The principle of optimisation is defined by the Commission as the source related process to keep the magnitude of individual doses, the number of people exposed, and the likelihood of potential exposure as low as reasonably achievable below the appropriate dose constraints, with economic and social factors being taken into account. According to the Commission's revised recommendations, this process of optimisation below constraint should be applied whatever the exposure situation; ie planned, emergency, or existing.*
>
> ICRP 2006. *Assessing dose of the representative person for the purpose of radiation protection of the public and the optimisation of radiological protection: broadening the process*. ICRP Publication 101, Elsevier Ltd.

#### 3.6.1.2 Monitoring and research programs

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 and results are reported to MTC members on a quarterly basis.

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

An application to optimise the Radiation and Atmospheric Monitoring Plan (originally submitted to the MTC in November 2008) was approved with the issue of Authorisation 0108-13 on 29 November 2011. Approval of this application resulted in a change to the quarterly reporting requirements for ERA and, instead of a quarterly report, SSD and other stakeholders are now provided with summary data that are then discussed during a meeting with ERA. This change first came into effect for the Quarter 1 2012 reporting period. All quarterly reports and summary data due during the 2012–13 reporting period were received and reviewed by SSD.

Dose constraints for the Ranger mine are revised annually and detailed in the Annual Radiation and Atmospheric Monitoring Report. The current dose constraints for Ranger mine are listed in Table 3.11.

**TABLE 3.11 ANNUAL RADIATION DOSE CONSTRAINTS FOR RANGER MINE (mSv)**

| | |
|---|---|
| Mine | 2.4 |
| Plant | 5.5 |
| Exploration Decline | 5 |
| Non-designated workers | 2 |
| Workers under the age of 18 | 2 |
| Members of the public | 0.3 |

## 3.6.2 On-site and off-site radiation exposure at Ranger mine

### 3.6.2.1 Radiological exposure of employees

The three primary pathways of radiation exposure to workers at Ranger are:

- inhalation of radioactive dust
- exposure to external gamma radiation
- inhalation of radon decay products (RDP).

Table 3.12 shows the annual doses received by designated and non-designated workers in 2012, and a comparison with the average doses from the year before as reported by ERA. The average and maximum radiation doses received by designated workers in the 2012 calendar year were approximately 6% and 22% respectively of the recommended ICRP (2007) annual dose limits (*The 2007 recommendations of the International Commission on Radiological Protection*, ICRP Publication 103, Elsevier Ltd).

**TABLE 3.12 ANNUAL RADIATION DOSES RECEIVED BY WORKERS AT RANGER MINE**

| | Annual dose in 2011 | | Annual dose in 2012 | |
|---|---|---|---|---|
| | Average mSv | Maximum mSv | Average mSv | Maximum mSv |
| Non-designated worker | Not calculated[1] | 1.2 | Not calculated | 1.0 |
| Designated worker | 1.0 | 5.4 | 1.2 | 4.5 |

1 A hypothetical maximum radiation dose to non-designated employees is calculated using the gamma exposure results of employees of the emergency services group, and dust and radon results measured at the acid plant. Consequently, the dose is conservative and would exceed actual doses received by non-designated employees, and are hence considered maximum doses.

All work groups, with the exception of electrical maintenance, received their greatest dose from the external gamma pathway. The electrical maintenance group received their greatest dose from the long-lived alpha activity pathway. The processing production workgroup received the highest average total dose of 1.45 mSv.

Average doses remained relatively constant compared with 2011 results with the exception of mine and processing production. Doses to these workgroups increased over last year due to increased mining access to high grade ore in the lower areas of the pit resulting in higher exposure levels across all pathways.

### 3.6.2.2 Radiological exposure of the public

National radiation protection standards require that the annual radiation dose received by a member of the public from practices such as uranium mining and milling must not exceed 1 mSv. This dose is on top of the radiation dose received naturally, which averages approximately 1.5 mSv per year in Australia, but which ranges from 1–10 mSv per year, depending on location.

Ranger uranium mine is the main potential source of above background radiation dose to members of the public in the ARR. The two main pathways of potential radiation exposure to the public during the operational phase of Ranger mine are inhalation and ingestion. The inhalation pathway results from radionuclides released to the air from the mine site, while the ingestion pathway is caused by the uptake of radionuclides into bushfoods from the Magela Creek system downstream of the mine.

*Inhalation pathway*

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

Figures 3.28 and 3.29 show hourly and quarterly average radon progeny potential alpha energy concentration (PAEC) monitoring data from Jabiru town and near Mudginberri community, respectively, for the 2012 calendar year. Gaps in the data are due to instrument maintenance and data quality issues.

The large fluctuations in the hourly PAEC data reflects the normal diurnal pattern in radon progeny concentrations in surface air. Higher concentrations typically occur in the early morning around sunrise when atmospheric conditions tend to be most stable. Thereafter the surface air becomes mixed by convection (solar heating) and advection (wind), which disperses the radon progeny into a larger atmospheric volume.

The quarterly average PAEC results show the typical wet-dry seasonal trend, with higher concentrations occurring in the second and third quarter of the year (dry season) and lower concentrations occurring in the first and fourth quarter of the year (wet season). The effect of rainfall is to suppress radon exhalation from the soil surface and thus decrease the radon progeny PAEC in air.

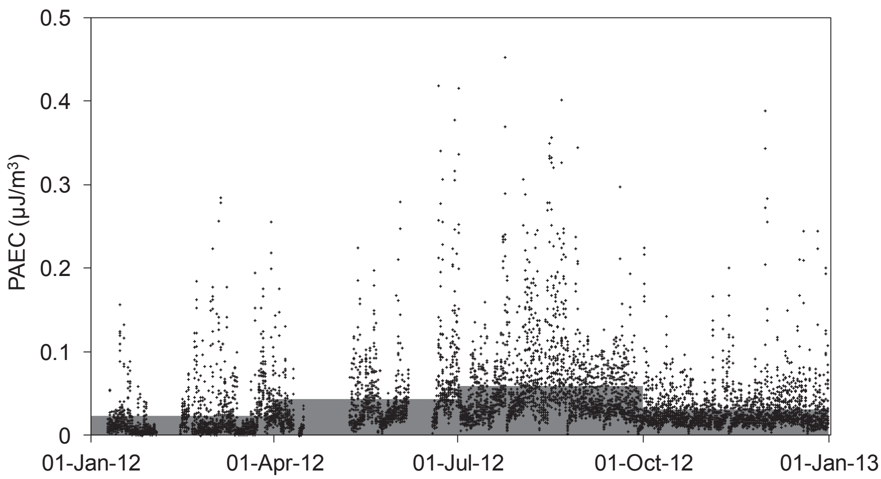


**Figure 3.28** Hourly (black crosses) and quarterly average (grey columns) radon progeny PAEC in air at Jabiru town in 2012

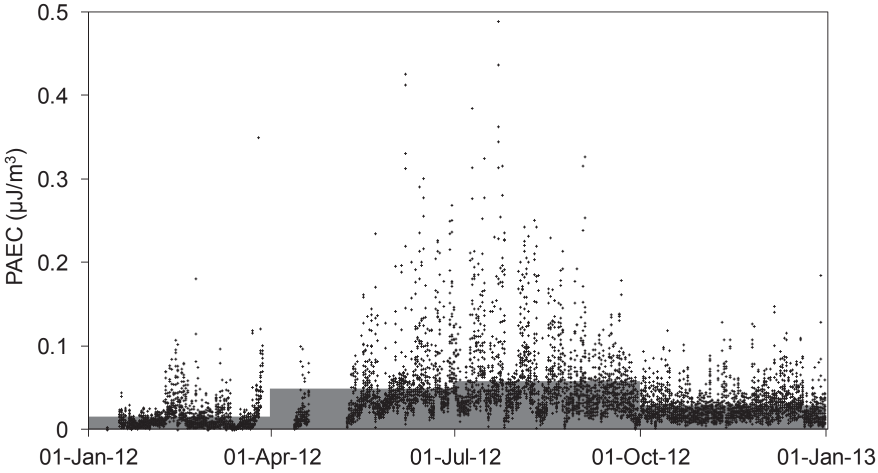


**Figure 3.29** Hourly (black crosses) and quarterly average (grey columns) radon progeny PAEC in air at Four Gates Road radon station near Mudginberri community in 2012

Table 3.13 provides a summary of annual average radon progeny PAEC in air and estimated doses to the public, as well as comparison with values reported by ERA for Jabiru town.

The total annual effective dose from radon progeny in air, which includes contribution from natural background, has been estimated to be 0.386 mSv at Jabiru town and 0.372 mSv at 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 International Commission on Radiological Protection (ICRP) and the assumed full year occupancy of 8784 hours.

**TABLE 3.13 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI IN 2012***

| | Jabiru town | Mudginberri |
|---|---|---|
| Annual average PAEC (µJ/$m^3$) | 0.040 (0.036) | 0.039 |
| Total annual dose (mSv) | 0.386 (0.330) | 0.372 |
| Mine-derived dose** (mSv) | 0.030 (0.055) | 0.005 |

* Values in brackets refer to data from the ERA Radiation Protection and Atmospheric Monitoring Program report for the Year Ending 31 December 2012.

** The radon progeny PAEC difference used in the SSD mine-derived dose calculation was 0.016 µJ/$m^3$.

The mine-derived annual dose from radon progeny in air at Jabiru town has been estimated to be 0.030 mSv, which is less than one tenth of the total annual dose via this pathway. 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, then multiplying this difference with the radon progeny dose conversion factor and the number of hours that the wind was from the direction of the mine. Hourly wind direction data for 2012 were obtained from the Bureau of Meteorology weather station at Jabiru Airport. Analysis of these data suggests that at Jabiru town the wind was from the direction of the mine (ie from the 90–110 degree sector) for 1724 hours during the year.

Differences between the SSD and ERA radon progeny PAEC results and public dose estimates for Jabiru town are most likely due to differences in monitoring regime. Whereas SSD aims to monitor continuous hourly radon progeny PAEC in air over the full year, the ERA regime is based on a minimum requirement of one week per month continuous monitoring.

Figures 3.30 and 3.31 show measured and quarterly average concentrations of dust-bound LLAA radionuclides in air at Jabiru town and near Mudginberri community, respectively, for 2012. Gaps in the data are due to instrument maintenance and data quality issues.

The general trend is for LLAA radionuclide concentrations to be higher in the second and third quarter of the year (dry season) and lower in the first and fourth quarter of the year (wet season). This is due to rainfall suppression of dust generation during the wet season.

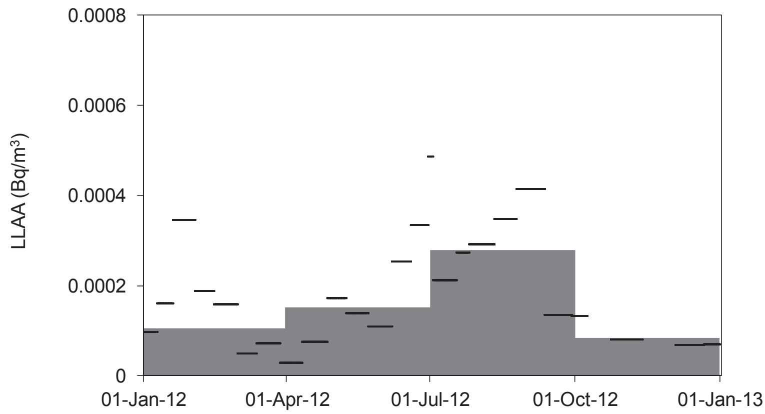


**Figure 3.30** Measured (black lines) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Jabiru town in 2012

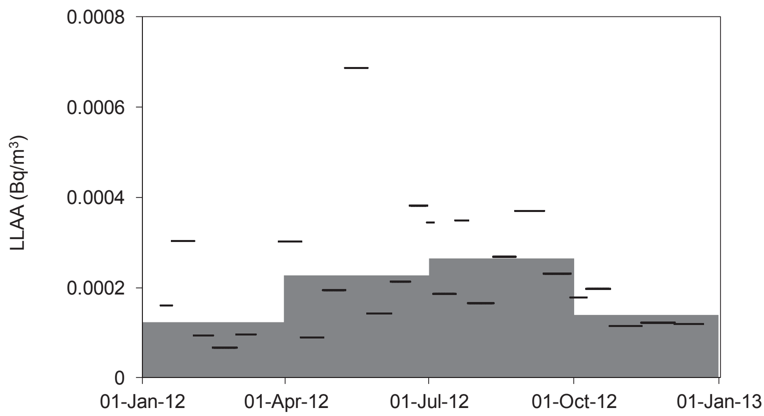


**Figure 3.31** Measured (black lines) and quarterly average (grey columns) concentrations of dust-bound LLAA radionuclides in air at Four Gates Road radon station near the Mudginberri community in 2012

Table 3.14 provides a summary of annual average LLAA radionuclide concentration and estimated total and mine-related doses to the public.

The total annual effective dose from dust-bound LLAA radionuclides, which includes contribution from natural background, has been estimated to be 0.007 mSv at Jabiru town and 0.008 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 $Bq_{\alpha}^{-1}$, breathing rate of 0.75 $m^3$ $h^{-1}$ and assumed full year occupancy of 8784 hours.

**TABLE 3.14 LLAA RADIONUCLIDE CONCENTRATIONS IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI IN 2012**

| | Jabiru town | Mudginberri |
|---|---|---|
| Annual average PAEC (μJ/$m^3$) | $1.7\times10^{-4}$ | $1.9\times10^{-4}$ |
| Total annual dose (mSv) | 0.007 | 0.008 |
| Mine-related dose* (mSv) | $5\times10^{-4}$ | $1\times10^{-4}$ |

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

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

*Ingestion pathway*

SSD routinely monitors the aquatic aspects of the ingestion pathway and collects and analyses mussels for both radionuclides and heavy metals each year at Mudginberri Billabong and every three years at Sandy Billabong control site in the Nourlangie catchment (Map 3). Local Aboriginal people have historically expressed concern about radionuclides in mussels from Mudginberri Billabong as these are a regularly consumed bush food item. SSD's monitoring focuses on $^{226}Ra$ as it has been shown that $^{226}Ra$ in mussels is the biggest potential contributor to mine-related ingestion dose from a hypothetical release of pond waters from the minesite. The $^{226}Ra$ activity concentration in Magela Creek waters is routinely monitored by both ERA and SSD and its limit is based on potential dietary uptake of $^{226}Ra$ by the Aboriginal people downstream of the mine. To this end no increase of $^{226}Ra$ activity concentrations in Magela Creek downstream of the mine has been observed (see section 3.2.3.1 *Surface water quality*).

Based upon the measured activity concentrations of $^{226}Ra$, $^{210}Pb$ and $^{210}Po$ in mussel flesh and the age distribution of mussels collected, an average annual committed effective dose from ingestion of these isotopes can be calculated for a 10 year old child who eats 2 kg (wet weight) of mussel flesh from Mudginberri Billabong. This dose amounted to 0.27 mSv in 2012. 60% of this dose is from $^{210}Po$, due to its comparatively high ingestion dose coefficient compared to $^{226}Ra$ and $^{210}Pb$. Figure 3.32 shows the doses from $^{226}Ra$ and $^{210}Pb$ ingestion estimated for individual years, and the median, 80 and 95 percentiles for all collections. In addition, the total dose (including $^{210}Po$) is shown for the 2012 collection.

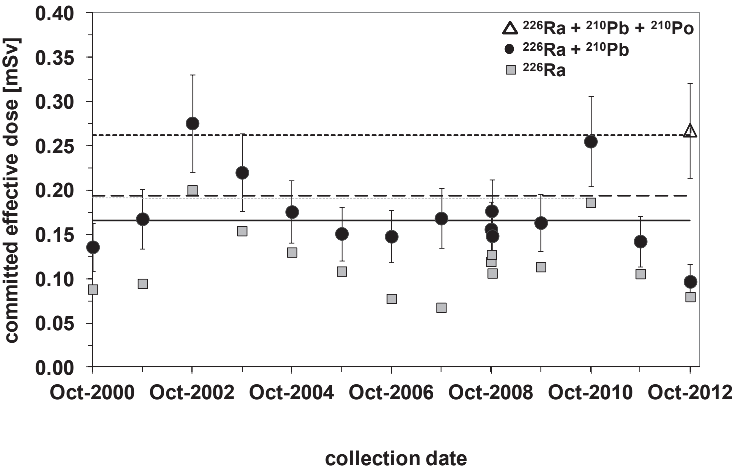


**Figure 3.32** Annual committed effective doses (point data) from $^{226}Ra$, $^{210}Pb$ and $^{210}Po$ for a 10 year old child eating 2 kg of mussels from Mudginberri Billabong. The median for $^{226}Ra$ + $^{210}Pb$ for all the data (solid line), the 80th percentile (dashed line) and 95th percentile (dotted line) are shown for reference.

As $^{210}Po$ (and $^{210}Pb$) is particle reactive in environmental waters, activity concentrations in Mudginberri Billabong are low and have not shown an increase over the past 30 years. In addition, in contrast to $^{226}Ra$ and uranium, $^{210}Po$ activity concentrations are only slightly elevated in mine compared to natural waters. The difference between $^{226}Ra$ activity concentrations measured in Magela Creek upstream and downstream of the Ranger mine is only very small (see section 3.2.3.1), and findings from previously reported research show that mussel $^{226}Ra$ activity loads in Mudginberri Billabong are currently due to natural catchment rather than mining influences. Consequently, the ingestion dose reported here is almost exclusively from natural background contributions and would be received irrespective of the operation of the Ranger mine.

With the rehabilitation of Ranger mine there will be radiological protection issues associated with ultimate use of the land by local Aboriginal people and a shift towards terrestrial food sources. These foodstuffs include both terrestrial animals and plants. Over the last 30 years, SSD has gathered radiological concentration data on bushfoods, soils and water throughout the Alligator Rivers Region in the Northern Territory. New data, in particular for terrestrial food items, are acquired on an ongoing basis. Data on radionuclide activity concentrations in bushfoods and environmental media from the ARR sampled by ***eriss*** and other organisation have now been consolidated into a consistent, quality controlled database (described in the 2010–11 annual report). This database (the BRUCE tool) provides a central data repository and facilitates calculation of radionuclide concentration ratios for bushfoods and calculation of ingestion doses for members of the public from consumption of these bushfoods. The uptake of radionuclides in wildlife of the ARR as determined using the tool is discussed in section 4.5).

### 3.6.3 Jabiluka

#### 3.6.3.1 Radiological exposure of employees

The Jabiluka Authorisation was revised in July 2003 and the statutory requirement of quarterly reporting of radiological monitoring data for Jabiluka was removed. The current Authorisation requires reporting of radiation monitoring data only if any ground disturbing activities involving radioactive mineralisation occur on site. No ground disturbing activities took place during this reporting period.

#### 3.6.3.2 Radiological exposure of the public

Although there were no activities reported at the Jabiluka Mineral Lease, the population group that may, in theory, receive a radiation dose due to future activities at Jabiluka is a small community approximately 10 km south of Jabiluka at Mudginberri.

SSD has a permanent atmospheric monitoring station at Four Gates Road radon station, which is located a few kilometres west of Mudginberri. Radon progeny and dust-bound LLAA radionuclide concentrations are measured at the station.

Figures 3.30 and 3.32 show radon progeny PAEC and dust-bound LLAA radionuclide concentrations measured in air at Four Gates Road radon station during 2012. Tables 3.13 and 3.14 provide public dose estimates for these exposure pathways for a person living at Mudginberri in 2012.

## 3.7 EPBC assessment advice

SSD continues to provide advice to the Environment Assessment and Compliance Division of SEWPaC on referrals submitted in accordance with the EPBC Act for new and expanding uranium mines. During the reporting period, SSD provided coordinated responses on the Ranger 3 Deeps underground mine proposal and the Wiluna uranium project in Western Australia.

# 4 ENVIRONMENTAL RESEARCH AND MONITORING

The *Environment Protection (Alligator Rivers Region) Act 1978* established the Alligator Rivers Region Research Institute (ARRRI) to undertake research into the environmental effects of uranium mining in the Alligator Rivers Region (see Map 1). The scope of the research program was widened in 1994 following amendments to the Act. The Alligator Rivers Region Research Institute was subsequently renamed the Environmental Research Institute of the Supervising Scientist (***eriss***).

The core work of ***eriss*** comprises ongoing monitoring and conduct of research to develop and refine leading practice monitoring procedures and standards for the protection of people and the environment, focusing on the effects of uranium mining in the Alligator Rivers Region (ARR). The expertise of the Institute is also applied to conducting research on the sustainable use and environmental protection of tropical rivers and their associated wetlands, and to providing (on a commercial basis) consultancy services that assist the management of water quality issues at other types of mines in the northern tropics. This consultancy work is limited to activities with a strategic alignment to core statutory responsibilities and is subject to assessment to ensure that it does not constitute any conflict-of-interest with other work of the Division.

The content and outcomes of the ***eriss*** research program are assessed annually by ARRTC using identified Key Knowledge Needs (KKNs). These KKNs define the key research topics within each of the geographic domains in the ARR relating to monitoring, closure and rehabilitation for current (Ranger and Jabiluka), rehabilitated (Nabarlek) and legacy (South Alligator River Valley) sites. The charter and activities of ARRTC are described in chapter 2 of this annual report and the current list of KKNs is provided for reference in Appendix 1.

***eriss*** contributes to the addressing of each of the KKNs by applying a broad range of scientific expertise across the research fields of:

- ecotoxicology
- environmental radioactivity
- hydrological and geomorphic processes
- monitoring and ecosystem protection
- spatial sciences and remote sensing

Highlights from the 2012–13 ***eriss*** research program are presented in this chapter. They represent a snapshot of the broader research program within ***eriss***, which covered approximately 30 projects across the above-mentioned disciplines. The full research project suite is listed in Appendix 2. The majority (>95%) of these projects were addressing issues associated with the current operational phase and/or proposed rehabilitation and post-rehabilitation phases of Ranger mine. More comprehensive descriptions of ***eriss*** research are published in journal and conference papers and in the Supervising Scientist and Internal

Report series. Publications by SSD staff in 2012–13 are listed in Appendix 2, while presentations given during the year are listed in Appendix 3. More information on the Division's publications, including the full list of staff publications from 1978 to the end of June 2013, is available on the SSD website at www.environment.gov.au/ssd/publications

## 4.1 Toxicity of manganese to tropical freshwater species

### 4.1.1 Background

Manganese (Mn) was recognised as a contaminant of potential ecotoxicological concern at Ranger mine in the early 2000s. Isolated observations of increasing Mn concentrations have been made in shallow groundwater adjacent to Magela Creek and in Coonjimba Billabong and Corridor Creek. However, despite these observations, Mn concentrations in the surface waters of Magela Creek itself have remained below the current site-specific guideline for Mn of 26 µg $L^{-1}$ (based on upstream reference site data when stream flow is <5 $m^3$ $sec^{-1}$). Consequently, the risks of Mn toxicity to aquatic biota have been considered low. However, the likelihood of higher concentrations of Mn being released to Magela Creek via Ranger mine waters may increase with the commissioning of the brine concentrator plant in mid 2013 to treat process water. A pilot-scale brine concentrator plant tested in 2011 produced distillate waters containing Mn at concentrations ranging from 130–240 µg $L^{-1}$ [2]. These Mn concentrations are higher than those currently measured in mine waters discharged from Ranger mine (eg. during 2011–2012, measured Mn concentrations in RP1 ranged from 0.2 to 63 µg $L^{-1}$). The addition of distillate potentially containing 100–200 µg $L^{-1}$ Mn to such waters may eventually result in Mn concentrations in the surface waters of Magela Creek higher than previously measured.

Historically, the acute and chronic toxicity of Mn to freshwater biota has been considered to be low (ie in the mg $L^{-1}$ range) as reflected in the relatively high Australian and New Zealand water quality trigger value (TV; for 99% species protection) of 1200 µg $L^{-1}$, published in 2000. However, a recent review of Mn toxicity in freshwaters by the Environment Agency (UK) has recommended a lower Predicted No Effect Concentration (PNEC) of 123 µg $L^{-1}$ (Peters et al 2010[3]). Furthermore, preliminary studies investigating Mn toxicity to local ARR species (***eriss*** unpublished data 1993; Harford et al 2009[4]; Harford et al 2013) have indicated that the green hydra, *Hydra viridissima*, is more sensitive to Mn than any other species reported in the literature, with no-observed-effect concentrations and

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[2] Harford AJ, Jones D & van Dam RA 2013. Highly treated mine waters may require major ion addition before environmental release. *Science of the Total Environment* 443, 143-151.

[3] Peters A, Crane M, Maycock D, Merrington G, Simpson P, Sorokin N & Atkinson C 2010. Proposed EQS for Water Framework Directive Annex VIII substances: manganese (total dissolved). Environment Agency, Bristol, UK.

[4] Harford AJ, Hogan AC, Cheng K, Costello C, Houston M & van Dam RA 2009. Preliminary assessment of the toxicity of manganese to three tropical freshwater species. In ***eriss*** *research summary 2007–2008*, Supervising Scientist Division, Darwin, NT, 12–19.

10% inhibition concentrations (IC10) between 20 and 180 µg $L^{-1}$. These concentrations are within the range of residual Mn concentrations measured in process water distillate and, thus, highlighted the need for a more comprehensive assessment of Mn toxicity under environmentally relevant conditions.

Currently, insufficient Mn toxicity data exist for local species in natural Magela Creek water (NMCW) to be able to (i) conclude with high confidence that no adverse effects would be expected given the current water quality, and (ii) predict at what Mn concentrations adverse effects would be expected to occur. This is particularly important given that the low water hardness and relatively low pH of NMCW represent favourable conditions for Mn bioavailability.

Consequently, a project was initiated, with the following aims:

1 Assess the toxicity of manganese (Mn) in NMCW (pH ~6–6.5) to six tropical freshwater species

2 Derive a site-specific water quality trigger value for Mn based on the toxicity data

## 4.2.2 Methods

Standard ecotoxicological protocols for six local freshwater species were used to determine the toxicity of Mn in NMCW. For each toxicity test, filtered (0.1 µm) Mn concentrations were measured at test commencement and end. For some toxicity tests, additional Mn chemistry was assessed (as described below). Average water chemistry of the NMCW samples used for the toxicity testing was as follows: pH ~ 6.4; conductivity ~ 16 µS $cm^{-1}$; alkalinity ~ 6 mg $L^{-1}$ as CaCO3; dissolved oxygen ~ 85% saturation; and dissolved organic carbon ~ 2.5 mg/$L^{-1}$.

At least two valid toxicity tests were completed for each species. The data from the tests were pooled and analysed using concentration-response regression modelling (3-parameter logistic, sigmoidal models or probit analysis). In addition to describing the full toxicity response, the concentration-response models were used to estimate the Mn concentration resulting in a 10% (IC10) and 50% (IC50) reduction in the measured organism response (eg reproduction, growth) relative to the control response.

## 4.2.3 Results

### Chemistry

With the exception of the freshwater hydra, *H. Viridissima,* and one snail, *A. Cummingi* tests (see discussion below), there was very little difference between the 0.1 µm filtered Mn concentrations measured before and after the tests, indicating negligible loss (including precipitation) of Mn from the test systems.

An unusual observation during the study was the loss of a significant proportion of Mn from the test solutions during the some of the hydra tests and a snail test, especially at Mn concentrations below 230 µg $L^{-1}$. This loss of Mn from the test waters has not been observed for any of the other test species and also did not occur in the toxicity test reported by

Harford et al (2009). Potential sources of Mn loss included adsorption to the test solution bottles and/or the test containers, precipitation and/or adsorption/absorption by the test animals. Experiments aimed to determine the fate of Mn in the test system were unable to definitively identify the cause of the loss. The toxicity estimates reported in Table 4.1 were based on Mn concentrations calculated by averaging the before and after test 0.1 µm filtered Mn concentrations in the test solutions.

### Toxicity

Manganese toxicity varied markedly between the six local tropical freshwater species assessed. Toxicity to the fish, *Mogurnda mogurnda*, duckweed, *Lemna aequinoctialis*, and green alga, *Chlorella* sp., was very low, with IC10 values all above 1000 µg $L^{-1}$ (Table 4.1). The aquatic snail, *Amerianna cumingi*, the cladoceran, *Moinodaphnia macleayi*, and the hydra, *H. viridissima* were markedly more sensitive, with IC10 values lower than 1000 µg $L^{-1}$ for these three species.

**TABLE 4.1 PRELIMINARY MANGANESE TOXICITY ESTIMATES FOR THE 6 TROPICAL FRESHWATER SPECIES**

| Species | Manganese toxicity (µg $L^{-1}$) | |
|---|---|---|
| | IC10[a] | IC50[a] |
| *Chlorella* sp. | 14 000 (nc[c]-21 000) | 60 000 (50 000-70 000) |
| *Lemna aequinoctialis* | 2400 (nc-4100) | 12 000 (10 000–15 000) |
| *Hydra viridissima* | 160 (80-250) | 1400 (1100-1900) |
| *Moinodaphnia macleayi* | 650 (550-740) | 1200 (1100-1300) |
| *Amerianna cumingi* | 290 (nc-1100) | 4700 (2300-9100) [d] |
| | LC05 [d] | LC50 [d] |
| *Mogurnda mogurnda* | 80 000 (40 000 - 110 000) | 240 000 (200 000 - 310 000) |

[a] IC10 and IC50: concentrations resulting in a 10% and 50% effect relative to the control response, respectively.
[b] NT: Not tested.
[c] nc: not calculable
[d] LC05 and LC50: concentrations resulting in 5% and 50% mortality relative to the control response, respectively.

*Hydra viridissima* was the most sensitive species that was tested, with an IC10 of 160 µg $L^{-1}$ (Table 4.1). However, this species was less sensitive in Magela Creek water compared with previous preliminary Mn toxicity testing undertaken using Ngarradj water (IC10 of 60 µg $L^{-1}$; Harford et al 2009). The bioavailability of Mn in Magela Creek water may be lower than in Ngarradj water due to the higher pH of Magela Creek. Typically, Mn no/low effect toxicity estimates (eg EC/IC10s, no-observed-effect-concentrations) for freshwater species are > 1000 µg $L^{-1}$. It is noteworthy that three of the species tested in the present study had IC10s < 1000g $L^{-1}$. The order of sensitivity of the six species to Mn was:

*H. viridissima* > *A. cumingi* > *M. macleayi* >> *L. aequinoctialis* >> *Chlorella* sp >> *M. mogurnda*.

The present study assessed Mn toxicity under conditions of low pH (ie pH <6.5) and very low water hardness (ie ~5 mg $L^{-1}$ as $CaCO_3$), where Mn was expected to be of higher toxicity. Only one other species, the amphipod *Hyalella azteca,* has been reported to be more sensitive to Mn exposure than *H. viridissima* exposed in these toxicity tests (Peters et al 2010). Algae have been found to be particularly tolerant to Mn exposure in low pH waters in this study and others conducted overseas. However, these comparisons do not further inform the role that pH and hardness play in determining Mn toxicity. Further studies would need to be initiated if the influence of toxicity modifying factors needs to be understood.

## 4.2 Solute and sediment losses from the trial landform

### 4.2.1 Introduction

With the current mine lease at Energy Resources Australia Pty Ltd's (ERA) Ranger uranium mine due to expire in 2021, there is an increasing focus on key aspects of progressive rehabilitation. ERA is establishing a mine closure plan with a key focus on reshaping and revegetating the final mine landform so that it may eventually be handed back to the traditional owners for possible incorporation into Kakadu National Park. It is important that the final landform resembles the surrounding landscape, is radiologically stable, exhibits erosion characteristics similar to the surrounding environment, and that it acts as a functional containment structure for the mine tailings which must be physically isolated from the environment for 10,000 years post closure.

A further challenge for rehabilitation will be to ensure that the Ranger Project area does not become a significant future source of elevated sediments and solutes to surrounding areas. Pits 1 and 3 are designated containment areas for mine tailings as well as the brine residue from the brine concentrator. While the final landform will include various engineered solutions to prevent expression of contaminated waters from Pit 3, potential for mobilisation of sediments and solutes via surface water runoff and seepage through the landform remains. Further work is required to understand the processes associated with sediment and solute generation and transport.

In collaboration with the SSD, ERA is undertaking research to determine the optimal design and composition of the final, rehabilitated landform for the Ranger Project Area. This work includes measurement of solute and sediment loads generated and transported from the landform during rainfall events. These data are also used for validation of predictive computer modelling of the long-term geomorphic behaviour of the proposed landform designs for the Ranger minesite, also carried out by the SSD (refer to section 4.8).

A trial landform of approximately 8 ha was constructed in late 2008 and early 2009 adjacent to the north-western wall of the tailings storage facility (TSF) at Ranger mine (Figure 4.1). The trial landform was designed to assess:

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

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

Since construction, measurements have been carried out to assess the generation and transport of sediments and solutes, and ability to achieve and sustain growth of plant species native to the region. This report provides the first preliminary assessment of the generation and transport of solutes since monitoring commenced, as well as an update on the hydrology and bedload yields, which have been reported in previous years.

### 4.2.2 Methods

Erosion plots were installed during the 2009 dry season on each of the four main treatment areas by physically isolating an approximately 30 x 30 m area (indicated by the cross hatched squares in Figure 4.1) from the surrounding landform surface by raised damp course and concrete borders on three sides and an open PVC drain on the down-slope side. Plots 1 and 4 were planted with tube-stock in March 2009 with infill planting to replace dead specimens in January 2010. Plots 2 and 3 were direct seeded in July 2009. However, because of poor germination, these plots were infill planted with tube stock in January 2011.

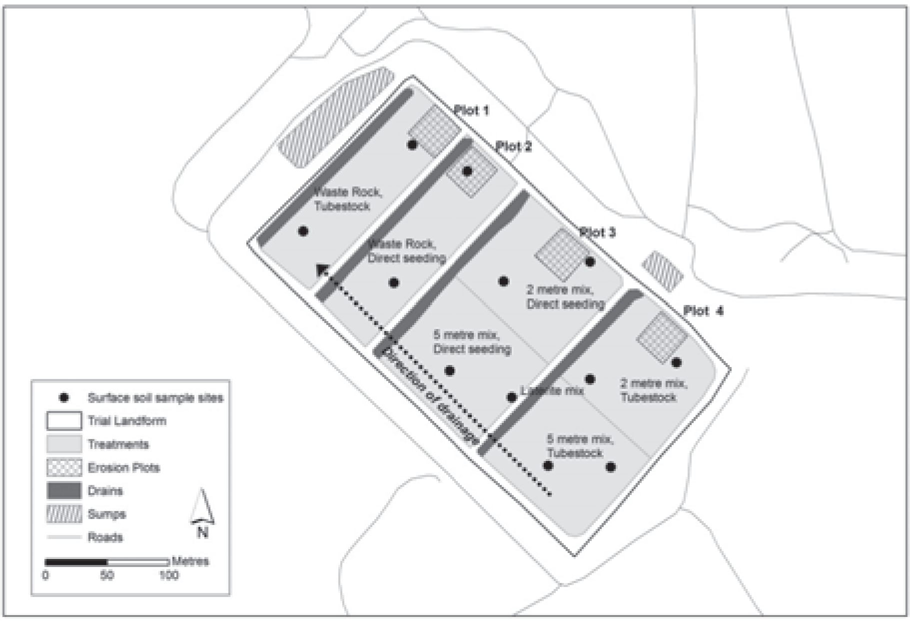


**Figure 4.1** Layout of the erosion plots on the trial landform

Each erosion plot was instrumented with a range of sensors that were described in detail in the 2009–10 SSD Annual Report. In summary, these included: rectangular broad-crested

(RBC) flume to accurately determine discharge; a tipping bucket rain gauge, a primary shaft encoder with a secondary pressure transducer to measure stage height; a turbidity probe from which suspended sediment concentration could be determined; electrical conductivity (EC) probes located at the inlet to the stilling basin and at the entry to the flume to provide a measure of the concentration of dissolved solutes in the runoff; an automatic pump sampler to collect event based water samples triggered by predetermined changes in EC and turbidity readings; and a data logger with mobile phone telemetry connection (Figure 4.2).

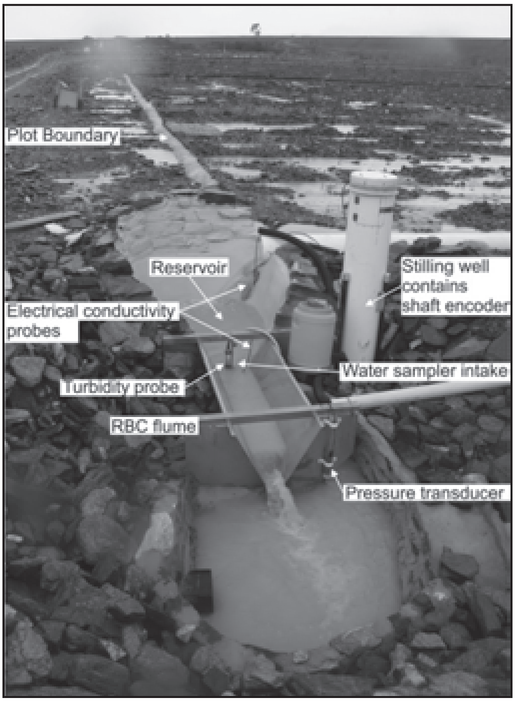


**Figure 4.2** Runoff through the flume on the trial landform erosion Plot 3 during a storm event

The water level above the crest of the flume was used to calculate discharge which was then used with time-integrated concentration data to calculate solute and sediment loads.

The samples triggered by EC changes were analysed in the laboratory for general water quality (EC and pH) as well as concentrations of dissolved (<0.45 µm) trace metals (uranium, manganese, aluminium, iron, zinc, copper, barium, nickel, silica and lead using ICP-MS) and major ions (magnesium, sodium, potassium, calcium, chloride, sulphate using ICP-OES).

The samples triggered by turbidity changes were analysed in the laboratory for turbidity and suspended sediment concentration. The suspended sediment concentration was measured by filtering a standard volume of sample through a 0.45 µm filter of known weight and then determining the oven dry weight of the sediment.

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

## 4.2.3 Rainfall and runoff

### 4.2.3.1 Overview

Data are presented for a 'water year', from September to August. Preliminary sediment and solute losses from the four erosion plots were presented for the first wet season of monitoring, in the 2009–10 Supervising Scientist Annual Report. Rainfall for all four plots and runoff from erosion Plot 1 are reported in this Annual Report. Plot 1 is the only plot for which runoff has been calculated to date for all four water years.

### 4.2.3.2 Rainfall and runoff results and discussion

The rainfall data for each plot and each water year are contained in Table 4.2 while the runoff data for Plot 1 are summarised in Table 4.3.

**TABLE 4.2 RAINFALL DATA FOR THE FOUR EROSION PLOTS ON THE TRIAL LANDFORM FOR THE FOUR YEARS OF MEASUREMENT**

| Water year | Erosion Plot 1 Rainfall (mm) | Erosion Plot 2 Rainfall (mm) | Erosion Plot 3 Rainfall (mm) | Erosion Plot 4 Rainfall (mm) | Mean Annual Rainfall ± Standard Error (mm) |
|---|---|---|---|---|---|
| 2009–10 | 1533 | 1531 | 1480 | 1528 | 1518 ± 13 |
| 2010–11 | 2227 | 2290 | 2205 | 2296 | 2255 ± 23 |
| 2011–12 | 1508 | 1531 | 1456 | 1489 | 1496 ± 16 |
| 2012–13 | 1283 | 1274 | 1260 | 1264 | 1274 ± 5 |

**TABLE 4.3 RAINFALL AND RUNOFF DATA FOR EROSION PLOT 1 ON THE TRIAL LANDFORM FOR THE FOUR YEARS OF MEASUREMENT**

| Water year | Maximum event rainfall (mm) | Number of runoff events | Runoff (L) | Runoff (mm) | Runoff coefficient (%) |
|---|---|---|---|---|---|
| 2009–10 | 76.6 | 135 | 74612 | 81 | 5.3 |
| 2010–11 | 189.4 | 210 | 275748 | 300 | 13.5 |
| 2011–12 | 58.0 | 152 | 96991 | 106 | 7.0 |
| 2012–13 | 72.8 | 92 | 112858 | 122 | 8.1 |

Mean annual rainfall at Jabiru Airport (Station No. 014198, located 2.3 km from the trial landform) is 1578 mm[5] (Bureau of Meteorology). The annual rainfall for the 2012–13 water year on the trial landform was the lowest for the four years of study (Table 4.2) and was much lower than the mean annual rainfall at Jabiru airport.

The number of discrete runoff events for 2012–13 is lower than for the three previous years. The number of runoff events that produced discharge over the crest of the flume was lowest in the 2012–13 wet season, the driest year and was greatest in the wettest year (2010–11). Unusually, annual runoff was less in the 2009–10 water year than in both the drier 2011–12 year and the much drier 2012–13 year (Table 4.3). The 2012–13 wet season had a late period of rainfall with more than half of the annual runoff, including the two largest runoff events, occurring between 28 March 2013 and 3 April 2013 (Figure 4.3). The lowest runoff occurred in 2009–2010 and is likely the result of the infilling with water of the initially empty pore space in the waste rock and laterite from which the trial landform was constructed. Annual runoff was greatest in the wettest year (2010–11) when 13.5% of rainfall was converted to runoff, and was least in 2009–10 when the trial landform was 'wetting up' (Table 4.3). As expected for small areas, the runoff coefficient for plots is much less than for larger catchments in the ARR. Areas up to about 1 km$^2$ behave as if they are drylands in the seasonally wet tropics.

There is a curvilinear relationship between event rainfall and event runoff over the full range of rainfall for all four years for Plot 1. Figure 4.3 shows this curvilinear relationship between total event rainfall and runoff for all 92 events on Plot 1 for 2012–13. When event rainfall exceeds 30 mm there is proportionately greater runoff than for smaller events (Figure 4.3). These smaller events do not totally infill the rip lines with water and so runoff is only produced from a small part of the plot near the down slope border. Event rainfall greater than 30 mm can totally infill the surface storage, hence generating runoff from the whole plot surface.

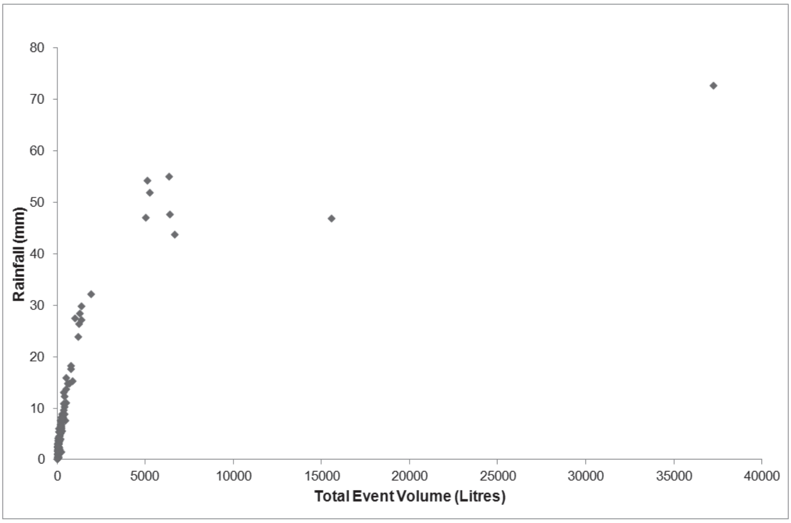


**Figure 4.3** Relationship between total event rainfall and runoff for Plot 1 for every runoff event in the 2012–13 water year

[5] www.bom.gov.au/climate/averages/tables/cw_014198.shtml, accessed 13 August 2013

### 4.2.4 Sediment results and discussion

**Suspended sediment**

Since monitoring of the trial landform commenced, a large number of water samples have been collected based on turbidity reading increases measured in the flume of each plot. These samples have been analysed in the laboratory for turbidity and suspended sediment concentration. The associated data have not yet been analysed and so cannot be reported here.

*Bedload*

The bedload yields recorded for each plot for each water year are shown in Table 4.4. The data clearly show that the annual bedload yield for each plot has declined progressively since construction. Time since construction has had a much greater effect on annual bedload yields than cover material type and development of vegetation because yields have declined progressively over time on all plots, except for plot 2 for 2012–13. Sediment yields for major land disturbances, such as construction or landslides, are usually characterised by an initial pulse followed by a rapid decline. This is true for the trial landform annual bedload yield, which is characterised by an exponential decline in annual bedload yield over the four years since construction (Figure 4.4).

**TABLE 4.4 ANNUAL BEDLOAD YIELDS (t/km$^2$.yr) FOR EACH PLOT FOR EACH YEAR OF MEASUREMENT**

| Water year | Plot 1 | Plot 2 | Plot 3 | Plot 4 | Mean Annual Bedload Yield ± Standard Error |
|---|---|---|---|---|---|
| 2009–10 | 106 | 147 | 111 | 143 | 127 ± 11 |
| 2010–11 | 59 | 113 | 54 | 56 | 71 ± 14 |
| 2011–12 | 34 | 48 | 38 | 15 | 34 ± 7 |
| 2012–13 | 28 | 50 | 14 | 14 | 26 ± 9 |

Previous research in the ARR has shown that sediment yields decline progressively over at least the first three years following a major surface disturbance, as a result of initial washout of fine sediment and the subsequent formation of a gravel-armoured surface. Clearly, time since construction, rather than rainfall, is the dominant driver of bedload yield as the greatest rainfall occurred in the second year (Table 4.4). Using the average rainfall per rain day as an index of rainfall intensity, the values for the four years were 14, 15, 12 and 10 mm/d for the 2009–10, 2010–11, 2011–12 and 2012–13 water years, respectively. The 2010–11 wet season was not only the wettest season but also had the most intense rainfall, further supporting the fact that rainfall is not a key driver for annual bedload yield on the trial landform.

The highest annual bedload yields were always generated from Plot 2 (Table 4.4). While it is still not clear why this happens, shallow rip lines dominate the lower part of Plot 2, resulting in direct connection of diffuse overland flow with the down slope plot drain.

In the fourth year after construction, a clear signature of the effect of vegetation establishment is evident in the annual bedload yields. The two plots (1 and 4), originally planted with tube stock, now have the greatest average tube stock heights (2.77 m for Plot 1 and 2.64 m for Plot 4) and both show lower bedload yields than the plots (2 and 3) initially planted by direct seeding (0.3 m for Plot 2 and 1.04 m for Plot 3) followed a year later by infill planting with tube stock. Plot 4 has the lowest yield because it has also been invaded by weeds which densely cover about half of the plot and mitigate against erosion.

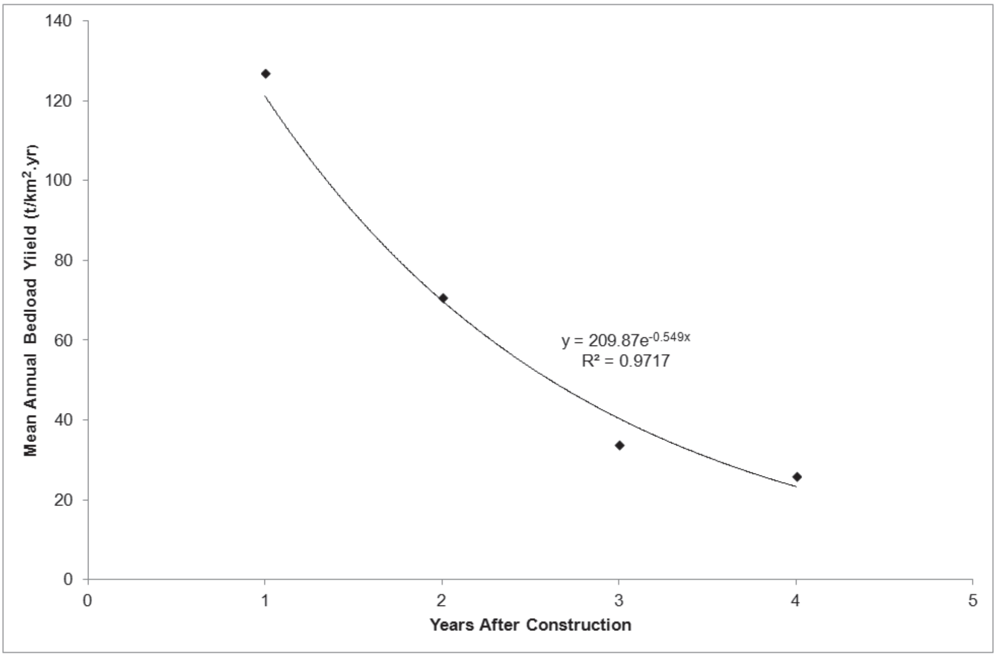


**Figure 4.4** Exponential decrease in mean annual bedload yield with time since construction for the four erosion plots on the trial landform

*Particle size analysis*

Table 4.5 shows the particle size of the bedload for each year of measurement. For Plots 1, 2 and 3 the sand fraction has the highest percentage (all over 50%). On Plot 4 the sand fraction was higher for years 2009–2010 and 2012–2013 and was essentially the same for the other two years. This indicates the importance of the sand fraction and shows that it is the main erosion product in the early years after construction of a rehabilitated landform. The gravel fraction makes up the next highest percentage with little silt and clay contained in the bedload. Surface armouring of coarse gravel has occurred by the washing out of silt and clay from the ground surface.

**TABLE 4.5 ANNUAL YIELD OF BEDLOAD FRACTIONS AS A PERCENTAGE OF TOTAL BEDLOAD YIELD FOR EACH PLOT FOR EACH YEAR OF MEASUREMENT**

| | EP1 | | | EP2 | | | EP3 | | | EP4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Water year* | *% gravel* | *% sand* | *% silt and clay* | *% gravel* | *% sand* | *% silt and clay* | *% gravel* | *% sand* | *% silt and clay* | *% gravel* | *% sand* | *% silt and clay* |
| 2009/10 | 34 | 60 | 6 | 34 | 55 | 11 | 37 | 59 | 4 | 35 | 61 | 4 |
| 2010/11 | 33 | 64 | 3 | 40 | 55 | 5 | 46 | 53 | 1 | 50 | 49 | 1 |
| 2011/12 | 44 | 53 | 3 | 42 | 55 | 3 | 47 | 52 | 1 | 50 | 49 | 1 |
| 2012/13 | 40 | 57 | 3 | 31 | 65 | 4 | 45 | 54 | 1 | 45 | 54 | 1 |

### 4.2.5 Solute generation and transport

The waste rock used to construct the trial landform originates from Ranger Pit 3 (Map 2). Waste rock is the most abundant substrate for capping the final landform. Previous work on the chemical characterisation of Pit 3 waste rock has shown its potential to generate soluble manganese, magnesium, sulphate, uranium, calcium, aluminium, iron and potassium. These solutes are mobilised during rainfall events and are transported via both the surface runoff and seepage pathways.

Typically, the rate of solute generation from waste rock declines over a period of years as the source becomes exhausted, and eventually stable, with inert end-products remaining. An intra-seasonal decline is also observed, with high solute concentrations causing a ‘first flush’ effect at the commencement of the wet season followed by a subsequent decline in concentration towards the end of the wet season. The first flush effect is attributed partly to the fact that rainwater in the region has a lower pH during the early wet season (compared to the late wet season) and is more effective at remobilising solutes and also to the fact that epsomite ($MgSO_4.7H_2O$), which is the dominant soluble salt formed as a result of weathering of Ranger waste rock, accumulates at the surface during dry periods and is flushed away during the first rains. This behaviour would be true for other major salts present.

It is important to monitor the quality of the surface runoff from the Ranger trial landform for a number of years to gain an understanding of the types of solutes present, their concentrations and exported loads (yields) and their behaviour over time. This will lead to more accurate assessments of the environmental significance of the surface runoff from the trial landform and ultimately, from the final Ranger landform. This report presents findings for the first three years of monitoring, focussing on chemical characterisation of the surface runoff and the inter- and intra-seasonal variation in runoff solute concentrations and loads. Data for Plot 1 only are presented, as the quality of the EC and solute data cannot be verified until the discharge data have been validated.

#### 4.2.5.1 Solute results and discussion

*Total dissolved solids load*

Table 4.6 shows the total rainfall and runoff and the loads of total dissolved solids (TDS) for Plot 1 for the first three wet seasons. The TDS has been calculated by applying an assumed standard conversion coefficient of 0.67 to the time-series EC data. The relationship between EC and TDS is typically linear with a slope between 0.5 and 0.9, depending on the solution matrix. The slope can be used as a conversion factor and a value of 0.67 is typically used for naturally occurring freshwater with an EC < 100 µS/cm if the actual relationship is unknown. Measurements of the EC-TDS relationship for the trial landform are currently being made. The loads were calculated using the method described by Walling[6], and illustrated by Equation 4.1, where $t$ is time, $i$ is a defined period of time, $[TDS]$ is instantaneous TDS concentration (mg/L) estimated using the EC data and $Q$ is instantaneous discharge (L/s).

$$\text{total load} = \int_{t=0}^{t=i} [TDS]\, Q\, dt \qquad (4.1)$$

By multiplying the TDS concentration by the corresponding discharge for each time increment and then summing over time, the total mass of TDS over a water year can be calculated. The TDS load/unit runoff (kg/m$^3$) was calculated by dividing the total annual TDS load by the total annual discharge. This normalises the TDS load data for the seasonal variation in runoff between wet seasons.

**TABLE 4.6 PLOT 1 ANNUAL RAINFALL, RUNOFF VOLUME AND TDS LOAD DATA FROM 2009 TO 2012**

| Wet Season | Rainfall (mm) | Runoff (m$^3$) | TDS Load (kg) | TDS load/ unit runoff (kg/m$^3$) |
|---|---|---|---|---|
| 2009–10 | 1528 | 72.17 | 0.74 | 0.01 |
| 2010–11 | 2224 | 273.4 | 1.19 | 0.004 |
| 2011–12 | 1509 | 94.52 | 0.49 | 0.005 |

While the second wet season (2010–11) had the highest rainfall, runoff and TDS load, the TDS Load/Unit Runoff was highest for the first wet season (2009–10) at 0.01 kg/m$^3$, after which the value halved and stabilised at around 0.005 kg/m$^3$. This initial flush of solutes was expected to occur during the first wet season as the freshly-exposed rocks came into contact with the slightly acidic rainwater and the various salts present dissolved and (re)mobilized

[6] Walling DE 1984. Dissolved loads and their measurement. In: *Erosion and Sediment Yield:Some Methods of measurement and Modelling*. RF Hadley and DE Walling (eds), Geo Books, Norwich, pp. 111-177.

the trace elements. These initial results are somewhat similar to the sediment transport observations described earlier.

*Inter-seasonal variation*

The mean annual concentration (and standard error) of key chemical analytes are presented in Table 4.7. Mann-Whitney tests (a non-parametric test used to test the equality of two annual medians) showed that since monitoring commenced, Cu and Ni concentrations have increased significantly each season and Ca, K, Na, $SO_4$, Mn, Si and Al concentrations have decreased significantly ($P<0.05$). There were no significant annual changes in the concentrations of Pb, Zn, U, Mg and Ba. These data show that the post-construction surface of the landform contained soluble salts and particularly fast weathering sources of Si and Al.

Table 4.7 also shows the mean concentrations of analytes measured at the upstream (control) sites on Magela and Gulungul Creeks between the 2009–10 and the 2011–12 wet seasons. The elevated concentration of $SO_4$, Ca, Na, K, Ba and U in the landform runoff, compared to the background levels in the creeks, show that the final landform may contribute significant amounts of these analytes to the surrounding waters during the early phase of rehabilitation. The surface water quality monitoring program currently carried out by SSD measures total concentrations of these analytes plus discharge in Magela and Gulungul Creeks on a fortnightly basis, except for Ba, which may need to be incorporated into the routine monitoring program. Previous Supervising Scientist Annual Reports describe observation of a significant Mg signal in Magela Creek in relation to input of mine-derived waters from RP1 and the Corridor creek catchment. However, the mean concentrations of Mg measured in the trial landform runoff are similar to background levels in the creeks. While the surface runoff is low in Mg it is likely that the higher Mg yields would be expressed in the seepage from the TLF, where the rainwater has a longer residency period in contact with the waste rock. The occurrence of efflorescence (precipitation of epsomite) frequently occurs at the toe of the tailings storage containment walls, which are also constructed from waste rock. ERA has collected data from two seepage collection sumps at the base of the trial landform but this data has not been assessed to date.

*Intra-annual variation*

The variation in major ion and U concentrations for Plot 1 within each water year is displayed in Figure 4.5 against cumulative runoff (which eliminates the effects of seasonal variation in runoff). As expected, a number of analytes (U, K, Ca, Mg, Na and $SO_4$) were inversely related to cumulative runoff volume, with higher concentrations measured at the beginning of the season (in the first 20 $m^3$ of runoff) compared to the end of the season (Figure 4.5). For K, Na and $SO_4$, this first flush effect was most obvious during the 2009–10 and 2010–11 wet seasons and by the 2011–12 wet season the relationship between concentrations and discharge was not as pronounced, confirming exhaustion of the key sources of these ions. The exhaustion is not as obvious for Ca, Mg and U, with the concentrations measured in the 2011–12 wet season spanning a similar range to previous wet seasons. The remaining analytes (Al, Ba, Ni, Si, Pb, Cu and Zn) did not exhibit any relationship to discharge over the duration of a wet season.

These results offer some insight into the intra-annual variability of each analyte. However, for the majority of runoff events, less than three good quality water samples were collected, which limits the extent to which the chemical variation during individual events can be characterised. There are no significant relationships between analyte concentration and event discharge ($m^3/s$). Concerns associated with collection of good quality water samples for chemical analysis will be rectified in future wet seasons by altering the control elements of the datalogger program as well as the physical sensor mounts on the trial landform to ensure that more samples are collected during runoff events.

**TABLE 4.7 ANNUAL MEAN CONCENTRATIONS IN TRIAL LANDFORM SURFACE RUNOFF AND MAGELA AND GULUNGUL CREEKS (STANDARD ERROR).**

| | Ca | K | Mg | Na | $SO_4$ | Al | Ba | Cu | Mn | Ni | Pb | Si | U | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | | | | | | | µg/L | | | | | | |
| **2009–10** | 1.6 | 1.3 | 0.61 | 2.9 | 5.8 | 32 | 18 | 0.18 | 1.6 | 0.06 | 0.15 | 2.3 | 10 | 0.66 |
| **SE (n = 6)** | (0.4) | (0.6) | (0.1) | (1.3) | (1.3) | (8.7) | (7.0) | (0.1) | (0.8) | (0.0) | (0.1) | (1.3) | (4.4) | (0.3) |
| **2010–11** | 1.3 | 0.47 | 0.59 | 0.61 | 2.9 | 7.9 | 20 | 0.22 | 0.66 | 0.06 | 0.03 | 0.45 | 4.7 | 0.69 |
| **SE (n = 15)** | (0.5) | (0.1) | (0.2) | (0.2) | (1.8) | (0.6) | (5.0) | (0.0) | (0.2) | (0.0) | (0.0) | (0.0) | (0.7) | (0.2) |
| **2011–12** | 1.2 | 0.56 | 0.56 | 0.57 | 2.0 | 16 | 43 | 0.56 | 1.6 | 0.11 | 0.09 | 0.63 | 6.4 | 0.78 |
| **SE (n = 15)** | (0.2) | (0.1) | (0.1) | (0.1) | (0.6) | (2.2) | (9.5) | (0.1) | (1.0) | (0.0) | (0.0) | (0.1) | (1.0) | (0.2) |
| **All Water Years** | 1.3 | 0.69 | 0.58 | 1.1 | 3.2 | 15 | 30 | 0.35 | 1.2 | 0.08 | 0.08 | 0.70 | 6.4 | 0.72 |
| **SE (n = 39)** | (0.2) | (0.1) | (0.1) | (0.3) | (0.8) | (2.0) | (5.0) | (0.1) | (0.4) | (0.0) | (0.0) | (0.1) | (0.9) | (0.1) |
| **Magela Creek** | **0.4** | **0.2** | **0.5** | **0.6** | **0.3** | **39** | **1.42** | **0.3** | **5.3** | **0.1** | **0.02** | **n/a** | **0.02** | **0.6** |
| **Gulungul Creek** | **0.4** | **n/a** | **0.9** | **n/a** | **0.2** | **52** | **n/a** | **0.2** | **3.1** | **n/a** | **0.03** | **n/a** | **0.08** | **1.1** |

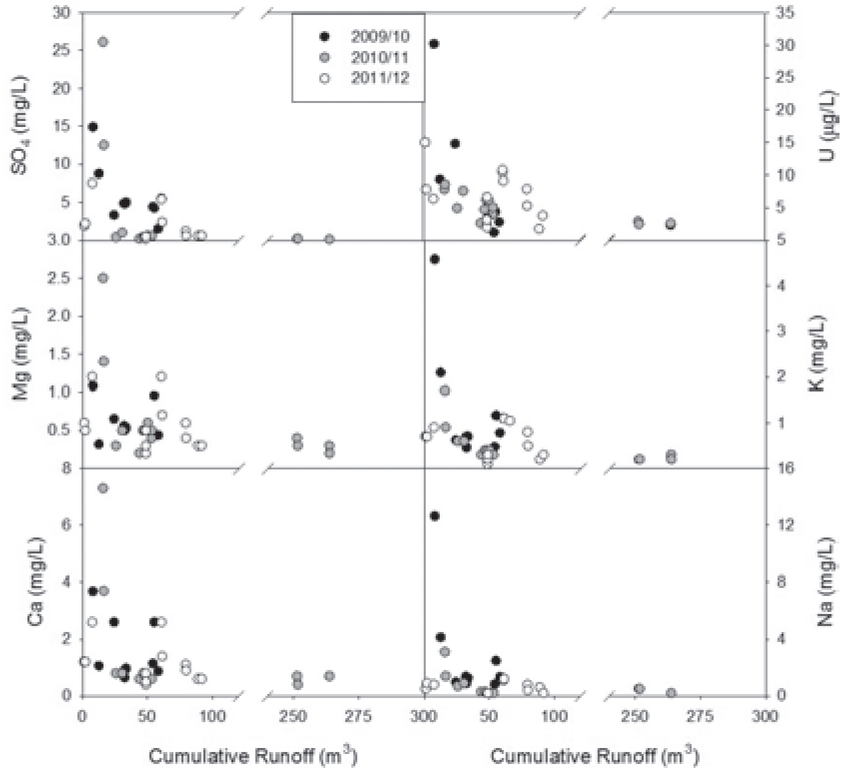


**Figure 4.5** Major ion and uranium response to cumulative runoff on Plot 1. Each wet season is represented by a different coloured point.

*Major ions*

The ternary diagram (Figure 3.6) shows the relative proportions of Ca, Mg and 'K plus Na' in each of the samples collected from Plot 1. The centre of the triangular crosshairs indicates equal contribution (33.33%) of each cation to the total amount of cations in each sample. Figure 3.6 shows that during the 2009–10 wet season, the majority of the samples were K/Na dominant, with these cations contributing 40-50% of the total cations present. The contribution of K/Na decreased over the following wet seasons, with the majority of samples collected in the 2010–11 and 2011–12 wet season being Ca dominant with significant amounts of Mg. This supports the results of the Mann-Whitney tests that show a decline in K and Na concentrations over time. Unfortunately, the corresponding anion ternary diagram cannot be constructed as alkalinity ($HCO_3^-$ and $CO_3^{2-}$) was not measured.

Figure 4.7 shows that Mg and Ca both have significant linear relationships with EC. These relationships were used, with the continuous EC record, to predict the continuous Mg and Ca concentrations. The discharge measured for each event was then used to calculate the Mg and Ca loads using equation 3.1. Table 4.8 summarises the Mg and Ca load data, including total annual loads, the load/unit runoff (as described earlier for the TDS loads) and the maximum event loads, along with the date and the rainfall associated with the event.

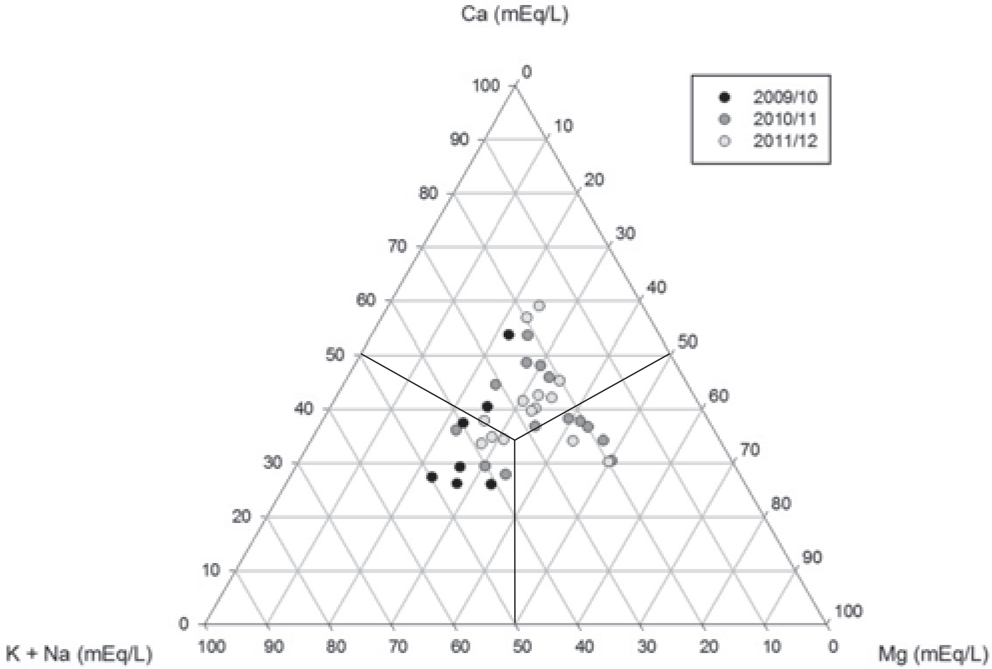


**Figure 4.6** Ternary plot showing cation (mEq/L) composition of surface water runoff over the 2009–10 (black), 2010–11 (dark grey) and 2011–12 (light grey) wet seasons

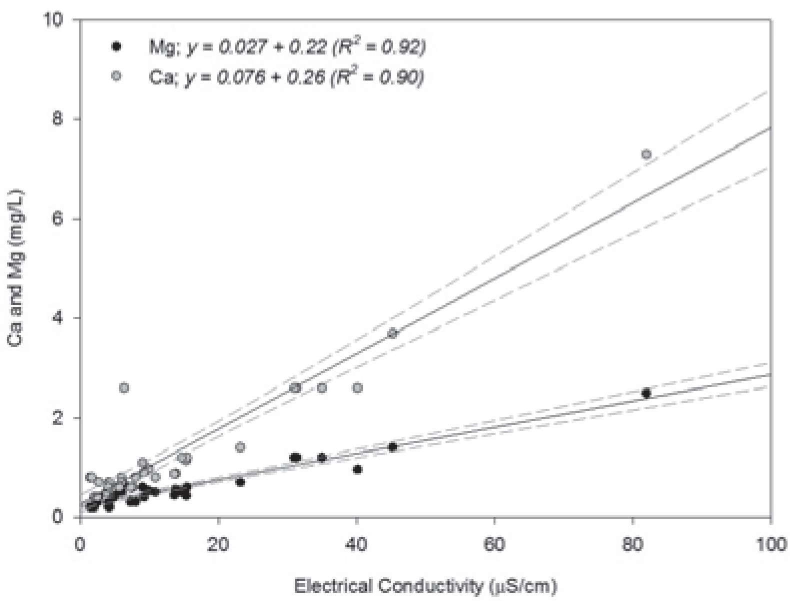


**Figure 4.7** Linear relationships between electrical conductivity and magnesium (black points) and electrical conductivity and calcium (grey points).

**TABLE 4.8 TOTAL SEASONAL LOAD (g), LOAD/UNIT RUNOFF (g/m$^3$) AND MAXIMUM EVENT LOADS (g) FOR Ca AND Mg**

| | Total seasonal load | | Load/unit runoff | | Maximum event load (date, mm rainfall) | |
|---|---|---|---|---|---|---|
| | Mg | Ca | Mg | Ca | Mg | Ca |
| **2009–10** | 37 | 92 | 0.52 | 1.28 | 6 (23/12/09, 45 mm)<br>6 (1/2/10, 77 mm) | 16 (23/12/09, 45 mm) |
| **2010–11** | 93 | 178 | 0.34 | 0.65 | 59 (21/2/11, 189 mm) | 101 (21/2/11, 189 mm) |
| **2011–12** | 31 | 66 | 0.33 | 0.70 | 17 (3/12/11, 85 mm) | 36 (3/12/11, 85 mm) |

The data in Table 4.8 show that the greatest loads of Mg and Ca were exported from the trial landform in the 2010–11 wet season. This is not surprising given that the runoff during this season was more than double that of the other wet seasons. However, using the load/unit runoff the rate of export was greatest during the first wet season and then decreased and stabilised over the following seasons.

### 4.2.6 Conclusion and future work

The priority for further work is to complete the calculation of runoff data from all plots, since the runoff must be determined before suspended sediment and solute loads can be derived. Discharge from Plots 2, 3 and 4 still remains to be determined. It is anticipated that sediment and solute load information from a subset of the plots will be available for presentation in the next annual report.

Work will also be carried out during 2013 to assess the movement of mine-related contaminants in suspended sediment. As stated earlier, a number of suspended sediment samples have been collected and require chemical analysis, which is scheduled for 2013. This work will be aligned with a number of other SSD projects, including the assessment of transport of mine-related contaminants in sediments in Magela and Gulungul Creeks, spectral imaging of sediments and radiological components in sediments on the trial landform.

It is planned to continue monitoring the trial landform until at least 2013–14 to track the trajectory of runoff, sediment and solute yields from an evolving and revegetating landform. Future monitoring objectives include quantifying the effect of developing vegetation on erosion rates, such that a much higher level of confidence can be placed in the predictions from the landform evolution models (see 2010–11 Supervising Scientist annual report) that are being used to predict long-term erosion performance and to assist with the design of the final mine landform. The runoff, sediment and solute loads that are being measured will also inform the design of sediment traps and wetland water quality polishing systems that will need to be incorporated into the rehabilitated mine footprint to manage the export of erosion products.

## 4.3 Development of turbidity closure criteria for receiving surface waters following Ranger minesite rehabilitation

### 4.3.1 Background

Turbidity is a water quality measure commonly used in aquatic ecosystems to represent the total suspended particulate and colloidal matter in the water column. Excessive and sustained turbidity in aquatic ecosystems can disrupt ecological function in aquatic ecosystems, including changes to other water quality variables (temperature, dissolved oxygen), changes to light conditions and hence to primary (plant) production, and disruption of feeding and respiration activities of aquatic organisms. Historically and following minesite construction, enhanced turbidity in aquatic ecosystems around Ranger mine associated with mine operations has been minimal. However, as Ranger moves into the decommissioning and rehabilitation phases, the risk to aquatic ecosystems from suspended sediment in runoff increases significantly, through the erodibility of newly-formed and initially unvegetated landforms.

The Environmental Requirements (ERs) for closure at Ranger stipulate that the minesite and associated waterbodies must be rehabilitated to a state which allows them to be incorporated into the surrounding Kakadu National Park. Water quality closure criteria are being developed in response to these requirements. The closure criteria aim to provide a management approach that allows water quality to remain within a range that will not compromise the long-term environmental objectives of the area. Turbidity is one of a number of water quality measures being developed to represent surface water quality closure criteria for receiving waters, including billabongs and stream channels, adjacent to the Ranger mine.

Biological-effects information for turbidity for the Alligator Rivers Region is available for two different ecosystem types, billabongs and sandy stream channels. The information for each ecosystem type is reported separately below, with an assessment then made as to whether or not different criteria would apply to each ecosystem type. For example and a priori, the ecology and biota of billabongs and flowing stream channels of the region differ, and so it is conceivable that each may differ in its general integrated response and sensitivity to enhanced and sustained turbidity.

### 4.3.2 Closure criteria derived from billabong data

Increased turbidity primarily acts to limit light penetration which reduces primary production, including that associated with phytoplankton. Turbidity can thus cumulatively affect various trophic levels, incurring direct biological impacts both to single biotic groups as well as to ecological processes. Chlorophyll-a is an indirect measure of the amount of phytoplankton in the water column and is thus often used as a surrogate for phytoplankton biomass and a component of primary production.

A study being undertaken for Georgetown Billabong (GTB), adjacent to the minesite (see Map 2), aims to combine existing historical turbidity and biological-effects data with similar recent field data to determine the appropriate boundaries for turbidity closure criteria. The closure criteria for turbidity would be relevant to the area around Ranger mine and would aim to meet the ERs for Ranger rehabilitation such that the integrated aquatic ecosystems, natural and (possibly) re-constructed, represent fully functional natural systems. This study evaluates the indirect relationship between turbidity, as suspended particulate matter, and primary production, as a representation of ecosystem function. While at the ecosystem level, cause-effect relationships are complex and difficult to discern, simplistic effects can be inferred when multiple lines of evidence are evaluated and where good conceptual understanding is available.

All data for the study have been collected from GTB. It is one of the first waterbodies to receive runoff from Ranger and thus has been used extensively to monitor water quality and biological changes over time. Most recently, chlorophyll a and turbidity have been continuously monitored over a 10 month period (ie since the 2012 dry season) to determine the relationship between changes in turbidity and primary biological response (chlorophyll-a). The dry season increases in turbidity in GTB are natural and are a consequence of (mainly) wind-induced re-suspension of the silt-clay sediments, exacerbated over the dry season as the billabong becomes increasingly shallow through evaporation.

Surface chlorophyll-a and turbidity data from the dry season of three sample years, 1981, 2009 and 2012, are presented in Figure 4.8. Data from 2009 suggested that phytoplankton are inhibited at values between 25 and 70 NTU[7]. Such a threshold is masked in the data of Figure 4.8 because individual fortnightly data have been averaged on a monthly basis. This was supported by data collected in 1981 which suggested inhibited phytoplankton production at values around 50 NTU (Figure 4.8). The 2012 dry season data reflect a similar threshold effect, with phytoplankton biomass peaking at an average turbidity value of 68 NTU. The rate of change in turbidity and chlorophyll-a was gradual over the 2012 dry season with no 'extreme' values occurring (ie turbidity values greater than 150 NTU). However, other monitoring programs in GTB have recorded turbidity values spiking from relatively modest to highly extreme values within a one month time period. The most dramatic example was found in 2003 when ERA recorded a turbidity increase from 16 to 782 NTU within one month and then a further increase to 1517 NTU within the next month. The present study did not experience such exceedingly high turbidity values or such rapid changes, warranting an assessment of ERA's long-term turbidity data, particularly for values that are not aligned either with SSD's continuous data or field checked monthly data.

The dry season studies summarised above reported a peak in chlorophyll-a in the mid dry season. In the current study, apart from the mid dry season chlorophyll-a peak, even higher values occurred, albeit briefly, within one week of initial wet season flows. In early January 2012, chlorophyll-a values reached 165 mg/m$^3$, a value four times that measured during the dry season. This value occurred when turbidity values had dropped from 75 to 10 NTU due to flushing flows. The low turbidity measured during this event indicates that phytoplankton

[7] Buckle D, Humphrey C & Jones D 2010. Effects of fine suspended sediment on billabong limnology. In ***eriss*** *research summary 2009–2010*. eds Jones DR & Webb A, Supervising Scientist Report 201, Supervising Scientist, Darwin NT, 143–149.

biomass may have a secondary, though short, response to rapid changes in turbidity, in this case, elicited by a return to higher water clarity with wet season re-wetting and inundation. Short-lived peaks in nutrients with first-flush waters in tropical systems have also been implicated in corresponding spikes in primary production. The full nutrient dataset associated with the present study has not been analysed yet to corroborate this.

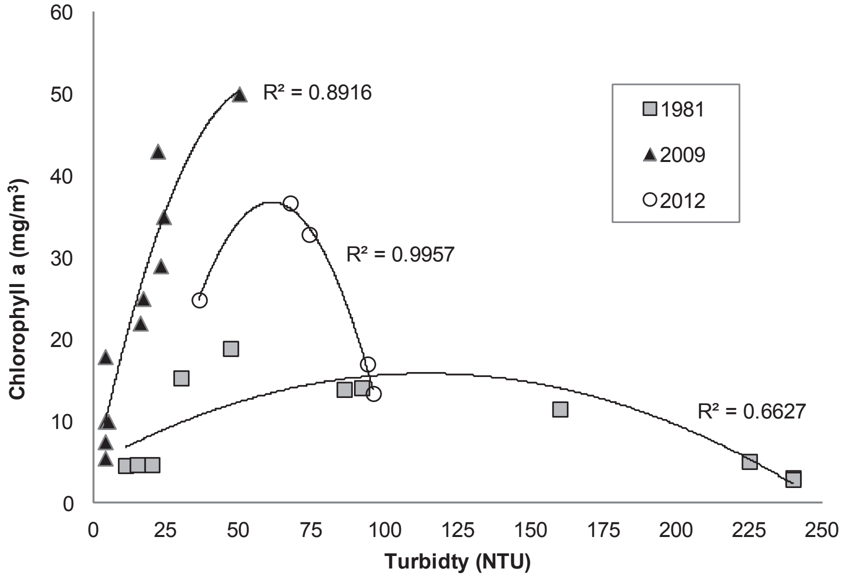


**Figure 4.8** Chlorophyll and turbidity relationship in Georgetown Billabong during 1981, 2009 and 2012. Each year shows the $R^2$ value for the second-order polynomial regression equation, indicating the strength of the relationship between chlorophyll a and turbidity. Data shown for 2012 are monthly averages (August to December) derived from weekly sampling, while data for 1981 are monthly measures (January to November). Data for 2009 regression are based upon fortnightly measures taken between May and October.

In the current GTB study, phytoplankton in three preserved water samples were identified and enumerated (Table 4.9). These samples represented periods of turbidity between 3 and 99 NTU and chlorophyll-a values between 7 and 26 mg/m$^3$. Cursory examination of the data suggest that the greatest diversity in phytoplankton may correspond with higher turbidity, while also suggesting the lowest diversity was associated with flushing flows and reductions in turbidity. Further data are required to adequately assess if a relationship exists between turbidity and taxa richness for this dry-wet season transition period. Half of the species that were found in the January sample were not present during the late dry period, thus illustrating a shift in species composition that may be a result of flow-related water quality changes. When the late dry season-early wet season chlorophyll data (from Table 4.9 and the value at initial billabong filling in January 2012, cited above) are compared with data from earlier in the (2012) dry season (Figure 4.8), it is evident that, in general, phytoplanktonic productivity is greatest during the mid dry season, although short-lived, but higher peaks are evident in response to flushing flows at the very beginning of the wet season.

**TABLE 4.9 PHYTOPLANKTON DIVERSITY AND ABUNDANCE IN GEORGETOWN BILLABONG, 2012–13**

| Sample date | 1/11/2012 | 6/12/2012 | 17/01/2013 |
|---|---|---|---|
| **Chlorophyll a** ($mg/m^3$) | 26 | 12 | 7 |
| **Turbidity** (NTU) | 99 | 91 | 3 |
| **Number of phytoplankton taxa** | 37 | 27 | 24 |

### 4.3.3 Closure criteria derived from sandy stream channel data

In the 1990s, an unformed stream-bed crossing on the upper reaches of Jim Jim Creek in Kakadu National Park (KNP) caused elevated turbidity in the flowing waters downstream of the crossing over of a period of several consecutive dry seasons. In response to KNP management concerns, research studies were conducted by SSD in 1996 to assess possible adverse effects of these increased suspended solids on macroinvertebrate and fish communities in the receiving waters[8,9]. While impacts upon the biota were demonstrated, data analysis techniques at the time were limited in their ability to better define possible thresholds of effect. Statistical techniques available today offer improved analytical performance in understanding the nature and extent of impact, including assessment of possible biological thresholds. The following study re-analyses the datasets acquired in 1996 to assess their potential for setting general water quality, including closure, criteria for turbidity in flowing-stream environments of the Alligator Rivers Region.

Jim Jim Creek in its upper reaches below Jim Jim Falls is a clear-water, sandy stream channel that flows for most of the year. A tourist road leading to the adjacent Twin Falls crosses Jim Jim Creek and is open to traffic for much of the northern dry season. Prior to 1997, early four-wheel drive access and traffic over the crossing washed away overlying sand deposited during the preceding wet season, to expose a clay creek-bed that gave rise, with ensuing regular traffic, to high suspended solids downstream for the remainder of the dry season.

Water physico-chemistry, including turbidity, and macroinvertebrate and fish communities were monitored in 1996 for two months prior to the opening of the creek crossing to tourist traffic in the early dry season (24 June) and for four months thereafter. A modified Before-After-Control-Impact Paired differences (BACIP) design was employed, which included at least paired sites in both Jim Jim Creek (upstream and downstream of the road crossing) and

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8 Stowar M, Pidgeon B, Humphrey C & Boyden J 1997. Effects of suspended solids on stream biota downstream of a road crossing on Jim Jim Creek, Kakadu National Park: Final report. Internal report 244, Supervising Scientist, Canberra.

9 Stowar M 1997. Effects of suspended solids on benthic macroinvertebrate fauna downstream of a road crossing, Jim Jim Creek, Kakadu National Park. Internal report 256, Supervising Scientist, Canberra. Unpublished paper.

Twin Falls Creek (a control stream, with analogous but undisturbed upstream and downstream sites) – see Figure 4.9.

Replicate macroinvertebrate samples were collected from each of five sites: one upstream (JJ1) and two downstream (JJ2 and JJ3, 200 and 1000 m downstream respectively) of the road crossing on Jim Jim Creek, and two in a similar upstream-downstream configuration in Twin Falls Creek (TF1 and TF2 respectively) (Figure 4.10). Data reported here refer to samples collected from root mat habitat (ie dense mats of fine fibrous roots of riparian shrubs and trees, mainly *Pandanus aquaticus* and *Melaleuca* spp). Sampling was conducted at each site on three occasions prior to opening of the road crossing and on four occasions after. Fish sampling was undertaken in large pools at sites JJ1, JJ2, TF1 and TF2 sites on one occasion prior to, and one occasion four months after, opening of the road crossing.

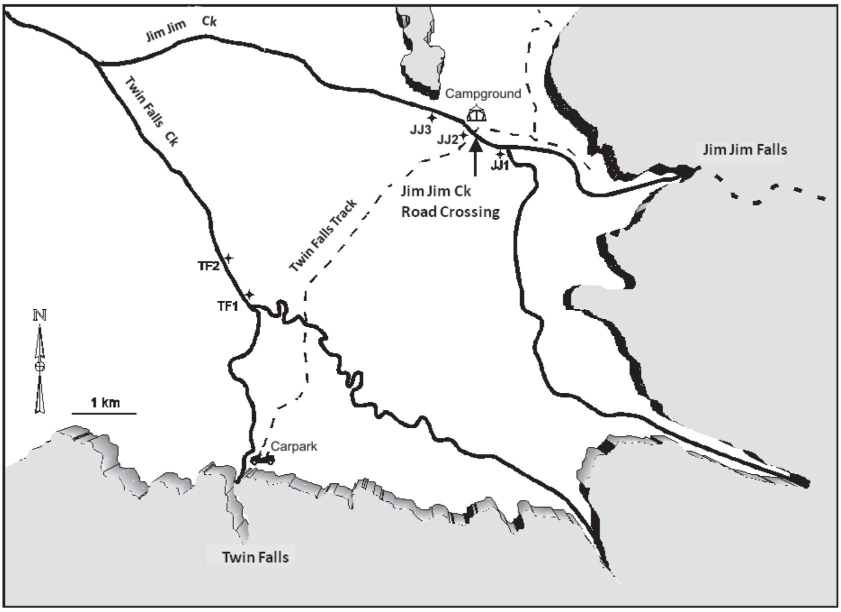


**Figure 4.9** Map showing location of upper Jim Jim Creek and road crossing, with associated sampling sites studied in the 1996 dry season.

The modified BACIP design used for macroinvertebrate community study applied the same principles as used in the equivalent biological monitoring study in Magela Creek catchment (see section 3.2.3.2 of this report). Thus, for each sampling occasion and for each pair of (upstream-downstream) sites for Jim Jim and Twin Falls Creeks, dissimilarity indices were calculated. These indices are a measure of the extent to which macroinvertebrate communities of the two sites differ from one another. A value of 'zero%' indicates macroinvertebrate communities identical in structure while a value of '100%' indicates totally dissimilar communities, sharing no common taxa. Disturbed sites may be associated with significantly higher dissimilarity values compared with undisturbed sites. The site pairs examined in this way included JJ1-JJ2, JJ1-JJ3 and TF1-TF2.

In the earlier studies, a plot of the paired-site dissimilarity data from the two streams revealed a temporal trend in the values for any paired sites that were not under the influence of elevated downstream turbidity (ie pairs TF1-TF2, and pairs JJ1-JJ2 and JJ1-JJ3 prior to the road opening). The seasonal dissimilarity values are reproduced here in Figure 4.10. The same trends are also evident in other unimpacted ARR streams for which seasonal data have been gathered, including those of permanent flow (data not shown here). Authors of the earlier studies interpreted JJ1-JJ2 and JJ1-JJ3 dissimilarities from low, late-dry season flow periods (ie post-road opening) that fell well outside of the 95% confidence limits of the regression relationship (Figure 4.10) as inferring turbidity-related impact. These outliers were assessed more closely using multivariate ordination, depicting the relationship of macroinvertebrate samples to one another, and ANOSIM (ANalysis of SIMilarity), a multivariate equivalent of ANOVA, to better define thresholds or gradients of possible impact associated with elevated turbidity.

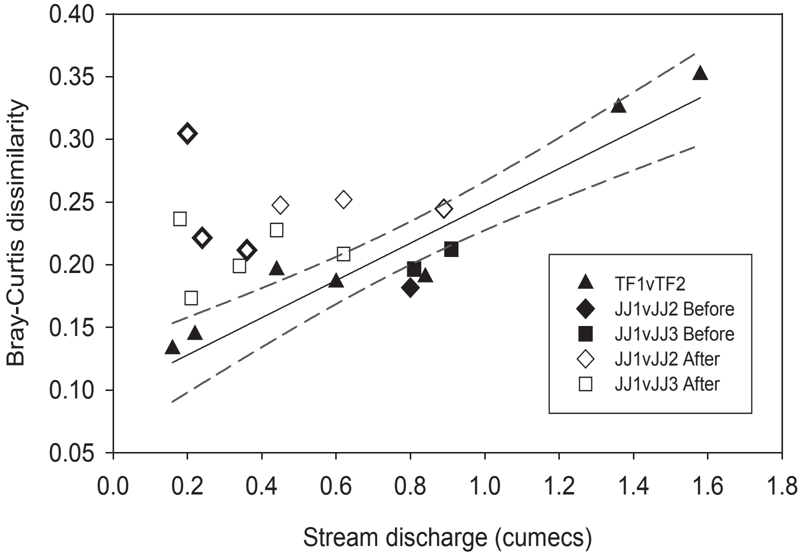


**Figure 4.10** Relationship between discharge and dissimilarity of macroinvertebrate community structure between upstream and downstream sites for Jim Jim (JJ) and Twin Falls (TF) Creeks using family level (log-transformed) data.

Before and After samples for Jim Jim Ck refer to before and after opening of the road crossing to traffic. The regression line and 95 percent confidence intervals were calculated using all 'unimpacted' (black enclosed) samples only and creek discharge at the time of sampling. $R^2$ values for regression is 0.8.

The ordination representing all sampling sites and sampling occasions in the post-road-opening period is shown in Figure 4.11. Notable in the ordination is the interspersion of most Jim Jim site 3 samples (JJ3/5, JJ3/6 and JJ3/7 representing post-road opening) with corresponding control samples from upstream of the crossing (JJ1) and from Twin Falls Creek, indicating little if any impact. Conversely, Jim Jim site 2 samples from late in the tourist season (JJ2/5, JJ2/6 and JJ2/7) are grouped together but are well separated from other sites and sampling occasions, indicating a distinctive community structure that reflects impact.

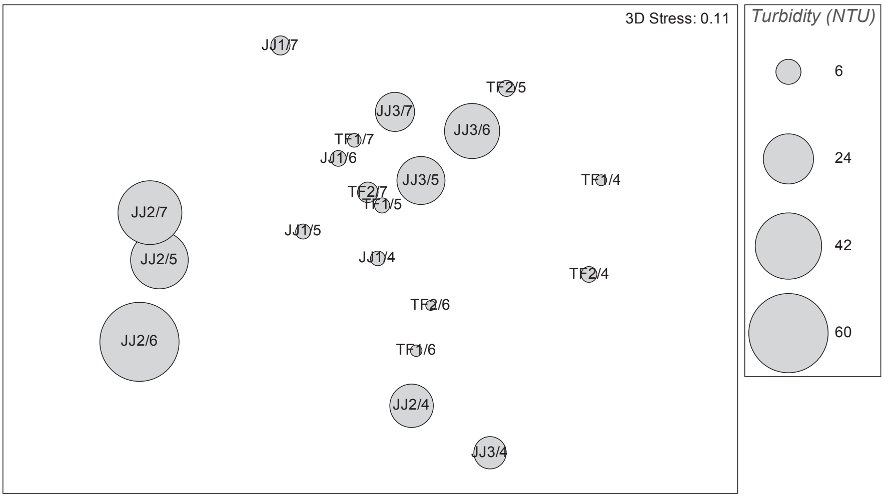


**Figure 4.11** Axes 1 and 3 of Multi-Dimensional Scaling ordination of macroinvertebrate communities from Jim Jim (JJ) and Twin Falls (TF) Creeks using family level (log-transformed) data. Each data point represents the average of three replicate samples per site per sampling occasion. Numbers after creek abbreviations refer to site number / sampling occasion, eg JJ2/6 – Jim Jim Creek site 2, sixth sampling occasion etc. Bubble plot indicates turbidity values associated with each sample.

The ANOSIM test statistic was used to compare the observed community differences *between* groups – in this case the separate sampling occasions for 'exposed' JJ2 and JJ3 replicate samples, versus control samples for each corresponding time period, ie JJ1, TF1 and TF2 sites – with the differences among replicates *within* the groups. The degree of separation between groups is denoted by the R-statistic, where the ANOSIM program's authors provide guidance on the R-statistic as follows: > 0.75 = groups well separated, > 0.5 ≤ 0.75 = groups overlapping but clearly different, and < 0.25 = groups barely separable. The resulting ANOSIM R values are plotted with corresponding ambient turbidity measured at the downstream Jim Jim sites in Figure 4.12. With increasing time after opening of the road crossing, there is an increasing separation of the Jim Jim downstream sites from the corresponding controls sites. Only JJ2 macroinvertebrate communities for sampling occasions 5, 6 and 7 differed significantly (ANOSIM $P<0.05$) from respective control samples and the ANOSIM R values for these samples (>0.3) approach or exceed thresholds of separation consistent with the ANOSIM authors' guidance (from above).

On the basis of ANOSIM results (Figure 4.12), supported by the distinct separation of the sites in ordination space (Figure 4.11), JJ2 macroinvertebrate communities for sampling occasions 5, 6 and 7 can be regarded as significantly impaired. These adverse effects appeared after turbidity had reached sustained values of 30 NTU (Figure 4.11).

JJ2 macroinvertebrate communities for sampling occasions 5, 6 and 7 are also depicted in the dissimilarity-discharge regression plot (Figure 4.10) as emboldened open diamond symbols. Given that other JJ2 and JJ3 samples post-road opening also sit outside the 95% confidence limits for the regression plot, it indicates that a number of different analytical methods must be used to correctly identify ecologically impaired communities.

The most significant observation made from the results of fish sampling (sites JJ1, JJ2, TF1 and TF2, before and after) was the dramatic (90%) decline of the numerically-dominant hardyhead, *Craterocephalus marianae*, from JJ2 late in the season. At all other sites, abundances of this species had increased from before to after the road opening (between 1.3 to seven-fold). This small-growing species is an active visual, predatory- feeder over benthic substrates of clear-water, sandy streams in the ARR. The significant decline in abundance of the species from JJ2 when turbidity was high is consistent with impairment of the fish's feeding behaviour.

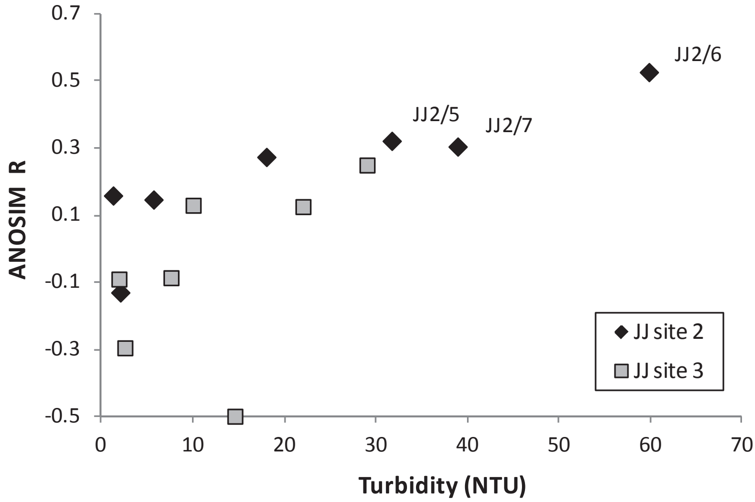


**Figure 4.12** ANOSIM (Jim Jim downstream sites versus control sites) R values in relation to ambient turbidity at the 'exposed' JJ2 and JJ3 sites. Each data point represents one of the seven different sampling occasions. Site labels refer as follows: JJ2/5 – Jim Jim Creek site 2, fifth sampling occasion etc. Negative R values indicate high replicate variability within-samples (ie within JJ and/or control samples)

### 4.3.4 Conclusions

Based on data collected to date, thresholds for biological effects of high and sustained turbidity in ARR ecosystems ranged between 50-70 NTU for phytoplankton in GTB, and 30 NTU for macroinvertebrate communities in the sandy Jim Jim Creek channel. Two caveats have been noted with respect to translating these values to minesite closure criteria:

1 The values are derived from dry season studies whereas erosion-induced, elevated turbidity associated with rehabilitation will occur during the wet season

2 The sources of turbidity for the two studies reported above differ from those to be expected to arise from erosion of rehabilitated mine landforms, ie laterite and Cahill schists.

These factors require further assessment, together with decisions on: (i) relative risks to biota in the wet versus dry season; (ii) whether different criteria are derived for billabong and sandy stream channel ecosystem types or whether the more conservative (sandy creek channel) value from above is applied for all ecosystem types; and (iii) whether the ongoing billabong study can provide information on the effects of relatively short-lived turbidity peaks (cf sustained exposure that has characterised the studies to date).

Future work will focus on refining the reported ranges in accordance with seasonal expectations for minesite erosion. A challenge for setting appropriate closure criteria is in understanding biological responses to rapid and unseasonal changes in turbidity. In addition to the ongoing field study, laboratory experiments are planned to help inform this issue.

# 4.4 Environmental factors associated with toxicity monitoring in Magela and Gulungul Creeks

## 4.4.1 Background and previous findings

Toxicity monitoring evaluates the responses of aquatic animals exposed in situ in Magela and Gulungul Creeks to diluted runoff water from the Ranger minesite. Egg production by the freshwater snail, *Amerianna cumingi*, over a four day deployment period, has been the method used in Magela Creek since 1990–91 and in Gulungul Creek since 2009–10 (see 'In situ toxicity monitoring' in section 3.2.3.2 of this report).

Following both the 2010–11 and 2011–12 wet seasons, statistical analyses and laboratory studies were undertaken to provide an improved understanding of environmental (viz water quality) conditions affecting the production of snail eggs during the toxicity monitoring tests.[10,11] This work helps distinguish between natural and mine-induced effects on snail egg numbers for impact assessment purposes.

The availability of continuous electrical conductivity (EC, $\mu S\ cm^{-1}$; a reliable surrogate of magnesium sulfate concentrations), water temperature and turbidity data between the 2006–07 and 2011–12 wet seasons provided opportunities to reliably assess the influence of these water quality variables on the snail egg production response. Over this period and for toxicity monitoring data from Magela and Gulungul Creeks, a number of significant correlations and interactions have been found between mean egg number and both median EC and water temperature, but not turbidity:

1 For the creek water temperatures most commonly encountered (<30°C), a statistically significant positive linear relationship has been observed between EC and snail egg number.

2 A significant unimodal (second-order polynomial or quadratic) relationship was found between water temperature and snail egg number, with a peak in egg number observed near 29°C.

[10] Humphrey CL, Buckle D & Davies C 2012. Ranger stream monitoring research: Further analysis of toxicity monitoring data for Magela and Gulungul creeks. In ***eriss*** *research summary 2010–2011*. eds Jones DR & Webb A, Supervising Scientist Report 203, Supervising Scientist, Darwin NT, 96–106.

[11] Humphrey CL, Ellis M, van Dam R & Harford A 2013. Analysis of toxicity monitoring and associated water quality data for Magela and Gulungul Creeks. In ***eriss*** *research summary 2011–2012*. eds van Dam RA, Webb A & Parker SM, Supervising Scientist Report 204, Supervising Scientist, Darwin NT, 102–107.

3 A significant interacting effect of water temperature and EC upon snail egg counts in Magela and Gulungul Creeks was observed. Specifically, enhanced egg production with increasing EC at lower water temperatures (27–29°C) was noted, as well as an increasingly neutral effect at intermediate temperature (~30°C) and an increasingly reduced/negative effect at higher water temperatures (>30°C).

4 Across the tests conducted during each wet season, a mean upstream-downstream egg number difference value is derived, and this mean has an associated error or variance. This variability in the egg number difference values was observed to be significantly correlated with the same variability in corresponding upstream-downstream EC difference values.

Laboratory experiments confirmed the optimal egg production observed around 29°C (ie observation 2 above) but did not support an interacting effect of water temperature and EC upon snail egg production (ie observation 3 from above). Notwithstanding, the collective studies indicated that reproductive responses of freshwater snails exposed in Magela and Gulungul Creeks in the wet season appeared to be stimulated by small increases in EC across the range of median (four-day) values recorded in these receiving waters (7–30 µS $cm^{-1}$). Median EC values greater than 20 µS $cm^{-1}$ 1in the main wet season months (January-April) are typically a consequence of mine water discharges, and so inputs of water from the minesite were implicated in at least part of the stimulatory response.

An examination of environmental influences upon the snail egg production response continued during the 2012–13 wet season in Magela and Gulungul Creeks. Features of the wet season and the testing regime that had potential to improve an understanding of the snail egg production response included: (i) a focus on different husbandry conditions under which the snails were reared at the Jabiru field station facility, (ii) the below-average rainfall and stream flows during this wet season, and related to this (iii) the lack of significant mine water discharges from Ranger in the 2012–13 wet season. In relation to (ii) and (iii), the lack of significant mine-water inputs to the receiving waters would reflect responses to near-natural, but low-flow, water quality conditions, representing water quality exposure conditions very different from those experienced since 2006–07.

## 4.4.2 Influences of different snail culturing conditions on the snail egg production response

### Background and methods

Until the 2012–13 wet season, no attention had been directed at the culturing conditions under which snails were reared at the Jabiru field station facility, as a potential source of variability in egg production during wet season test exposures in the creeks. Snails have typically been cultured in shallow (<0.5 m water depth) fibreglass or glass aquaria under static conditions but various systems, housed under or out of cover, have been used since 1991.

Since 2006–07, shallow containers held in a dedicated under-cover aquaculture facility have been used for culturing. Containers are ‘seeded’ for the ensuing wet season with stock from egg masses placed in the containers in the late dry season. Progeny, and ensuing generations, from this initial stocking would also be used for wet season testing as their shell length reached the minimum requirement (10 mm). For the 2011–12 wet season, snail stocks for sampling were sourced from both static shallow (0.5 m) and deep (~1.1 m) fibreglass containers, the latter using a Recirculating Aquaculture System (RAS). Both the shallow static and deep RAS containers and culturing regimes were also deployed for the 2012–13 wet season testing, and for this season the opportunity was taken, a posteriori, to compare the egg production under routine creek testing conditions of snails arising from the two different culturing regimes.

Husbandry-related factors that were examined for the 2012–13 wet season included (i) container type (shallow static, deep RAS), (ii) 'age' of the snail cohort, as measured by length of time from initial container seeding to use of the snails in a toxicity monitoring test, (iii) snail length and (iv) snail weight. Cohort age was a coarse measure of snail age because, as indicated above, there was continuous growth and recruitment of snails from the progeny of ensuing generations of snails held in each container. This mixed-age and size confounding was reduced by periodically eliminating snails from the containers and re-stocking. A record of the container source was made for each snail used in each of the toxicity monitoring tests conducted over the wet season.

Nevertheless, a significant deficiency in the design of this (a posteriori) study was the necessity for *pairs* of snails to be placed in egg-laying chambers — a feature of the monitoring protocol that has been in place since 1991. This gave rise to two difficulties: (i) the pairing made it impossible to assign an egg count to an individual snail; and (ii) there was potential for sourcing of any snail from the pair from different container types (see below). Because of this, some measure of independence of the egg counts was introduced for data analysis by splitting the count data into two. Thus for each test and site (i) the total egg count in each replicate egg-laying chamber (16 chambers per upstream and downstream site) made at the end of the four-day exposure period was assigned to each snail in the pair, (ii) the total count was attributed to both culturing containers from which the two snails were derived, and (iii) two datasets were derived, corresponding to each snail of the pair and the corresponding culturing containers, even though the egg production of the snail pair was a combined value and could not necessarily be apportioned to the original culture container.

In practice, it was more usual (55% of replicate snail pairs) for the snail pair to have been derived from the same container type (shallow or deep) than for the two snails to have been derived from different container types. Nevertheless, the high proportion (45%) of snail pairs for which individuals were derived from different container types represents a significant subsumption of variation in the attributed egg counts for these snail pairs.

Analysis of covariance testing (ANCOVA) was used to examine the effects of different husbandry conditions – culture container type and container cohort 'age', as well as the covariates snail shell length and shell weight, on snail egg number for the two creek systems, site in each creek (upstream/downstream) and period of the wet season (represented by test order). A problem with the analysis was the uneven distribution of container cohort age amongst the other factors. Hence, this factor could only be nested within other factors, resulting in it having little interpretative value.

**Results**

ANCOVA results of the analysis for one of the duplicate datasets, as defined and described above, may be summarised as follows:

1 Egg number per snail pair was significantly different between creeks (P = 0.035) and amongst tests (test order, P = 0.0002), while creek*test order (P = 0.0001), and creek*site (up/downstream, P = 0.025) interactions were also significant. From an examination of Figure 2.18B, it is immediately evident, and unsurprising, that these factors and associated interactions are significant as egg production is highly responsive to water quality conditions over time and amongst different locations.

2 Egg number also correlated with snail length (P = 0.03) and snail weight (P = 0.0002) and again this is unsurprising given the positive fecundity-size relationship most freshwater organisms exhibit.

3 While container cohort age was significant in the analysis (P = 0.022), its nesting within other factors makes it impossible to ascertain interactions with other factors that are contributing to this significance.

4 Container type (shallow/deep) was highly significant in the analysis (P = 0.0001).

Results for the other duplicate dataset were very similar to those described above and hence are not considered further. To examine the significant container type effect further, for each toxicity monitoring test and each creek, the mean total egg count assigned to each snail in each snail pair (from above, combined datasets) for the two culture container types was determined, with values plotted in Figure 4.13

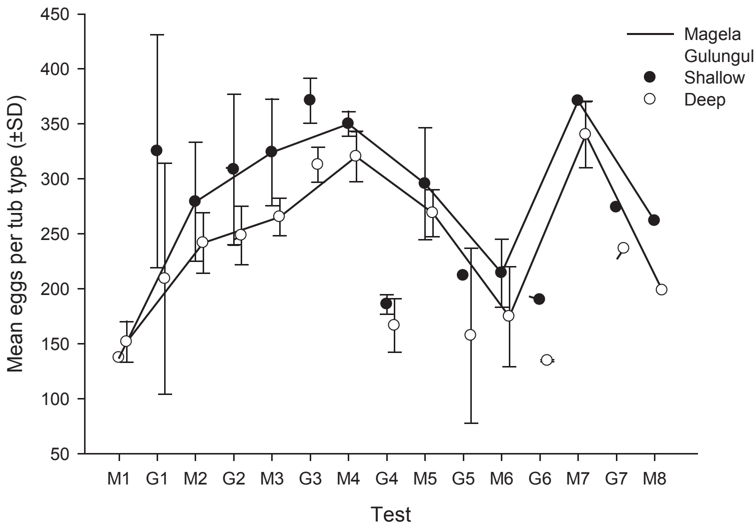


**Figure 4.13** Mean total egg count assigned to individual snails sourced from shallow static and deep RAS culture container types for Magela and Gulungul toxicity monitoring tests conducted in the 2012–13 wet season. Horizontal axis shows the test order over the wet season, with M and G referring to Magela and Gulungul Creeks, respectively. Values with no error bars indicate single snail value.

Figure 4.13 shows the consistently higher egg production associated with snails from the shallow static containers compared to egg production associated with snails from the deep RAS containers. A practical concern of this result, revealed only in the latter part of the 2012–13 wet season, is the potential for snails from one of the two culture types to have been inadvertently and disproportionately allocated to one of the two sites (up/downstream) within a creek for a particular test. If a site had disproportionately more snails from one of the culture types, the upstream-downstream difference value for the test may reflect an artefact of culture type, as opposed to its proper representation of detecting changes in water quality. An examination of the datasets indicated even distribution of snails from the culture types between sites and across tests and in support of this, the Site*Tub type and Site*Tub type*Test order interactions in the statistical analysis described above were not significant. Further discussion of culture type is provided in section 4.4.4 below (Conclusions).

### 4.4.3 Influences of ambient water quality on the snail egg production response

The below average rainfall for the 2012–13 wet season provided an opportunity for new insights to the snail egg reproduction response to water quality. Further, the observations of higher upstream-than-downstream egg production in Magela Creek and much higher downstream-than-upstream egg production in Gulungul Creek for the first three tests of this season (see section 3.2.3.2) prompted further investigation of water quality influences. As discussed above (section 4.4.1), significant relationships have been observed in previous wet seasons between both water temperature and EC and the snail egg laying response. Hence, the median values of these two water quality variables over the four-day exposure periods of each test were plotted against mean egg number per snail pair for each creek and site to discern patterns (Figure 4.14).

The patterns depicted in Figure 4.14 appear to be consistent with the water temperature response reported previously (section 4.4.1), ie an optimal egg laying response was observed, between 30 and 31°C, after which egg number (in Magela Creek) declined. Lack of any apparent relationship between egg number and EC in Figure 4.14 is masked by an interacting effect of water temperature. To examine the possible enhanced egg production with increasing EC at lower water temperatures but increasingly reduced/negative effect at higher water temperatures, egg number versus EC plots were prepared for these temperature extremes, as shown in Figure 4.15. The plots confirm the earlier findings with statistically significant ($P<0.05$) increase and decrease in egg production with increasing EC observed at lower and higher water temperatures, respectively. With the median water temperatures annotated next to each test (Figure 4.15), it is clear that the EC effects are independent of water temperature.

In light of these results, 2012–13 wet season toxicity monitoring observations may be assessed, in particular, the generally lower downstream (compared to upstream) egg production observed in Magela Creek, and the particularly high downstream (compared to upstream) egg production observed in the first three tests in Gulungul Creek. For this assessment, exemplary data points in Figure 4.14 have been annotated according to creek, test number and site, to aid interpretation.

From Figure 4.14 it is evident that different water temperature regimes prevailed in Magela and Gulungul Creeks over the 2012–13 wet season: median water temperatures were typically between 30 and 32°C in Magela Creek but lower, between 27 and 30°C, in Gulungul Creek. These respective water temperature ranges span either side of the optimal water temperature for the egg laying response observed in this and previous wet seasons, whereby the Gulungul temperature range provides enhanced egg production while the Magela range is typically associated with a reduction in snail egg production.

Further, over the lower (Gulungul) temperature range, increasing EC has historically correlated with increasing egg production while over the higher (Magela) temperature range, increasing EC has historically correlated with decreasing egg production, over the range 10–30 µS $cm^{-1}$ (see section 3.4 of the Supervising Scientist's annual report, 2011–2012). These patterns were affirmed for the 2012–13 wet season (see Figure 4.15). In both creeks and across all tests for the 2012–13 wet season, median water temperature was higher at the downstream monitoring sites.

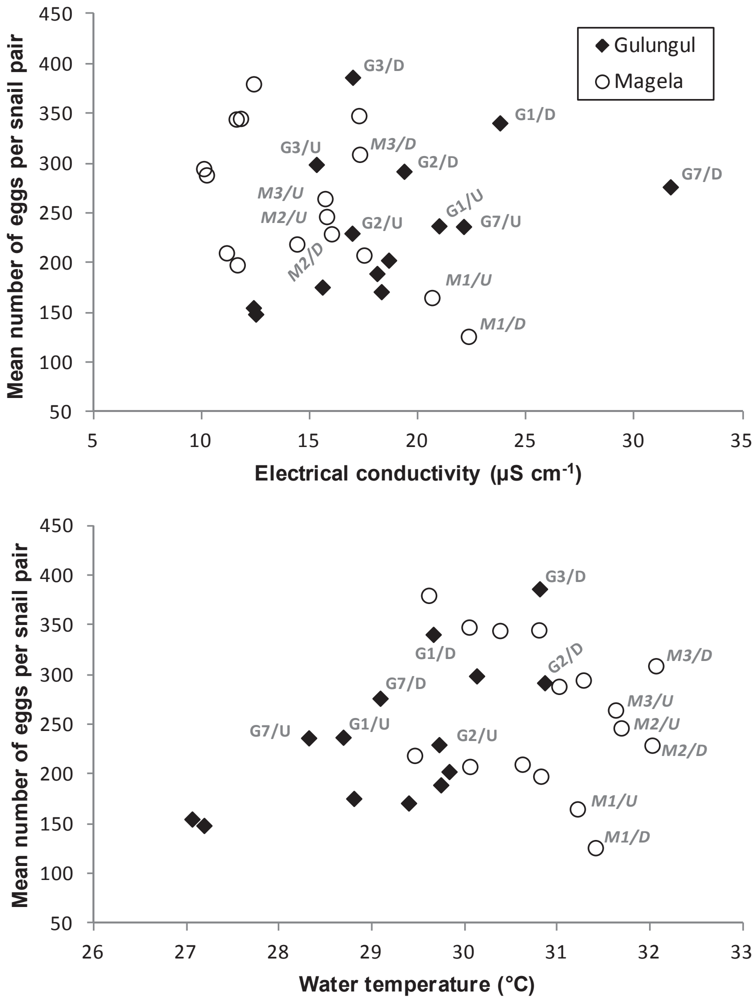


**Figure 4.14** Relationships between mean snail egg number for each creek and site, and ambient electrical conductivity and water temperature over the four-day exposure test periods of the 2012–13 wet season. Selected tests are denoted by annotations, eg M1/D – Magela Creek test 1, downstream site, G7/U – Gulungul Creek test 7, upstream site etc.

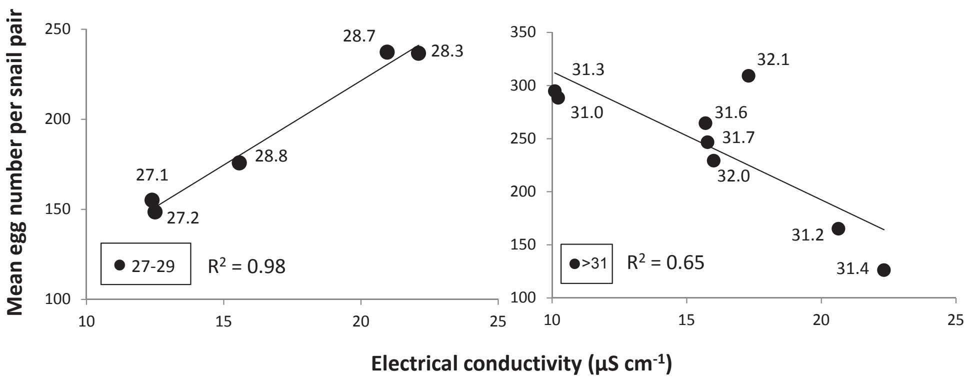


**Figure 4.15** Significant (P<0.05) relationships between mean snail egg number for each creek and site, and ambient electrical conductivity, for specific water temperature ranges (27-29 and >31°C) of the 2012–13 wet season. Annotations are the median water temperatures measured over the four-day exposure test periods.

In the light of these findings and observations, the generally lower Magela, but higher Gulungul, downstream egg production, compared to respective upstream sites, reflects the inhibitory and enhanced effects respectively, associated with the different water temperature regimes in each of the creeks. The higher downstream EC in Gulungul Creek (compared to upstream), in association with 'favourable' water temperature range, would have the effect of exacerbating a stimulatory egg laying response – evident in the first three Gulungul tests (Figure 3.18B). The generally lower downstream egg production in Magela Creek appears to be solely a ('high') water temperature effect, though the first test of the season (M1, Figure 4.14) was also associated with relatively high (natural) ECs for the season.

For only one toxicity monitoring test (the last Gulungul test, Figure 3.18) was the median EC value greater than 25 µS $cm^{-1}$, indicating for both creeks and across the 2012–13 wet season, very limited mine water inputs (see section 3.2.3.1). Thus, the toxicity monitoring results for 2012–13 reflect patterns associated with natural water quality (water temperature, EC) conditions in both creeks. There was no evidence of mine-related effects upon snail egg production over the wet season.

The 2012–13 wet season observations, made under near-natural, but low-flow, water quality conditions, upheld observations made in the previous two wet seasons, thus:

1 A significant (P = 0.05) unimodal relationship was found between water temperature and snail egg number using the combined Magela and Gulungul datasets (Figure 4.14), while the significant interacting effect of water temperature and EC upon snail egg counts in Magela and Gulungul Creeks continued (Figure 4.15).

2 Significant correlation (P <0.05) between variability in the wet season upstream-downstream egg number difference values and the same variability in corresponding upstream-downstream EC difference values was previously shown in the 2011–2012 Supervising Scientist Annual Report (Figure 3.18 of that report). Addition of 2012–13 wet season data points to that dataset (graph not included here) supported and continued that relationship.

### 4.4.4 Conclusions

Toxicity monitoring results for the 2012–13 wet season revealed for the first time the significant influence of snail culturing conditions upon the egg laying response in ensuing toxicity monitoring tests. A measure of how important culturing history is, compared to ambient creek water quality, in determining the magnitude of the egg laying response is possible from the ANCOVA results described above. The proportion of the variation associated with treatments/factors is available from the Sums of Squares column of the ANCOVA (not provided here). Variation in snail egg counts accounted for by culture conditions and ambient creek water quality is associated with factors container type and test order respectively. For these, variation associated with ambient water quality was about 2.5 times greater than culture-type variation. Given that it was not possible in many instances to accurately assign egg count data to culture container type, this proportional estimate of variation may underestimate the true contribution of culture type.

In future wet seasons, attention will be focused on designing a rigorous experimental approach to assessing the influence of husbandry conditions on the snail egg laying response. This design would include at least the current two culturing conditions, it would consider the effects of different seasons in which containers are 'seeded' and established, and it would require that each snail pair used in a replicate egg-laying chamber was sourced from the same culture container type.

The same culturing conditions as used in the 2012–13 wet season were also employed in the 2011–12 wet season, yet the magnitude of egg production observed in the latter wet season was much lower than that observed in the 2012–13 wet season (Figure 3.18). Monitoring staff noted that culturing container establishment for the 2011–12 wet season may have occurred earlier in the 2011 dry season, compared to the following year. Earlier seeding would have coincided with lower water temperatures and would have allowed for establishment of older (and possibly less vigorous-for-size) snails by the time they were required for wet season testing. These hypotheses can be tested in the design of future research studies on this topic.

## 4.5 Radionuclide uptake by wildlife

### 4.5.1 Introduction

The International Commission on Radiological Protection (ICRP) now recognises the environmental exposure of wildlife (ie wild animals and plants) as a distinct exposure category for which it has developed a radiological protection framework. Radiation doses to wildlife from radionuclides released into the environment by human activities should be considered and assessed where the potential for environmental effects exists or where required by legislation to do so. Nuclear fuel cycle activities (including uranium mining) can release significant quantities of radionuclides into the environment and may lead to environmental exposures of wildlife of potential concern.

The radiation dose to wildlife comes from radionuclides both internal and external to the organism. Radionuclides taken up by the organism can account for a significant portion of the dose received. Information on radionuclide activity concentrations within an organism is needed to calculate the internal doses to wildlife.

The uptake of radionuclides by wildlife is typically quantified as the concentration ratio (CR) between the radionuclide activity concentration in the whole organism and that in the surrounding environmental media (eg soil or water). CR integrates radionuclide uptake across all pathways (eg ingestion, inhalation, filter feeding, root uptake, etc) without the need for specific knowledge of the factors affecting uptake. Dose assessment tools for wildlife such as ERICA (Environmental Risk from Ionising Contaminants Assessment and Management) use CRs to estimate radionuclide uptake and calculate internal doses.

CRs for a range of organisms will be needed for wildlife dose assessments for site rehabilitation of the Ranger mine in order to demonstrate compliance with closure criteria for radiological protection of the environment. While generic worldwide CR values have recently been derived by the International Atomic Energy Agency (IAEA) to assist operators and regulators to undertake such assessments, these values may not be representative of radionuclide uptake by wildlife in the ARR. In this context, ***eriss*** has consolidated its data on radionuclide activity concentrations in biota and environmental media into a computational tool to facilitate the calculation of region—and site-specific CRs for use in wildlife dose assessments.

### 4.5.2 Methods

The BRUCE (Bioaccumulation of Radioactive Uranium-series Constituents from the Environment) tool (described in the 2010–11 annual report) was used to calculate CRs for $^{226}$Ra in flesh for freshwater and terrestrial wildlife groups (Table 4.13). CRs were calculated relative to filtered water for freshwater wildlife and relative to soil for terrestrial wildlife. Only water and soil samples that were collected within one year of the organism being collected and from the same location were included in the CR calculation. The flesh CRs were converted to whole organism CRs using conversion factors from the scientific literature. No conversion factor was available for the bird-herbivorous wildlife group and so the conversion factor for mammal-herbivorous was used instead.

### 4.5.3 Results

Figure 4.16 shows whole organism geometric mean CRs for $^{226}$Ra uptake by ARR aquatic and terrestrial wildlife and comparison with the IAEA worldwide generic values.

$^{226}$Ra CRs for ARR aquatic wildlife were generally greater than the IAEA values, particularly for the fishes and mollusc-bivalve (freshwater mussel) wildlife groups. This is believed to be the result of low calcium and magnesium concentrations in water in the ARR. $^{226}$Ra has similar chemical properties to calcium and magnesium, meaning that wildlife 'see' it as an essential nutrient and preferentially take it up from the water column if calcium and magnesium concentrations in water are low.

$^{226}$Ra CRs for ARR terrestrial wildlife were one order of magnitude greater than the IAEA value for mammal-herbivorous and one order of magnitude less than the IAEA value for mammal-marsupial. The mammal-marsupial wildlife group is effectively uniquely

Australian. The IAEA value for $^{226}Ra$ for this wildlife group comes from studies of kangaroos in semi-arid and desert areas in Australia. Higher dust loads in these dry environments are likely to enhance radionuclide uptake via the inhalation and ingestion pathways, resulting in a higher CR than for marsupials (wallaby and bandicoot) in the ARR.

**TABLE 4.13 WILDLIFE GROUPS AND ARR SPECIES INCLUDED IN EACH GROUP**

| Wildlife group | Species |
|---|---|
| ***Freshwater*** | |
| Bird-Herbivorous | Magpie goose (*Anseranas semipalmata*) |
| Crustacean | Shrimp (*Macrobrachium rosenbergii*) |
| Fish-Benthic | Black catfish (*Neosilurus ater*); Ell-tailed catfish (*Neosiluris hyrtlii*); Mouth almighty (*Glossamia aprion*); Sharp-nose grunter (*Syncomistes butleri*); Toothless catfish (*Anodontiglanis dahlia*) |
| Fish-Forage | Archer fish (*Toxotes chatareus*); Banded grunter (*Amniataba percoides*); Black bream (*Hephaestus fuliginosus*); Black-banded rainbowfish (*Melanotaenia nigrans*); Blue catfish (*Arius graeffei*); Bony bream (*Nematalosa erebi*); Chequered rainbowfish (*Melanotaenia splendida inomata*); Fork-tailed catfish (*Arius leptaspis*); Saratoga (*Scleropages jardini*); Sleepy cod (*Oxyeleotris lineolatus*); Spangled grunter (*Leiopotherapon unicolour*) |
| Fish-Piscivorous | Barramundi (*Lates calcarifer*); Long tom (*Strongylura kreffti*); Tarpon (*Megalops cyprinoides*) |
| Insect | Chironomid midge; Dragonfly |
| Mollusc-Bivalve | Mussel (*Velesunio angasi*) |
| Reptile | File snake (*Acrochordus arafurae*); Crocodile (*Crocodylus johnstoni*) |
| ***Terrestrial*** | |
| Mammal-Herbivorous | Buffalo (*Bubalus bubalis*) |
| Mammal-Marsupial | Wallaby (*Macropus agilis*); Bandicoot (*Isoodon macrourus*) |
| Mammal-Omnivorous | Pig (*Sus scrofa*) |
| Reptile-Carnivorous | Olive python (*Liasis olivaceus*) |

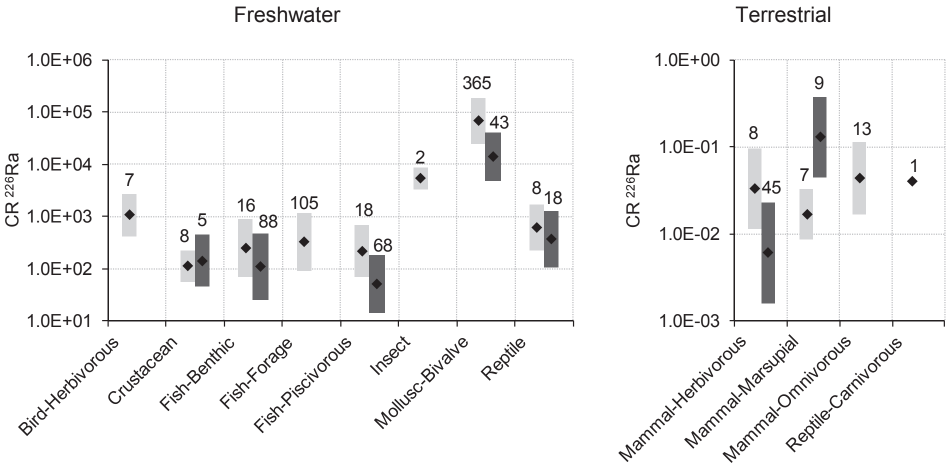


**Figure 4.16** Whole organism CRs for $^{226}Ra$ uptake in freshwater and terrestrial wildlife in the ARR and comparison with IAEA worldwide generic values (black dots indicate the geometric mean value, light grey vertical bars indicate one geometric standard deviation in ARR values, dark grey vertical bars represent one geometric standard deviation in IAEA values, the number above the vertical bar indicates the number of samples on which the geometric mean is based)

### 4.5.4 Conclusions and future work

***eriss*** has consolidated more than 30 years of data on radionuclide activity concentrations in biota and environmental media that can be used to calculate CRs for quantification of radionuclide uptake by ARR wildlife. Comparison of ARR and IAEA whole organism CRs for selected wildlife groups indicates that worldwide generic values can either under- or over-estimate radionuclide uptake by wildlife in the ARR. The implication is that region-specific CRs should be used in wildlife dose assessments for the Ranger mine, as this will help to ensure integrity of the assessment.

From Figure 4.16 it is apparent that ***eriss*** has CRs for $^{226}Ra$ for some wildlife groups not included in the IAEA data summary. This includes bird-herbivorous, fish-forage and insect from the freshwater wildlife groups and mammal-omnivorous and reptile-carnivorous from the terrestrial wildlife groups. ***eriss*** participates in the IAEA MODARIA program (see section 5.3 *The IAEA's MODARIA program*) to help improve global knowledge of radionuclide transfer in the environment and will contribute its CR results for radionuclide uptake by wildlife in the ARR to this program.

***eriss*** currently has more data for aquatic wildlife than for terrestrial wildlife, as indicated by the range of wildlife groups and sample count values shown in Figure 4.16. Rehabilitation of the Ranger mine will lead to the re-establishment of terrestrial habitats for a range of wildlife. Those species which colonise the rehabilitated landform may receive increased environmental exposures from $^{226}Ra$ and other radionuclides. Future work will therefore include: (i) identifying a set of representative organisms for wildlife dose assessment of the rehabilitated landform environment; (ii) determining the radionuclides of importance to the environmental exposure of wildlife on the landform; and (iii) evaluating whether the existing ***eriss*** data are sufficient for assessment or whether additional targeted sampling is required.

## 4.6 Mapping of vegetation and annual variation for 2010–2013 using high spatial resolution multispectral satellite data

### 4.6.1 Introduction

This project involves the mapping for four consecutive years of the vegetation communities within the Magela Creek floodplain, a Ramsar-listed wetland within Kakadu National Park (KNP). The vegetation communities within the floodplain are spatially, seasonally and annually dynamic, but there has been little research of the drivers behind these dynamics. Suitable spatial and temporal scale mapping and analyses of the vegetation communities within the floodplain will provide data that may allow identifying these drivers. It will also inform ecological risk assessment for floodplain management. Current ecological risks are identified as weeds, feral animals and unmanaged wildfire. In addition, the Magela Creek floodplain is a down-stream receiving environment for the Ranger minesite and off-site monitoring of this area will become increasingly important in the years following closure and rehabilitation of the minesite (post 2026). Therefore, time series mapping of floodplain vegetation will provide a contemporary baseline of annual vegetation dynamics on the floodplain to assist with analysing change during and after rehabilitation. High spatial resolution multispectral remotely sensed imagery provides spatially continuous data that is suitable for creating vegetation maps of the floodplain.

### 4.6.2 Method

WorldView-2 multispectral imagery (8 spectral bands) covering the study area has been captured in the early dry season for 2010 (11 May), 2011 (14 May), 2012 (9 June) and 2013 (2 June) at the same time of day (±6 min). The 2010 imagery was geometrically orthorectified to sub-pixel accuracy as reported in section 3.10 of the 2010–11 SSD Annual Report. The 2011, 2012 and 2013 imagery were registered to the 2010 base image. To correct for atmospheric effects and differing off-nadir view angles (including sensor orientation, satellite azimuth and elevation), radiometric calibration of the imagery was undertaken using the Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) atmospheric correction algorithm to convert the at-sensor digital numbers to surface reflectance. The 2013 imagery is yet to be analysed.

Images were classified using a geographic object-based image analysis (GEOBIA) approach, which involves segmenting images into objects based upon spectral and spatial homogeneity and classifying these objects using their inherent spectral and contextual features. The analysis was undertaken using eCognition© image analysis software package. Areas affected by cloud and cloud shadow (only visible in 2010) were eliminated from the image analysis and open water (visible in imagery from all years) was classified by the application of threshold masks based in the near infra-red (NIR) bands. The floodplain boundary was then delineated based on a 6 m threshold applied to a digital elevation model of the region and analysis confined within this boundary. Further image segmentation and classification was based on a series of multi-threshold segmentation algorithms. Objects representing floodplain vegetation community classes were created using a series of rules based upon four spectral indices (Table 4.14). Descriptions of these indices can be found in section 3.9 of the 2011–2012 SSD Annual Report. A series of iterations involving segmentation, classification and reshaping were undertaken to create the class objects, where objects were iteratively partitioned into increasingly spectrally homogeneous objects and classified until an object's index threshold was met (Figure 4.17). This was achieved by analysing object values for the indices and establishing thresholds that achieved maximum separability between classes. Objects that were still spectrally variable were considered to contain two or more classes and subsequently re-segmented and classified. The final classes derived from the index thresholds where then assigned to vegetation community classes based on expert knowledge.

**TABLE 4.14 SPECTRAL INDICES USED IN THIS PROJECT**

$$NDVI = \frac{(NIR2 - Red)}{(NIR2 + Red)}$$

$$EVI^{*} = \frac{G \times (NIR2 - Red)}{(NIR2 + (C1 \times Red) + (C2 \times Blue) + L}$$

$$FDI = NIR2 - (RE + Blue)$$

$$LI = (NIR2 + RE) - Blue$$

where NDVI, EVI, FDI and LI are the Normalized Difference Vegetation Index, Enhanced Vegetation Index, Forest Discrimination Index and Lily Index respectively. NIR2, R and B are the WV-2 near infrared 2 (860–1040 nm), red (625-690 nm) and blue (450-510 nm) bands respectively. *Within EVI, G=2.5, C1=6, C2=7.5 and L=1.

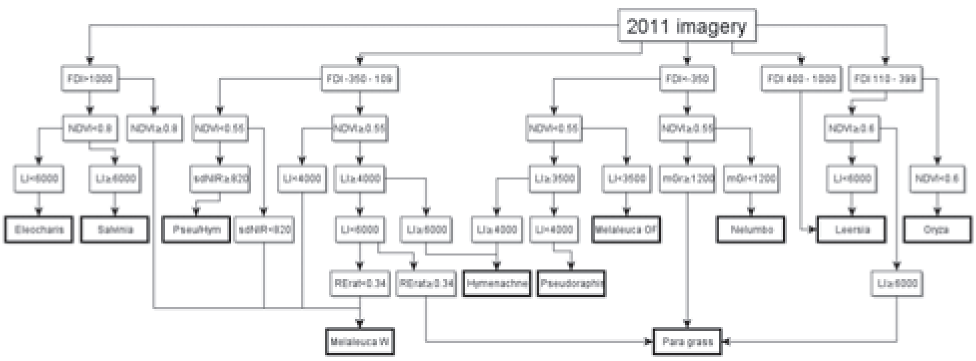


**Figure 4.17** 'Decision tree' for classifying the 2011 imagery. Final classes are highlited by a thicker border. Note: mGr = Mean green band value, sdNIR = standard deviation NIR2 band, and RErat = red edge ratio.

For accuracy assessment purposes, reference data for each year was collected using field and aerial surveys coincident with the image capture dates. Due to accessibility issues and on ground/water safety, vegetation surveys over the floodplain were conducted using a helicopter and airboat for 2010, and helicopter for 2011–2013. Data collected included visual observations and photography, GPS-tagged digital photography (2011–2013) and GPS-tagged HD video (2012–2013). The vegetation classes determined at each sample site were compared to the classified imagery and thematic accuracy measures calculated.

### 4.6.3 Results

Each of the final vegetation community maps (for 2010, 2011 and 2012) consisted of 11 vegetation classes labelled based on the dominant *Genera* for the community (Figure 4.18): *Eleocharis* sedgeland, *Hymenachne* grassland, *Leersia* grassland, *Melaleuca* open forest, *Melaleuca* woodland, *Nelumbo* herbland, *Oryza* grassland, para grass (*Urochloa mutica*), *Pseudoraphis* grassland, *Pseudoraphis/ Hymenachne* grassland and *Salvinia* floating mats. These class types are consistent with the classes identified and mapped previously and the overall accuracies (based on comparison with the reference data) show over 70% for each of the maps. Overall accuracy is calculated by dividing the total number of correctly identified sample sites for all classes by the total number of sample sites.

There is a noticeable increase in surface water from 2010 to 2011, and a reduction from 2011 to 2012 (Table 4.15). The changes in water area are coincident with changes in area for the classes: '*Pseudoraphis*', '*Pseudoraphis/Hymenachne*', '*Melaleuca* woodland' and '*Melaleuca* open forest'. The area for para grass has also increased from 2010–2012 as patches have expanded.

There is a level of uncertainty associated with this analysis. While differences in reflectance can be used to analyse change in vegetation community structure and composition, changes in reflectance are also associated with the relative positions of sun and sensor, the sensor view angle, the amount of aerosols (eg water vapour and smoke) in the atmosphere, the extent of open and surface water and plant phenology. Sun angle probably has minimal influence due to each year's imagery having been captured at the same time of day within a three week bracket. Sensor view angle appears to have more of an influence. There is also a fine although noticeable haze in the 2011 image which may have affected the atmospheric correction algorithm. In addition, communities may not have change in structure or composition however the plants within the community may be in different growth phases due to water availability.

Results of the change analysis indicate that for large areas there was minimal community change; however there are areas that changed composition each year. Much of this change is attributable to varying extent (and potentially depth) of open water which is associated with inter-annual rainfall variability, while some change could be attributed to fire disturbance history.

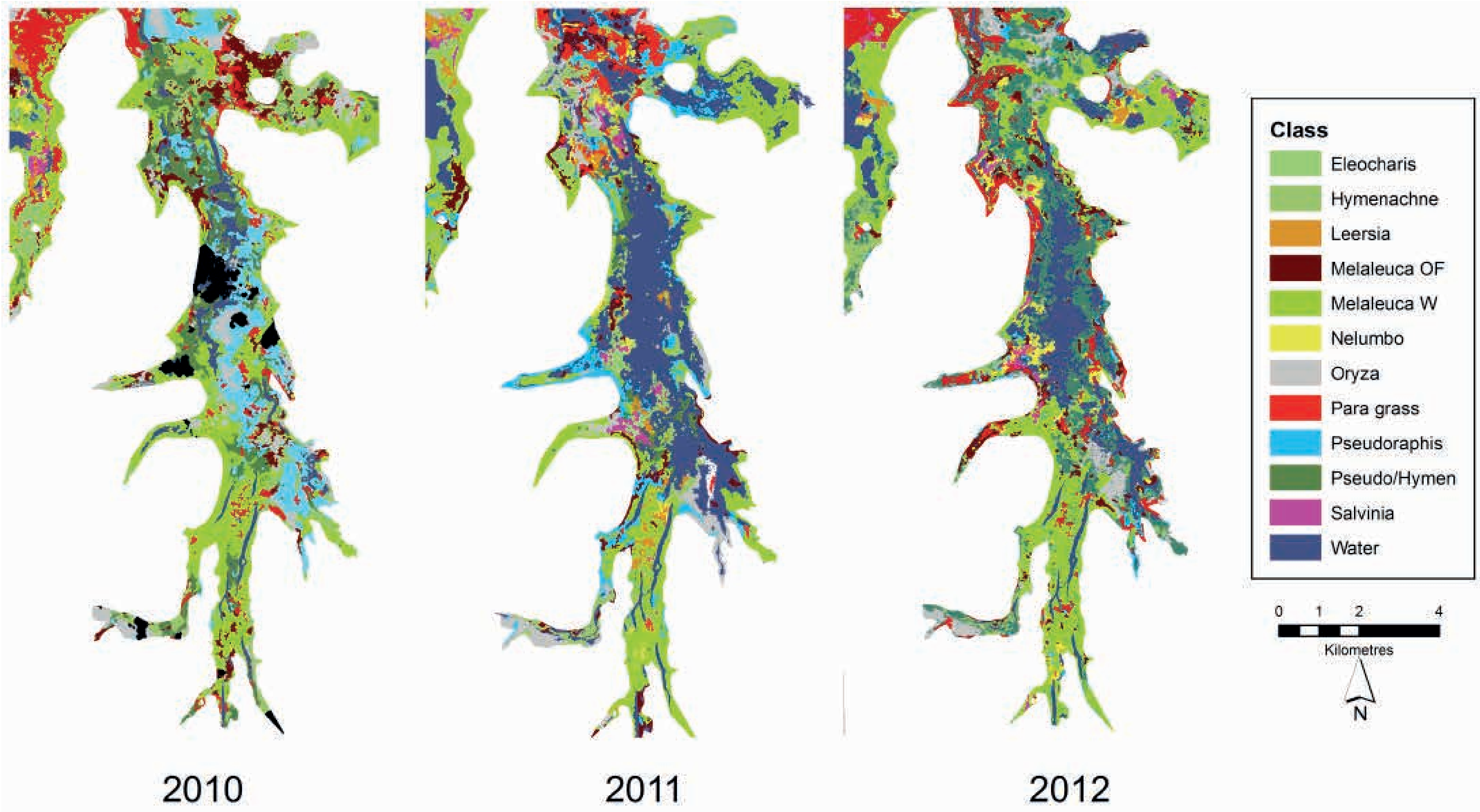


**Figure 4.18** Vegetation maps for the southern portion of the Magela Creek floodplain for 2010, 2011 and 2012 respectively. The *Eleocharis* class was not represented in this region. Black shading in the 2010 image represents cloud or cloud shadow.

**TABLE 4.15 TOTAL AREA (HA) OF CLASSES FOR REGION DISPLAYED IN FIGURE 3.1**

| Vegetation class | 2010 | 2011 | 2012 |
|---|---|---|---|
| *Eleocharis* | 0.0 | 0.0 | 0.0 |
| *Hymenachne* | 557.0 | 518.8 | 348.4 |
| *Leersia* | 32.6 | 172.9 | 40.0 |
| *Melaleuca* open forest | 335.8 | 242.8 | 205.0 |
| *Melaleuca* woodland | 1560.3 | 1250.0 | 1345.3 |
| *Nelumbo* | 26.3 | 62.8 | 143.7 |
| *Oryza* | 395.7 | 285.2 | 287.6 |
| Para grass | 464.8 | 339.7 | 499.1 |
| *Pseudoraphis* | 661.9 | 450.4 | 117.1 |
| *Pseudoraphis/Hymenachne* | 626.5 | 150.3 | 1175.7 |
| *Salvinia* | 32.8 | 79.5 | 65.4 |
| Open water | 382.4 | 1674.4 | 1006.8 |

### 4.6.4 Conclusions and future work

By applying relative measures as opposed to absolute (that is, reducing the reliance on exact values for individual wavelength bands), it was anticipated the segmentation and classification process would be transferrable from one year to the next. On the whole, the described methodology was transferrable with only minor threshold adjustments required.

This project describes the application of the GEOBIA technique to time-series mapping of floodplain vegetation using high spatial resolution imagery. By using a rule-set that included a number of well-known spectral indices and sensor band specific ratios it was possible to segment and classify objects representative of the vegetation communities within the floodplain from the imagery. Comparison with reference data indicate the rule set was able to distinguish the majority of floodplain classes. This method will now be applied to mapping the floodplain vegetation using the imagery acquired for June 2013. The complete time series of maps will enable the annual variation between communities to be tracked, and facilitate identification of the key contributors to the changes that are occurring. Further work will involve some adjustment of class rules to improve the thematic accuracy of the 2010–2012 maps.

Once vegetation maps are available for all dates an object-based change detection algorithm will be used to identify objects that had changed classes between dates. Objects will be identified as either stable (not changing class) or dynamic. Further analysis of the dynamic objects will be undertaken to distinguish between objects displaying actual change (ie a change in class associated with a change in community composition) and change due to either geometric mis-registration between the images, spectral differences associated with differing viewing geometries or phenology, or the presence or absence of water and/or cloud/cloud shadow. From the analyses, three change maps will be created: 2010–2011, 2011–2012 and 2012–2013. The maps include polygons belonging to consistent classes through the dates and polygons where classes had changed (from-to classes) and will be shown in subsequent Annual Reports. This change could then be matched to external variables such as annual rainfall in the region and fire scar mapping for the time frame.

## 4.7 Stressor pathway conceptual models for the operational, rehabilitation and post-rehabilitation phases for Ranger uranium mine

### 4.7.1 Background

Conceptual models of potential stressor pathways associated with uranium mining at Ranger uranium mine have been developed as part of the evolving ecological risk assessment framework that was started by the Supervising Scientist in the early 1980s. Stressor pathway conceptual models for the operational phase of mining were revisited during the mid to late 2000s, and were subsequently completed during 2012-13 (Bartolo et al 2013)[12]. Also during 2012-13, an ecological risk assessment commenced for the rehabilitation and post-rehabilitation phases of Ranger mine (referred to herein as the rehabilitation risk assessment). The rehabilitation risk assessment is a collaboration between ERA, SSD and other key stakeholders, and represents a key activity under the ARRTC Key Knowledge Needs (KKN 2.7.1 – *Ecological risk assessments of the rehabilitation and post rehabilitation phases*). The main activity during 2012-13 was the development of contaminant cause-effect conceptual models for the various key values and phases. This paper provides an overview of the completion of the operational phase conceptual models and the initial development of the rehabilitation conceptual models.

### 4.7.2 Operational phase conceptual models

Progress on the operational phase conceptual models was last reported in the 2010–11 SSD Annual Report. The models and associated narrative have since been completed and compiled in an Internal Report[1]. A total of 31 stressor-pathway models were identified and developed, with a screening analysis indicating that five of the stressor-pathway combinations were of high importance (see *2010–11 SSD Annual Report* for details). An

[12] Bartolo R, Parker S, van Dam R, Bollhöfer A, Kai-Nielsen K, Erskine W, Humphrey C & Jones D 2013. Conceptual models of stressor pathways for the operational phase of Ranger Uranium Mine. Internal Report 612, January, Supervising Scientist, Darwin.

example of a completed stressor-pathway conceptual model is shown in Figure 4.19, for the transport of inorganic toxicants from on-site water bodies to off-site water bodies. These models have been used to identify knowledge gaps and are also informing the recently commenced rehabilitation risk assessment (see Figure 4.19).

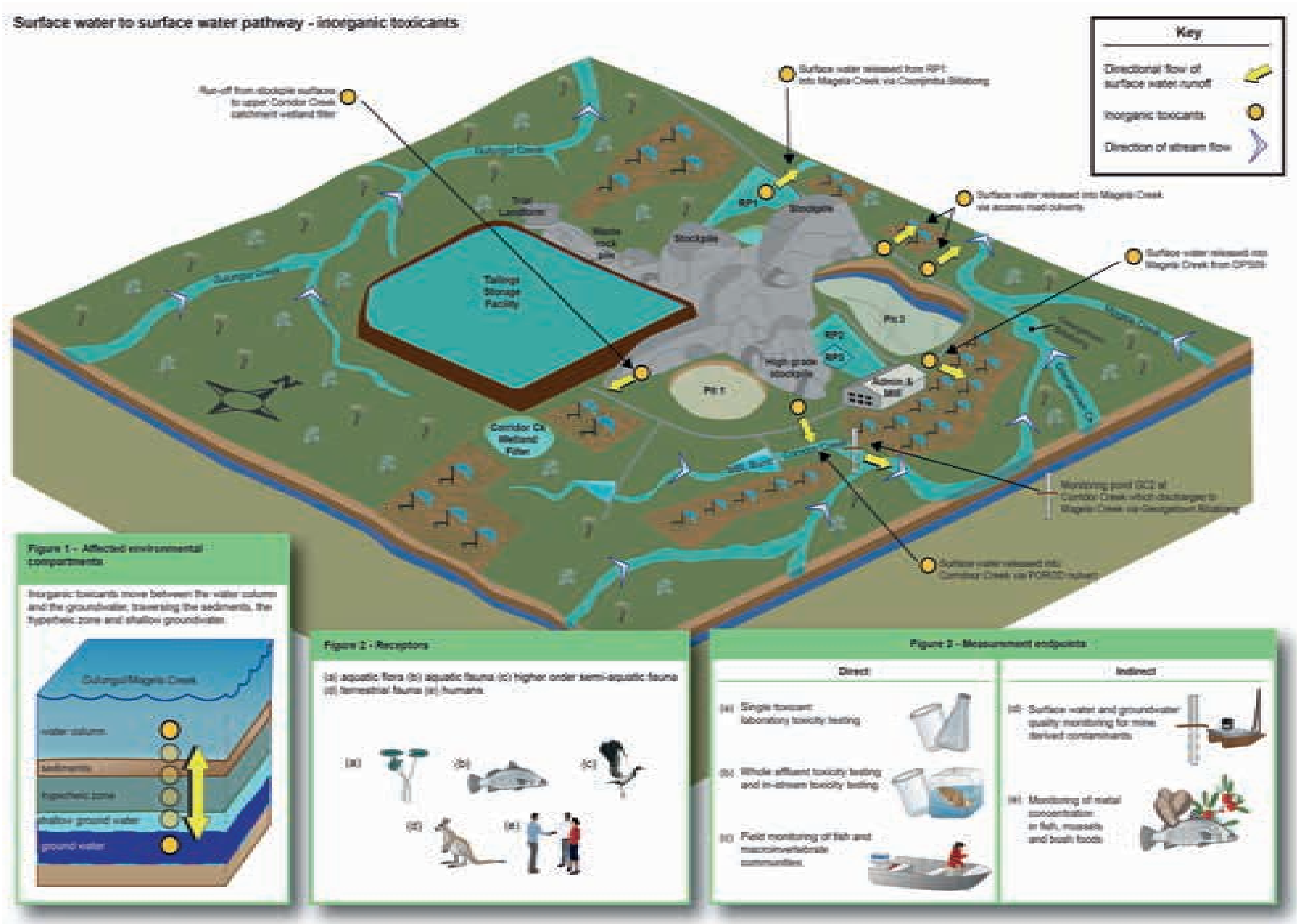


**Figure 4.19**
Conceptual model for the transport of inorganic toxicants from on-site surface water bodies to off-site surface water bodies.[13]

13 Some Symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/)

### 4.7.3 Ecological risk assessment for rehabilitation and closure

ERA is required to rehabilitate Ranger uranium mine by January 2026 and, thus, a large number of research and assessment projects are underway by both ERA and SSD to ensure the necessary knowledge is available to inform the rehabilitation and closure strategy. The rehabilitation risk assessment provides a structured and comprehensive framework for confirming that all the key issues related to ensuring the protection of the off-site environment and successful rehabilitation of the on-site environment are identified.

The rehabilitation risk assessment has been separated into two distinct phases in the first instance:

1 problem formulation

2 risk analysis

The problem formulation phase was largely undertaken in 2012-13, through a stakeholder workshop aimed at developing causal conceptual models for the key stressors and values that can be used in the subsequent phases of the risk assessment. The workshop was facilitated by CSIRO. The temporal and spatial scope of the risk assessment was constrained as follows:

*Temporal scales*

- decommissioning—now to 2026
- stabilisation— decadal: 30, 40, 50 years; considering incorporation into KNP
- long-term post-closure monitoring— shorter term, ~300 years, and longer term, 10 000 years, as per the requirement for tailings to be contained for at least this long

*Spatial scales*

- the Ranger Mine site (disturbed footprint)
- the Ranger Project Area
- the Magela sub-catchment
- the Kakadu National Park and the Alligator Rivers Region

Break-out groups focusing on four key overarching values – aquatic ecosystems, terrestrial ecosystems, human health and cultural landscapes – worked to identify assessment endpoints (ie aspects of the natural and/or cultural landscape that need to be protected or restored) and, for each of these, mine-related stressors and their sources, and measurement endpoints. These elements were combined to form the causal models.

Following the workshop, a sub-group was established to progress the conceptual causal models to ensure appropriateness and consistency in terminology and structure. Table 4.16 lists the current draft assessment endpoints. An example conceptual causal model is shown in Figure 4.20 for the risks to landform stability on the Ranger mine site.

**TABLE 4.16 DRAFT ASSESSMENT ENDPOINTS FOR THE RANGER REHABILITATION RISK ASSESSMENT**

| High level value | Assessment endpoints |
|---|---|
| Protection of off-site aquatic ecosystems | Off-site water quality meets agreed closure criteria specified for water quality<br>Biodiversity (structure and function) of off-site aquatic ecosystems are comparable to the agreed reference condition<br>Habitat diversity of off-site aquatic ecosystems is comparable to the agreed reference condition |
| Restoration/rehabilitation of on-site aquatic ecosystems | On-site water quality is on a trajectory towards meeting agreed closure criteria specified for water quality on-site<br>Biodiversity (structure and function) of on-site aquatic ecosystems are on a trajectory towards meeting agreed closure criteria<br>Habitat diversity of on-site aquatic ecosystems is on a trajectory towards meeting agreed closure criteria |
| Protection of off-site terrestrial ecosystems (Landscape) | Spatial pattern of the landscape in the Magela sub-catchment and broader KNP is comparable to the habitat diversity and ecosystem functions for an agreed reference condition<br>Aesthetic values meet the expectations of the stakeholders in the ARR |
| Restoration/rehabilitation of on-site terrestrial ecosystems (Ranger Project Area) | Erosion characteristics of the rehabilitated landform meet agreed closure criteria<br>Vegetation on the disturbed sites of the RPA is on a trajectory towards meeting agreed closure criteria<br>Wildlife on the rehabilitated site is on a trajectory towards meeting agreed closure criteria |
| Re-creation of a cultural landscape in which traditional owners can resume traditional practices | Landform is able to be accessed, and is traversable, by people<br>Presence of cultural important species at right time and abundance<br>Landform, vegetation and water bodies on-site meet agreed cultural closure criteria<br>Return of traditional practices (eg burning, harvesting) |
| Protection of human health on the rehabilitated site | Radiation doses to people from the rehabilitated site are less than the dose limits<br>Rehabilitation works do not negatively impact on worker safety |
| Protection of human health off the rehabilitated site | Water resources used for drinking continue to meet drinking water limits for mine-derived contaminants<br>Water resources used for recreation continue to meet recreational water quality limits for mine-derived contaminants<br>Radiation doses to people from the rehabilitated site are less than the dose limits |

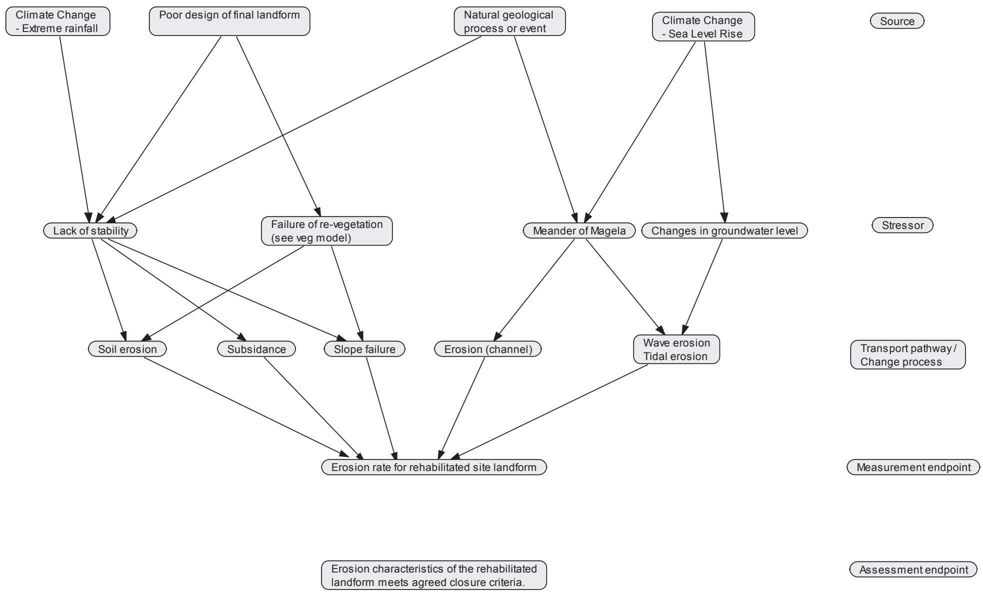


**Figure 4.20** Draft conceptual causal model for risks to landform stability on the Ranger mine site

Once the causal models are finalised, they will be used as the basis for scoping the risk analysis phase of the risk assessment. Moreover, the nature of the models will enable their further development as Bayesian networks for the risk analyses. Bayesian networks are probabilistic graphical networks, which can be used to directly apply the conceptual model from the problem formulation in a modelling platform for quantifying risks and associated uncertainties. The risk analysis phase of the rehabilitation risk assessment will commence in collaboration with ERA in 2013–14.

# 4.8 Initial assessment of the conceptual rehabilitated Ranger landform

## 4.8.1 Introduction

SSD, in collaboration with research partners at the University of Hull (Professor T. Coulthard) and the University of Newcastle (Associate Professor G. Hancock), have carried out an initial assessment of the geomorphic stability of a conceptual rehabilitated landform of the Ranger mine using the CAESAR-Lisflood landscape evolution model (LEM). CAESAR-Lisflood is an enhanced version of the CAESAR LEM that had previously been used to assess the geomorphic stability of the Ranger trial landform. Crucially, this is the first time that CAESAR-Lisflood has been applied to an entire conceptual rehabilitated mine landform. Energy Resources of Australia Ltd (ERA) provided two conceptual landform scenarios to SSD for assessment: the first represented a landform with an additional quantity, or surcharge, of material on the surface of the landform to allow for consolidation of the capped tailings in the pit; and the second a non-surcharged landform representing the final consolidated land surface (Figure 4.21). For the purposes of this study, the digital elevation models (DEMs) of both conceptual landforms (surcharged and non-surcharged) were divided into a series of sub-catchments which were individually modelled (Figure 4.22).

The assessment was divided into two distinct parts. Part 1 focussed on the potential impacts of the consolidation of the Pit 1 landform, and its impact on the catchment of Corridor Creek. Part 2 focussed on the impact of the conceptual landform on the catchments of Djalkmara, Coonjimba and Gulungul creeks. It is important to note that the modelling results reported here assumed that the whole model domain is covered by waste rock material. This condition will be refined in subsequent modelling evaluations following the provision of a more precise distribution of final surface types.

### 4.8.2 Methodology

The application of the CAESAR-Lisflood LEM to the trial landform required the collation and integration of data from a range of different sources. The key data inputs used by the model were a digital elevation model (DEM) for each scenario; rainfall data and surface particle size data.

The DEMs were generated through the integration of two-metre interval contour data (produced from a LiDAR survey of the mine in 2011) with two-metre contours representing the various conceptual landform scenarios to produce a grid surface with a horizontal resolution of two metres. The final DEMs used for modelling purposes were compiled to a horizontal spatial resolution of 10 metres. Ten metres was determined to be the optimal resolution at which the CAESAR-LisFlood LEM could function within the spatial extent of the study catchments, and over the temporal periods modelled.

Rainfall data collected at Jabiru airport over the period 1971–2006 were processed and used to produce a dataset containing 22 years of continuous rainfall data. This dataset was used to produce 2 rainfall scenarios:

1 A 45-year simulation, incorporating two iterations of the 22 year data with the addition of data from an extreme rainfall event from March 2007. In the course of the latter event, 785 mm of rainfall was recorded in the three day period between 27 February and 2 March; rainfall intensity for most durations in this period exceeded a 1-in-100 year storm event.

2 A 1,000 year simulation was run in which the 22-year Jabiru rainfall was looped out to a period of 1,000 years. The 2007 extreme rainfall event was not used in this simulation due to computational limitations.

Grain size data for CAESAR-Lisflood were obtained from size fractionated bulk samples of surface material collected at eight points on the waste rock surface of the Ranger trial landform. Grain size analysis was completed on these samples and the results averaged into nine grain size classes.

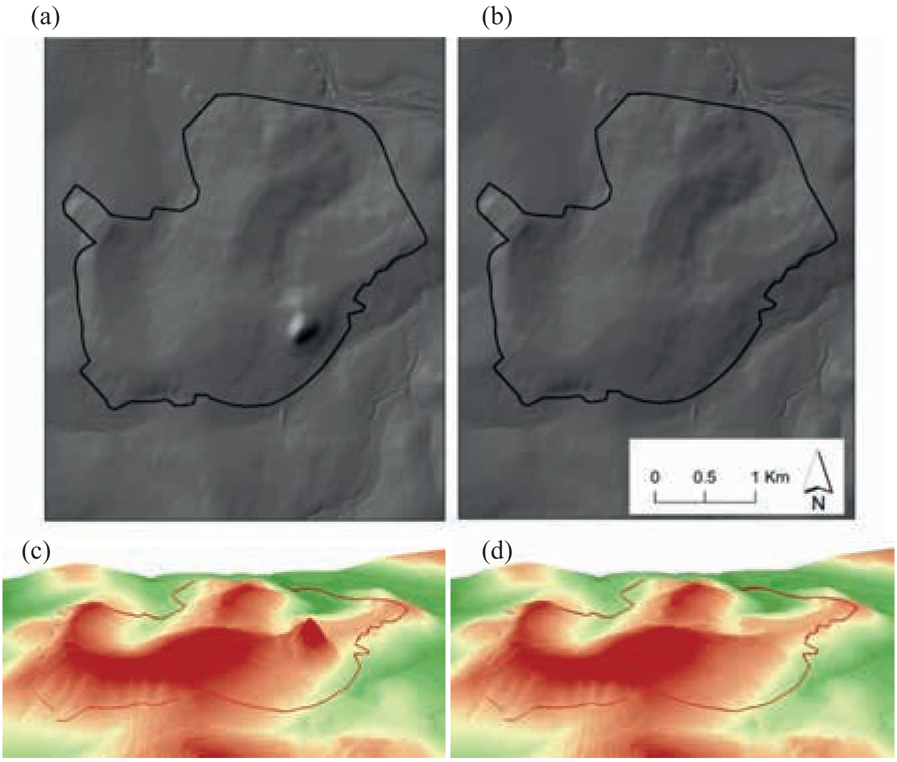


**Figure 4.21** Surcharged (a) and non-surcharged DEMs (b) of the landform. Oblique perspectives of the surcharged and non-surcharged landforms are shown in (c) and (d). The black line represents the boundary of the rehabilitated landform.

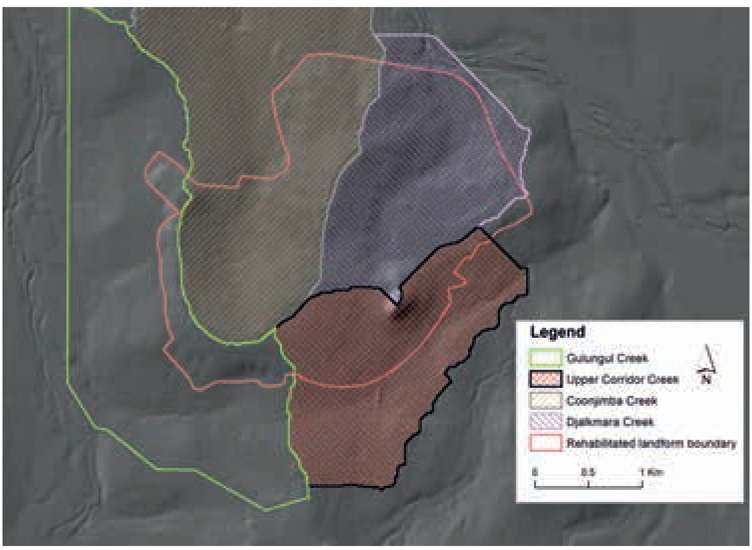


**Figure 4.22** Catchment areas used for assessing the Ranger conceptual landform.

The effect of differential consolidation on the surface of the surcharged landform was done by calculating the depth of tailings fill placed in Pit 1. The depth of tailings was calculated by subtracting the present day LiDAR DEM of Pit 1 (filled with tailings) from a DEM of the unfilled Pit 1 and creating a file of tailings depths. ERA engaged consultants ATC-Williams in 2009 who simulated consolidation over five core depths (30, 60, 90, 120 and 150 m) and provided a point data file for each of these depths. Exponential decay functions were fitted to the consolidation time series data. These functions were then built into the model so that consolidation occurred at the correct rates and extents across the backfilled pit area of the model domain. CAESAR-Lisflood determined the consolidation rates for fill depths between these values by interpolating between the rates for different depths.

Simulations were done on a catchment-by-catchment basis, for vegetated ('best case') and unvegetated ('worst case') scenarios of simulated periods of 45 years and 1000 years. Vegetated scenarios simulated the development of a mature grass community on the landform. In the case of the Corridor and Djalkmara creek catchments, additional simulations were done to investigate the impact of the consolidation of the landform. The 45 year time frame was used to model the evolution of the landform for the duration that consolidation was likely to occur on the landform, whilst the 1000 year time frame was used to provide a longer-term analysis of the landform evolution.

### 4.8.3 Results

The catchments studied in Part 2 produced very different results from the catchment studied in Part 1. Specifically, large scale erosion producing a channel/incised floodplain hundreds of metres wide by tens of metres deep is predicted in the catchments of Djalkmara and Coonjimba catchments over a period up to 1000 years, under both 'best case' (where vegetation is present) and 'worst case' (vegetation absent) scenarios. This is a particular concern in Djalkmara catchment (Figure 4.23), where the predicted path of the channel would pass through the current area of Pit 3, which may contain contaminated material as part of a future rehabilitated landform design.

An example of the sediment load predicted by the model from the conceptual landform, using Djalkmara catchment as an example is shown in Table 4.17. For all catchments, the predictions of sediment load and denudation rate at both the 45 year and 1000 year periods are much higher than published rates for the region, regardless of the presence of vegetation. These results may be partially attributed to the nature of the material being modelled (that is, the assumption that the entire modelled landform was composed of waste rock) and the increased vulnerability of the freshly constructed surface at the beginning of the simulation period. During this initial phase, finer particles within the freshly made landform surface will be preferentially eroded and irregularities in the topography are smoothed, resulting in initially higher sediment yields and denudation rates.

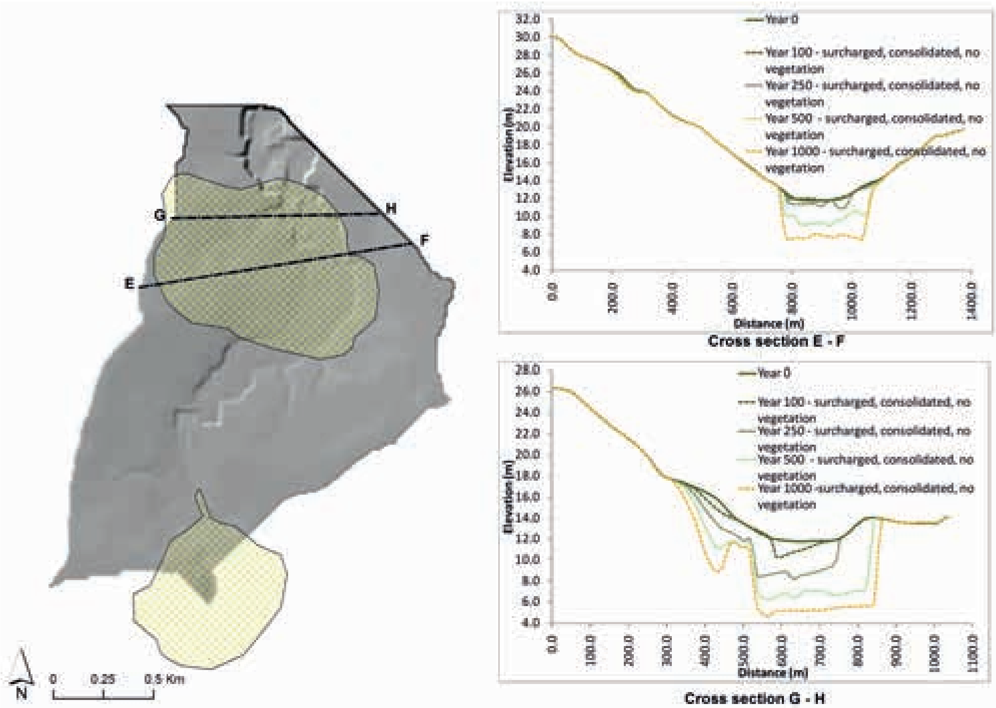


**Figure 4.23** Unvegetated ('worst case') 1000 year surface of Djalkmara Creek catchment. Hatched areas represent current extent of Pit 1 (lower) and Pit 3 (upper).

**TABLE 4.17 SEDIMENT YIELD AND DENUDATION RATES AFTER 1000 YEARS FROM CAESAR-LISFLOOD – DJALKMARA CATCHMENT**

| | Surcharge | | | | No Surcharge | |
|---|---|---|---|---|---|---|
| | Vegetated | | No Vegetation | | Vegetated | No Vegetation |
| | Consolidation | No Consolidation (static) | Consolidation | No Consolidation (static) | | |
| Total Load ($m^3$) | 582365 | 572237 | 3381335 | 3338057 | 546430 | 3522639 |
| Denudation rate (mm $y^{-1}$) | 0.20 | 0.20 | 1.15 | 1.14 | 0.19 | 1.20 |

The relative proportions of the total sediment yield in Djalkmara catchment were representative of the sediment load in all the catchments modelled, with the majority composed of bedload, with a small proportion (10–20%) of suspended material (Figure 4.24). Importantly, the impact of an extreme weather event can also be seen in Figure 4.24, where the rainfall data for the extreme rain event recorded in March 2007 is introduced at the end of the 45 year cycle and can be seen to produce increased sediment loads off the (unvegetated) landform. Clearly, it is essential to have as much data as possible on the magnitude and frequency of such extreme events for future model simulations.

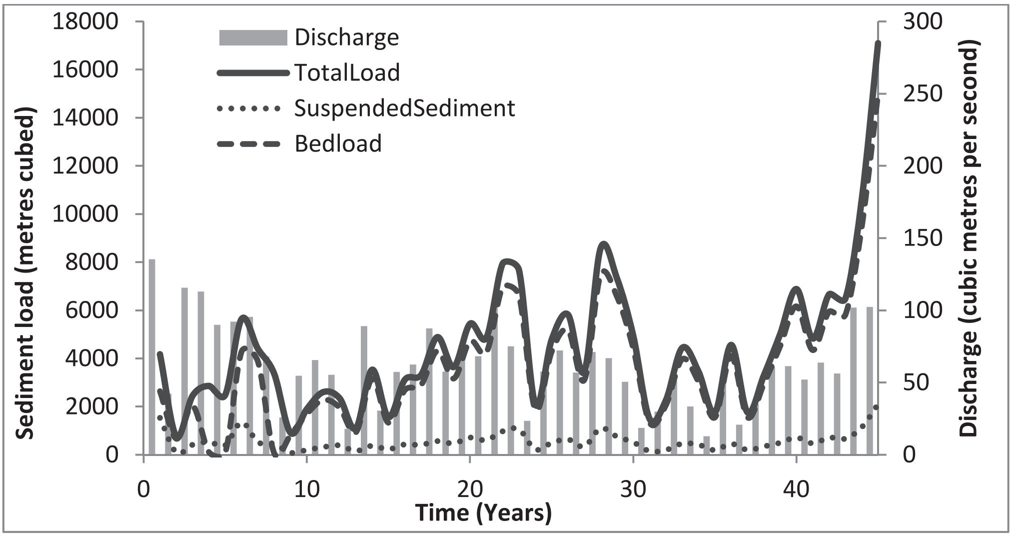


**Figure 4.24** Variation in bedload and suspended load in the unvegetated Djalkmara catchment over the 45 year period. The largest historical storm occurred in year 45.

### 4.8.4 Conclusions and future work

The predictions of the geomorphic stability of the Ranger conceptual landform are prefaced with two important caveats. First, all simulations assumed that the entire surface of the area modelled was composed of the same type of material (waste rock). This is an unrealistic scenario for a final landform, where (1) a proportion of the footprint will comprise natural land surface; (2) erosion control structures including armouring of steeper drainage lines and sediment traps will be in place; (3) lined and engineered catchment drainage lines will be present; and (4) there will be an initial post rehabilitation program of works to correct or remediate any excessive local areas of erosion that occur. Second, it is also recognised that the 'worst case' scenario of an unvegetated landform for a simulated period of 1000 years is unrealistic for the Ranger site. However, it has been retained to provide an example of an extreme worst case.

The study identified several engineering issues which should be considered when designing the final landform, and which may serve to reduce or minimise the erosion predicted. These include reducing the slope within the catchments (thereby reducing the flow velocity and erosive capacity of surface runoff); increasing the elevation and/or armouring areas containing buried materials which need to be protected (ensuring water flows around, rather than through them); and reducing the size of the catchments (reducing the ultimate energy available for erosion and transport).

Future designs submitted for modelling assessment should therefore incorporate erosion control devices, different surface treatment options to reduce sediment yield, and downstream sediment traps to contain eroded material.

The introduction of vegetation into model scenarios was found to reduce total load and denudation rate. Further work needs to be undertaken to quantify the effect of the development of different vegetation communities on erosion rates and to assess approaches to including the potential effects of climate change (eg rainfall event frequency, duration and intensity) in the model runs.

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

## 4.9 Radiological monitoring and assessment at the El Sherana airstrip containment

### 4.9.1 Introduction

The El Sherana airstrip containment is a near-surface disposal facility located in the South Alligator Valley in the south of Kakadu National Park. It contains approximately 22 000 $m^3$ of contaminated waste from the remediation of legacy uranium mining sites in the area. Background on the remediation of legacy uranium mining sites in the South Alligator Valley has been provided in the *Supervising Scientist 2008–09 Annual Report*.

The containment was constructed, filled and covered in the 2009 dry season. It is currently in the institutional control period. This is the period following closure of the facility during which public access to, or alternative use of, the site must be restricted. A boundary fence and warning signs are in place at the containment to restrict access and deter against alternative uses of the site, including camping. Parks Australia has primary responsibility for the containment and is licensed and regulated by ARPANSA for its management of the site.

***eriss*** conducts periodic radiological monitoring at the containment. The purpose is to assess its performance through time, including whether site radiological conditions are stable. A summary of the monitoring results is presented here together with an assessment of expected maximum annual doses for occupational and public exposure scenarios.

### 4.9.2 Methods

***eriss*** has made dry season measurements of external gamma dose rates and radon ($^{222}Rn$) activity flux densities at the containment during the following years:

- 2007 (gamma dose rates) and 2009 (radon exhalation): baseline conditions
- 2010: one year after closure
- 2012: three years after closure.

External gamma dose rates were measured across the containment using environmental dose rate meters. The above background component of the measured gamma dose rate after containment construction was determined by subtracting the mean 2007 baseline gamma dose rate from the gamma dose rates measured in 2010 and 2012.

Radon activity flux densities were measured using brass canisters filled with activated charcoal, which were deployed on the containment for around three days to entrap radon exhaled from the soil surface. The canisters were then collected and sealed for radioactivity analysis. Radon trapped on the charcoal decays and the activity of radon decay products in the canisters is measured using a sodium iodide detector. The radioactivity measurement coupled with the length of the deployment and measurement periods enabled radon activity flux densities from the soil surface to be determined. The above baseline radon activity flux densities were determined by subtracting the baseline from the radon activity flux densities measured in 2010 and 2012.

Soil samples from the top 5 cm were also collected in 2012 from directly underneath the canisters deployed on the containment above the buried waste. This was done to determine the soil $^{226}Ra$ activity concentration, using the ***eriss*** high purity germanium detectors in Darwin, and establish a relationship with radon activity flux density.

### 4.9.3 Results

Figure 4.25 shows the location and magnitude of the 2007 baseline and 2012 gamma dose rate and the 2010 and 2012 radon activity flux density measurements at the containment site overlaid on an aerial photograph of the area from March 2007. The outer white rectangle indicates the approximate location of the boundary fence around the containment. The inner rectangle shows the approximate location of the containment and buried waste.

The baseline gamma dose rate in 2007 was no different to the arithmetic mean measured in 2012 ($0.13\pm0.01\ \mu Gy\cdot hr^{-1}$), thus the above baseline gamma dose rate three years after containment construction was zero. In contrast, the geometric mean radon activity flux density has increased from about 13 $mBq\cdot m^{-2}\cdot s^{-1}$ in 2009 (baseline), to 18 $mBq\cdot m^{-2}\cdot s^{-1}$ in 2010 and 56 $mBq\cdot m^{-2}\cdot s^{-1}$ in 2012, with maxima in excess of 300 $mBq\cdot m^{-2}\cdot s^{-1}$. As $^{226}Ra$ activity concentrations measured in surface soils at the El Sherana containment were low (mean: $23\pm6\ Bq\cdot kg^{-1}$), the increase in radon activity flux was most likely coming from the buried waste, due to changes in the physical properties of the containment cover, caused by roots penetrating into the surface soils or drying and cracking of the compacted clay layer immediately on top of the buried waste.

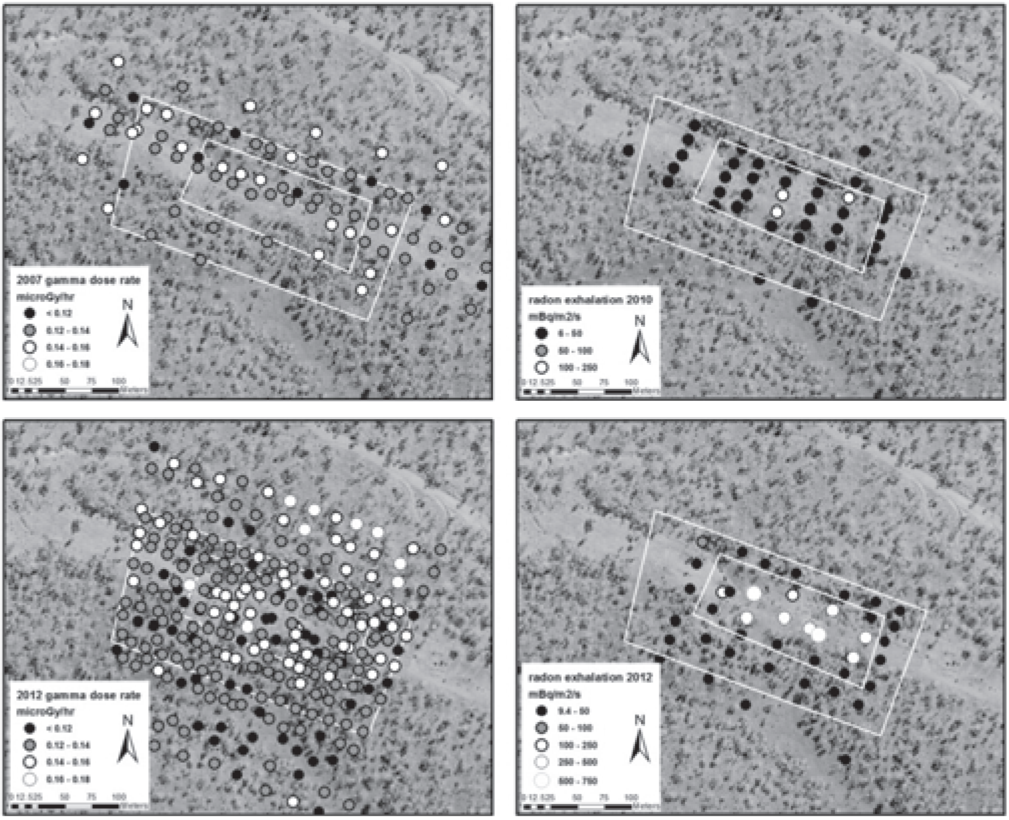


**Figure 4.25** Baseline and 2012 external gamma dose rates [$\mu Gy \cdot hr^{-1}$] and radon activity flux densities [$mBq \cdot m^{-2} \cdot s^{-1}$] measured at the El Sherana containment in 2010 and 2012

### 4.9.4 Dose assessment

Using the 2012 monitoring results, an assessment of expected maximum annual doses has been made for the normal (passive) operation of the containment for occupational and public exposure scenarios. No breach of the surface cover of the containment, either intentionally or by natural processes, has been assumed in the assessment of each scenario.

**Exposure scenarios**

*Occupational*

It was assumed that a Park Ranger spends 80 hours per year working at the containment. Work conducted at the site was assumed to include general maintenance, weed and fire management and downloading in-situ monitoring equipment. Digging into the buried waste or repair of the capping layer or surface cover was not considered in the assessment, as this was not considered to be part of the normal (passive) operation of the containment.

*Public (tourist camping)*

It was assumed that a tourist camped for four nights (40 hours in total) next to the boundary fence of the containment. The camping location was assumed to be immediately downwind of the containment to give the highest possible exposure scenario. No inadvertent or intentional intrusion of the fence was assumed.

*Public (Aboriginal person)*

An exposure scenario for Aboriginal people was not assessed, as anecdotal evidence suggested that they do not spend time in the immediate vicinity of the containment, but rather prefer other sites in the South Alligator Valley for hunting, fishing and camping. The likelihood of exposure of an Aboriginal person was considered negligible.

**Exposure pathways**

The exposure pathways included in the occupational scenario were radon progeny inhalation and external gamma radiation. The only pathway included in the public (tourist camping) scenario was radon progeny inhalation, as external gamma radiation from the containment will be negligible outside the boundary containment fence.

The dust inhalation pathway was not considered in either scenario as the contaminated waste was assumed to be permanently buried under a clay capping layer and clean soil cover, with no breach of the capping layer. Any radionuclides in dust from the soil cover were considered part of the natural background.

The ingestion pathway was not included as bushfoods and locally sourced water were not considered to be consumed in either the occupational or public exposure scenario. Additionally, it is unlikely that any terrestrial plant-based bushfood would be collected onsite by the public, nor is it likely that terrestrial animals (such as wallaby, pig or buffalo) that are sometimes consumed by Aboriginal people would be able to access the site and take up radionuclides from the buried waste due to the presence of the boundary fence during the institutional control period. Groundwater levels are deeper than the buried waste and flow of groundwater from the containment to the South Alligator River is slow (hydraulic conductivities are less than $10^{-7}$ m·s$^{-1}$). Consequently, the ingestion pathway for aquatic bushfoods and water is negligible, at least during the institutional control period.

**Assessment method**

The maximum dose from external gamma radiation was calculated from the 99th percentile of the above baseline dose rate (0.03 µGy·hr$^{-1}$) and time spent onsite. The maximum dose from radon progeny inhalation was calculated using the RESRAD-Offsite computer model, with the 99th percentile of the above baseline radon exhalation flux density (900 mBq m$^{-2}$ s$^{-1}$) used to determine the radon progeny concentration in air on and downwind of the containment for highly stable atmospheric conditions.

**Assessment results**

Table 4.18 gives the expected maximum doses to a park ranger and a member of the public from the containment for the assumed exposure scenarios. The results indicate that in both cases the expected maximum dose from all pathways is less than 10 µSv per year for the current radiological characteristics of the containment. The tourist camping received the higher dose due to radon progeny as it was assumed the park ranger was in the centre of the containment and thereby only exposed to radon expressed from the upwind section, whereas the camper is downwind of the entire containment footprint.

**TABLE 4.18 EXPECTED MAXIMUM ABOVE BACKGROUND ANNUAL EFFECTIVE DOSES (µSv) TO A WORKER AND THE PUBLIC FROM THE CONTAINMENT**

| | Gamma | Inhalation | | Ingestion | Total |
|---|---|---|---|---|---|
| | | Radon progeny | Dust | | |
| Park Ranger | 3 | 1 | 0 | 0 | 4 |
| Public (tourist camping) | 0 | 6 | 0 | 0 | 6 |

### 4.9.4 Conclusions and future work

Our assessment of the maximum above background annual effective doses showed that doses are less than 10 µSv per year for the current radiological characteristics of the containment. This is less than 1 per cent of the public dose limit and of no concern to people working on site or camping in its vicinity. There is some evidence to suggest that radiological site characteristics have changed between 2010 and 2012, allowing more radon to diffuse through and exhale from beneath the containment cover. Further increases in radon exhalation from the site would imply higher maximum expected doses than those given in Table 4.18 and may also indicate further cracking of the containment cover. SSD will continue to monitor the radon activity flux density from the site, to assess whether it increases further or stabilises to a value similar to that measured in 2012.

# 5 OTHER SCIENCE AND TECHNICAL ACTIVITIES

## 5.1 Introduction

In addition to research and monitoring on the impacts of uranium mining in the ARR, SSD also undertakes a significant number of additional activities associated with environmental protection in Australia and overseas related to uranium and other environmental issues. These activities include assisting the Department with EPBC-related approvals and other significant projects, membership on technical committees, collaborative research with other research institutions and participating in international environmental protection activities. A summary of the key activities undertaken during 2012–13 is provided below.

## 5.2 National initiatives for radiation protection of the environment

Two research scientists from the ***eriss*** Environmental Radioactivity program, Dr Andreas Bollhöfer and Dr Che Doering, are involved with ARPANSA-coordinated national initiatives for radiation protection of the environment.

Dr Doering is a member of the Radiation Health Committee working group for development of a safety guide for radiation protection of the environment. The safety guide aims to provide nationally uniform best practice advice to industry and regulators on how to assess environmental impacts from ionising radiation associated with releases of radionuclides. The working group was established in March 2012 and comprises technical experts from both industry and government. The safety guide is currently under development, with an expected completion date in 2014.

Dr Bollhöfer was the expert scientific member of the steering committee for the joint ARPANSA and DRET project to review existing radionuclide activity concentration data in non-human biota inhabiting Australian uranium mining environments. The steering committee was established in November 2011 to provide guidance and strategic directions for the project and to facilitate the collection of data from published and unpublished sources. The review is now completed and results will be published in the ARPANSA Technical Report Series.

## 5.3 The IAEA’s MODARIA program

The International Atomic Energy Agency’s (IAEA) four-year Modelling and Data for Radiological Impact Assessment (MODARIA) programme was launched in November 2012, to continue some of the work of the EMRAS (Environmental Modelling for Radiation Safety) and EMRAS II programmes in the field of radioecological modelling (see 2010–11 Annual Report). Researchers from ***eriss*** have contributed to various EMRAS publications in the past year, including three scientific papers and an IAEA Technical Report, and now continue their input as members in the MODARIA Working Groups.

The overall objective of the MODARIA programme is

> ‘to enhance the capabilities of Member States to simulate radionuclide transfer in the environment and, thereby, to assess exposure levels of the public and in the environment in order to ensure an appropriate level of protection from the effects of ionizing radiation, associated with radionuclide releases and from existing radionuclides in the environment’

It consists of four Themes with ten individual Working Groups (WGs). Of immediate relevance to the Department are Theme 1 (Remediation of Contaminated Areas), which will compare and further develop radionuclide transport models and radiological impact assessment approaches that can be applied to support decision making for remediation of contaminated areas affected by residues from eg the mining industry, and Theme 3 (Exposures and Effects on Biota), which will further develop biota radionuclide transfer models. Dr Andreas Bollhöfer from SSD attended the inaugural MODARIA meeting in Vienna in November 2012, and interim technical meetings of WG3 (Application of models for assessing radiological impacts arising from NORM and radioactively contaminated legacy sites to support the management of remediation),WG4 (Analysis of radioecological data in IAEA Technical Reports Series publications to identify key radionuclides and associated parameter values for human and wildlife exposure assessment) and WG 8 (Biota modelling: Further development of transfer and exposure models and application to scenarios) in May/June 2013. During these meetings he gave three presentations on radionuclide uptake data gathered by SSD over the past 30 years and the monitoring and management of former uranium mining and milling sites in the Alligator Rivers Region.

SSD will continue its involvement with the MODARIA program in 2013/14 to remain informed on best practice developments and policy issues related to (a) the remediation of contaminated sites and recommendations on radiological impact assessment methodologies, and (b) protection of humans and the environment from the harmful effects of ionising radiation. This will also be beneficial to national initiatives supported by the SSD such as the Radiation Health Committee and Australian Radiation Protection and Nuclear Safety Agency sponsored Working Group to develop an Australian ‘Safety Guide on Radiological Clearance/Closure Criteria and Management of Sites Contaminated as a Result of Past and Present Activities’.

## 5.4 Revision of National Water Quality Guidelines

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000) and *Australian Guidelines for Monitoring and Reporting* (2000), constituting Guidelines 4 and 7 of the National Water Quality Management Strategy, respectively, are currently undergoing a targeted revision. These guidelines represent key source information in Australia and New Zealand for managing natural water quality and protecting aquatic ecosystems. SSD continued to support the revision activities through the technical coordinator roles of ***eriss*** research scientists, Dr Rick van Dam and Dr Chris Humphrey, and the hosting of the revision project coordinator, Ms Kate Dixon. During 2012–13, the detailed scoping of the projects was undertaken, and some revision projects were commenced. These included: developing an ecoregionalisation and aquatic ecosystem schema for Australia, for guideline population; updating the toxicant trigger value derivation software package, Burrlioz; developing a revised method for deriving toxicant trigger values; providing guidance on the use of ecogenomic techniques for monitoring and assessment; and finalising the revised sediment quality guidelines. ***eriss*** will continue to work with DSEWPaC's Water Reform Division during 2013–14 to progress the revision activities.

## 5.5 Basslink

Two SSD staff, Dr Chris Humphrey and Dr Mike Saynor, as Australian Government representatives on the Gordon River Scientific Reference Committee (GRSRC), provided comment on the 2011–12 Gordon River Basslink Monitoring Annual Report which evaluated the monitoring program after the sixth year of Basslink operations.

## 5.6 National Environmental Research Program (NERP)

The National Environmental Research Program (NERP) being managed by DSEWPaC replaces the Commonwealth Environment Research Facilities (CERF) program and focuses more on biodiversity and improving research delivery to the Australian Government, other end-users and stakeholders. Researchers from ***eriss*** are collaborating in the NERP Northern Australia Hub.

A number of the research themes and projects within the NERP Northern Hub are focused in Kakadu National Park. ***eriss*** staff, Dr Renée Bartolo is collaborating on projects in the 'Aquatic Biodiversity Conservation' and 'Biodiversity Monitoring and Reporting' themes. ***eriss*** staff managed the delivery of LiDAR data for the floodplains of the Alligator Rivers Region, to NERP researchers. Dr Tim Whiteside also supplied an updated Magela Creek floodplain vegetation map to NERP researchers. See section 4.6 for more information about the vegetation mapping project.

## 5.7 Kakadu Research Advisory Committee

The leader of the Spatial Sciences and Data Integration Group, Dr Renée Bartolo, is a member of the Kakadu Research Advisory Committee (KRAC). Members of the committee are appointed by the Parks Board of Management to advise the Board and the Director of National Parks on strategic research issues and priorities required to support the socio-cultural and biophysical management objectives for the Park. During the reporting period, Dr Bartolo provided advice to Parks Australia staff through the KRAC.

## 5.8 EPBC compliance audits

***oss*** staff did not participate in the conduct of any compliance audits against approval conditions issued under the *Environment Protection and Biodiversity Conservation Act* 1999 in this reporting period.

## 5.9 Rum Jungle Technical Working Group

The Rum Jungle legacy uranium and copper mine site is located close to the town of Batchelor, approximately 80 km south of Darwin. In 2008, the Rum Jungle Technical Working Group (RJTWG) was formed to progress and implement:

- environmental maintenance activities
- continuation of appropriate environmental monitoring programs
- development of contemporary site rehabilitation strategies for the site

The group comprises representatives from DME, NRETAS, Australian Government Department of Resources, Energy and Tourism (DRET), NLC and SSD. Mr Alan Hughes (Supervising Scientist) and Dr David Jones (Director ***eriss***) represented SSD up until their departures in April 2013 and November 2012 respectively. Mr Richard McAllister (Acting Supervising Scientist) and Dr Rick van Dam (Acting Director ***eriss***) continue to represent SSD following the departure of Mr Hughes and Dr Jones.

An allocation of $7 M of special purpose funds was made in the 2009 Federal Budget to progress assessment of the site over a period of four years. The program of work is being managed by DoR under the terms of a 'National Partnership Agreement (NPA) between DME and the Australian Government Department of Resources Energy and Tourism. The ultimate objective of the work is to develop a costed rehabilitation plan consistent with contemporary best practice. The RJTWG provides technical advice and oversight of the projects commissioned to address the terms of the National Partnership Agreement (NPA). Background material and project updates have been published by DME on the website that has been created to inform members of the general public about the progress of activities carried out under the NPA: www.nt.gov.au/d/rumjungle. Further funding has been sought for the next 3 years for the continuation of the work undertaken by the NPA.

During 2012-13, SSD attended four meetings of the RJTWG, reviewed and provided comment on various drafts of the Conceptual Rehabilitation Plan, and Environmental Values reports, and sampling reports undertaken by consultants. The SSD was also heavily involved in the Multiple Accounts Analysis of all the potential rehabilitation options and the selection of the preferred strategy for closure. This preferred strategy provided the basis for the submission for further funding for the NPA.

## 5.10 Advice to SEWPAC's expert panel for major coal seam gas projects

The Australian Government plays a role in regulating coal seam gas proposals which could have a significant impact on matters protected by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This includes Matters of National Environmental Significance (MNES), actions involving the Commonwealth and actions taken on, or impacting on, Commonwealth land.

To help inform the Government's role, the former Minister approved the appointment of the Expert Panel for Major Coal Seam Gas Projects in March 2011, to provide him with advice on the three Queensland coal seam gas projects approved under the EPBC Act. Those projects include the Queensland Curtis LNG project, the Santos Gladstone LNG project, and the Australia Pacific LNG project. The Expert Panel provides advice on the adequacy of water management plans which the companies must submit under the conditions of approval.

***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford, have continued to provide specialist ecotoxicological advice to the Expert Panel in relation to the potential for hydraulic fracturing chemicals and fluids from proposed coal seam gas operations to impact on relevant Matters of National Environmental Significance. This role is expected to continue in 2013–14.

## 5.11 Developing toxicity testing methods for tropical marine species

A review by ***eriss*** and Australian Institute of Marine Science (AIMS) research scientists in 2008[14] identified a lack of laboratory-based methods for assessing the effects of contaminants on Australian tropical marine species. In 2012–13, funding was secured from Rio Tinto alumina and aluminium operations, the Northern Territory Research and Innovation Board and the Northern Australian Marine Research Alliance to undertake a three year project to develop such methods. ***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford, are collaborators on the project in conjunction with scientists from AIMS, Charles Darwin University and Rio Tinto.

Key outcomes in the first year of the project included: (i) the establishment of an operational marine culturing aquarium at AIMS' research facility in Darwin; (ii) associated culturing of various marine species for assessing their suitability for toxicity testing purposes; and (iii) the development of a reliable test method for the tropical unicellular alga, *Isochrysis galbana*, and subsequent assessment of the toxicity of aluminium. In 2013–14, the research team will proceed with further toxicity test development and subsequent assessment of the toxicity of aluminium, gallium and molybdenum.

## 5.12 Other contributions

Supervising Scientist Mr Alan Hughes was (until his departure in April 2013) a member of the Mt Todd Minesite Rehabilitation Reference Group established by DME. The group has not met since April 2013. Mr Richard McAllister is the nominated member in his capacity as Acting Supervising Scientist. The Supervising Scientist provides an independent scientific perspective to the group which is a community consultative forum for discussing environmental management issues at the Mt Todd minesite near Katherine. Meetings of this group are typically held annually following the wet season.

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[14] van Dam RA, Harford AJ, Houston MA, Hogan AC & Negri A 2008. Tropical marine toxicity testing in Australia: A review and recommendations *Australasian Journal of Ecotoxicology* 14(2/3), 55-88.

Mr Hughes continued to be a member of the Water Resources Review Panel under the NT *Water Act* during 2012–13 until his departure in April 2013. The Review Panel advises the Controller of Water Resources and the Minister in assessing the number of appeals regarding licensing decisions against Water Allocation Plans and Bore Construction Permit Refusals in the Northern Territory.

Dr Wayne Erskine is collaborating with Dr Anita Chalmers, Plant Ecologist, of the School of Environmental and Life Sciences, The University of Newcastle, Ourimbah, NSW on dendrochronological potential of Australian native riparian trees and on structure and function of Melaleucas on Gulungul Creek, Ranger Mine Lease.

Dr Erskine is also collaborating with Drs John Tilleard and Tony Ladson of Moroka Pty Ltd and Dr Michael Cheetham of Earth Tech Pty Ltd on a project for the Goulburn-Broken Catchment Management Authority (Victoria) on the geomorphic basis of river management problems on the Yea and Acheron Rivers and their tributaries.

# 6 COMMUNICATION ACTIVITIES

## 6.1 Introduction

SSD keeps its primary stakeholders (mining companies, Traditional Owners, government and NGOs) informed about supervisory, research and monitoring activities through indigenous consultation, statutory committees, assessment and reporting. SSD also engages with the general public through school-based apprenticeships, intermittent employment for ad-hoc/ seasonal projects, displays and exhibits at festivals, school visits (to the Jabiru Field Station) and community publications.

Communication with academic and research organisations is also prioritised in the context of SSD remaining at the forefront of research in its relevant fields, and being a desirable research partner.

General SSD communications activities are coordinated through the Office of the Supervising Scientist while communication with indigenous stakeholders and the community is managed by the Jabiru-based Community Liaison Officer (CLO) in conjunction with other SSD staff.

SSD community engagement activities in the ARR during 2012–13 included display booths at the Mahbilil Festival and the 30th Birthday of Jabiru, school talks and participation in a careers expo, interactive informal information sessions on country with local traditional owners, a series of presentations to Kakadu district rangers and hosting visits to the Jabiru Field Station. These activities assist in strengthening SSD's relationships with local indigenous stakeholders, non-governmental environmental groups and the general public.

Other activities undertaken in the reporting period included hosting visits from interstate and international delegates and conference participation and presentations for professional development.

The SSD website is another important means of raising community awareness of the work of the Division and providing public access to the Division's scientific data and reports, such as the results of SSD's research and environmental monitoring programs.

## 6.2 Communication with the public including local community and students

SSD is committed to providing employment and training to local indigenous people. During 2012–13, SSD was once again a host employer for Group Training Northern Territory (GTNT) trainees studying through Charles Darwin University. This year, two indigenous trainees were employed at the Jabiru Field Station under the scheme. Associated with this, Jabiru Field Station was nominated as a finalist in the Host Employer of the Year Category for the 2013 GTNT Awards.

Our first indigenous trainee commenced in 2009 as a school-based apprentice completing the qualification of Conservation and Land Management (CaLM) certificate II. He became a full-time SSD employee and is in the final stages of completing his CaLM certificate III.

Our most recent trainee from the community of Mamukala in Kakadu National Park started a school-based apprenticeship this year. She is also studying for a CaLM certificate II and has helped with recessional flow monitoring projects and infrastructure management.

Employment of Indigenous people for activities such as field research provides SSD staff the opportunity to work alongside landowners on their country, sharing knowledge and gaining greater insight into traditional cultural values. It is also provides an opportunity for indigenous people to gain valuable technical skills and a greater understanding of how SSD does its work. Regular meetings between SSD's Jabiru-based Community Liaison Officer (CLO) and the Gundjeihmi Aboriginal Corporation (GAC) are held to facilitate this interaction. Matters addressed in these meetings include employment, day labour payment details and updating of GAC's employment register. The CLO delivers specially tailored inductions sessions addressing the role of the Division, workplace health and safety, and emergency procedures to facilitate employment with SSD.

SSD has a focussed 'closing the loop' strategy for communicating to the local Aboriginal people the findings from the monitoring and research projects carried out in the region. For example, the same water chemistry control charts that are posted on the SSD website are taken by the Community Liaison Officer (CLO) to Indigenous communities in the ARR to show the levels of uranium and other elements measured in the local creeks. Explanation of the significance of the levels and any observed upward variations is provided to local residents in a 'hands-on' practical manner. In addition, the CLO maintains regular informal contact with Indigenous communities in the Region including the Mirarr people – the traditional owners of the land on which Ranger and Jabiluka lie This provides greater opportunity to communicate our role and function, and helping us keep the local communities well informed about our monitoring and research programs.

The CLO also regularly liaises with the broader ARR stakeholder group, including Energy Resources of Australia Ltd (ERA) community relations staff, Parks Operations and Tourism Branch staff, local Indigenous corporations and the Northern Land Council to ensure there is a continuous supply of information on current and proposed SSD activities. Consultation also occurs with local people to explain SSD projects and seek permission to carry out research on indigenous land, and with Park Operations and Tourism to advise when and where SSD will be carrying out research activities within Kakadu National Park (see section 5.2.3).

## 6.3 Communication with primary stakeholders including technical advisors and Traditional Landowners

Two meetings of the ARRAC and two meetings of the ARRTC were held during the period. Indigenous stakeholders and the traditional owners of Kakadu National Park are also kept informed on SSD activities through the involvement of GAC and NLC on these committees. Further information on ARRAC and ARRTC is provided in Chapter 2 of this report.

As detailed in the 2011–12 Annual Report, a focus for liaison activities continues to be informing Kakadu National Park Rangers about the work that SSD has been doing, and about work that is planned to occur in their specific regions. This communicates at a local level the material contained in the PAN-***eriss*** protocol submission each year (see 6.4 below).

SSD hosted a booth at the Mahbilil Festival held in September 2012 in Jabiru. The festival is held in late August to September when the afternoon breezes increase and large numbers of magpie geese gather across the wetlands to lay their eggs. Mahbilil is the Gundjeihmi name of a myth related to the afternoon breeze that occurs in Gurrung (the local calendar name for that time of year). The SSD displays focussed on water and air monitoring, spatial science and mapping and research being conducted on the trial landform rehabilitation landform at Ranger.

Locals and visitors alike browsed the displays and discussed with our staff various aspects of SSD's role. It is important that SSD continues to have a presence at the Mahbilil event to respond to general community concerns that might not otherwise be raised.


**Figure 6.1** SSD staff engaging with a member of the public at the Mahbilil Festival


**Figure 6.2** Staff at the SSD stall for the Jabiru 30th Birthday

Similarly, SSD also hosted a display at the 30th Birthday of Jabiru held in July 2012. Locals and tourists were engaged by a display of historical photos, audio visual demonstrations and some early monitoring equipment. Further information on SSD's monitoring and research programs was provided by the experienced Jabiru Field Station staff that were looking after the display.

Each year Parks Operations and Tourism Branch, in conjunction with the West Arnhem College, runs a Junior Ranger Program for school children. The program runs for the school year and the students attend weekly activities, excursions and lessons. One of the lessons aims to teach the Junior Rangers about research and monitoring. SSD's Jabiru Field Station traditionally provides the tutorial and venue. Once again, good use was made of the Division's macroinvertebrates in providing a practical basis to achieve the aims of the lesson.

World Wetlands Day is held on 2 February each year. This year SSD and Parks organised street stalls to celebrate the day and highlight the importance of wetlands and the significance of the Magela floodplains as a recognised wetland under the international Ramsar Convention.

SSD hosted a stall at a Schools Careers Expo in September 2012 in the Jabiru Town Hall. This was a good opportunity to promote SSD's scientific activities, showcase the Division as a future employer and provide reassurance about environmental issues.

All of the above activities served to enhance awareness and understanding of the work and role of SSD and to maintain the Division's profile within the local and wider community.

## 6.4 Research protocols for Kakadu National Park

Details of proposed 2012–13 SSD research and monitoring activities within Kakadu National Park were submitted to Parks Australia and the Northern Land Council in April 2013 as required under the revised protocols agreed by the Director of National Parks and the Supervising Scientist in 2008.

The protocols define working arrangements for effective and timely communication between ***eriss*** and Parks Australia staff, the Kakadu Board of Management and Traditional Owners in relation to ***eriss*** research and monitoring activities within Kakadu National Park.

## 6.5 Internal communication

SSD currently nurtures an open exchange of information amongst staff within the Division, and in a broader context, within the Department.

The Division supports effective internal communication between staff of all levels through regular staff and section meetings. Various working groups are also convened as required to address important strategic business issues within the Division. Staff awareness of the results of SSD scientific research activities is maintained through monthly seminars with both internal and external speakers from relevant fields outside the Division.

The ***eriss*** Research Innovations Group (established in August 2011) continued holding regular meetings that aim to explore and test new ideas to support scientific research and next generation leadership within SSD. Within the reporting period, the group identified and implemented a number of initiatives to improve the research culture and related business processes at SSD. These included improving internal business and research systems (such as the establishment of an electronic literature database) and strengthening linkages both within SSD and externally (via collaborations with relevant research institutions).

IiP (Investor in People) activities undertaken during 2012–13 are described in Chapter 7.

## 6.6 Science communication (including conferences)

Results of research and investigations undertaken by SSD are made available to key stakeholders and the scientific and wider community through publication in journals and conference papers, and in a range of in-house reports. In-house productions include the Supervising Scientist Report and Internal Report series (for detailed reporting on scientific projects), and other media such as posters and educational material to suit specific requirements or events.

In addition, a number of the Division's staff contribute to external scientific, technical and other professional organisations, including various editorial boards and panels.

The complete Supervising Scientist Report series is available in PDF format on the SSD website. The move towards electronic distribution supports the Department's policy of reducing its environmental footprint. The website subscription facility, which incorporates an automatic email notification when a new SSD publication is released, continues to improve the level of service to our stakeholders.

A full list of papers and reports published during 2012–13 is provided in Appendix 2. Papers presented at National and international conferences are listed in Appendix 3.

In February 2012, DSEWPaC began the process of redeveloping the department's website, including SSD's website. The system will be upgraded to a modern content management system while continuing to meet its intended legal and communication objectives. SSD staff were trained in the new system and carried out an audit and update of the SSD section of the website, due to be complete in the 2013-14 financial year.

SSD hosts researchers and visitors from other organisations to undertake collaborative funded projects, for sabbatical periods, or to present seminars or training workshops (Table 6.1).

In 2012–13, ***eriss*** staff supervised one post-graduate research project:

- The effect of multiple Mg pulses on tropical freshwater species with an emphasis on recovery and carry over toxicity (Honours, RMIT University, to be completed December 2014)

SSD staff presented papers at a number of national and international conferences during the reporting period as described in Table 6.2.

Participation in international events allows staff to share their knowledge and expertise with peers and maintain awareness of international best practice in relevant areas. Participation is also seen as important in ensuring SSD maintains its profile as a part of the broader scientific and technical community.

**TABLE 6.1 RESEARCHERS AND OTHER VISITORS, 2012–13**

| Activity | Visitor/organisation | Date |
|---|---|---|
| Assessing geomorphic stability of the Ranger capped Pit 1 landform using the CAESAR landform evolution model | Professor Tom Coulthard, University of Hull | 25 June – 6 July 2012 |
| Support/advice re assessment of conceptual rehabilitated landform using SIBERIA landform evolution model | Associate Professor Greg Hancock, The University of Newcastle NSW | 2–6 July 2012 |
| Presentation on the Australian National Radiation Dose Register | Dr Robert Guilfoyle, ARPANSA, Melbourne | 25 July 2012 |
| Erosion monitoring/modelling activities (Tin Camp Creek) | Associate Professor Greg Hancock, The University of Newcastle NSW | 9–17 August 2012 |
| Soil hydraulic measurements on landslides on Oenpelli Dolerite in Arnhem Land with a PhD student (collaboration with Physico-Chemical Processes group project on the significance of landslides as a sediment source in the ARR) | Dr Andy Fourie, University of Western Australia | 13–16 August 2012 |
| Finalise paper with EnRad staff & present 'Developments in Radiological Impact Assessment for Radon' to SSD | Dr Paul Martin, ARPANSA, Melbourne | 15 August 2012 |
| Study tour in Australia with interest in Ranger Uranium Mine and environmental management | Students of University of Vienna | Sepember 2012 |
| SSD hosted separate brief visits from delegations of officials from the Governments of Thailand and Vietnam' | Various International delegates | Oct–Dec 2012 |
| Discussion and training in the use of the RESRAD-Offsite computer modelling software | Dr Mat Johansen, ANSTO, Sydney | 17–18 April 2013 |
| Working on a journal publication with EnRad staff on measurement of $^{228}Ra$ in environmental samples | Dr Paul Martin, ARPANSA, Melbourne | 12 June 2013 |
| Discussion of existing collaborative work on toxicity of saline mine waters and potential future opportunities. | Associate Professor Monique Gagnon, Curtin University | 13 June 2013 |
| SSD co-hosted (with Parks Australia North) officials from Timor Leste | Delegates from Timor Leste | 21 June 2013 |

| TABLE 6.2 CONFERENCE PRESENTATIONS | |
|---|---|
| **Conference** | **Place/date (no. Papers)** |
| Life-of-Mine 2012 Conference | Brisbane, July 2012 (1 paper) |
| 2nd Society of Environmental Toxicology and Chemistry (SETAC) – Australasia Conference | Brisbane Qld, July 2012 (3 papers, 3 posters) |
| 16th Australasian Remote Sensing and Photogrammetry Conference | Melbourne, August 2012 (1 paper) |
| ARPS 2012, 37th Australasian Radiation Protection Society (ARPS) conference | Sydney, October 2012 (2 papers) |
| SPERA 2012, 12th South Pacific Environmental Radioactivity Association (SPERA) conference | Sydney, October 2012 (5 papers) |
| AusIMM International Uranium Conference | Darwin, NT, June 2013 (2 papers) |

# 7 ADMINISTRATIVE ARRANGEMENTS

## 7.1 Human resource management

### 7.1.1 Supervising Scientist

The Supervising Scientist is a statutory position established under the *Environment Protection (Alligator Rivers Region) Act 1978*. Section 8 of the Act requires that the Supervising Scientist be engaged under the *Public Service Act 1999*.

Mr Alan Hughes was appointed to the position in December 2005. Mr Richard McAllister was appointed to the position in an acting capacity on April 2013 following Mr Hughes departure on long service leave prior to his proposed retirement from the Department in February 2014.

### 7.1.2 Structure

SSD consists of two branches, ***oss*** and ***eriss***.

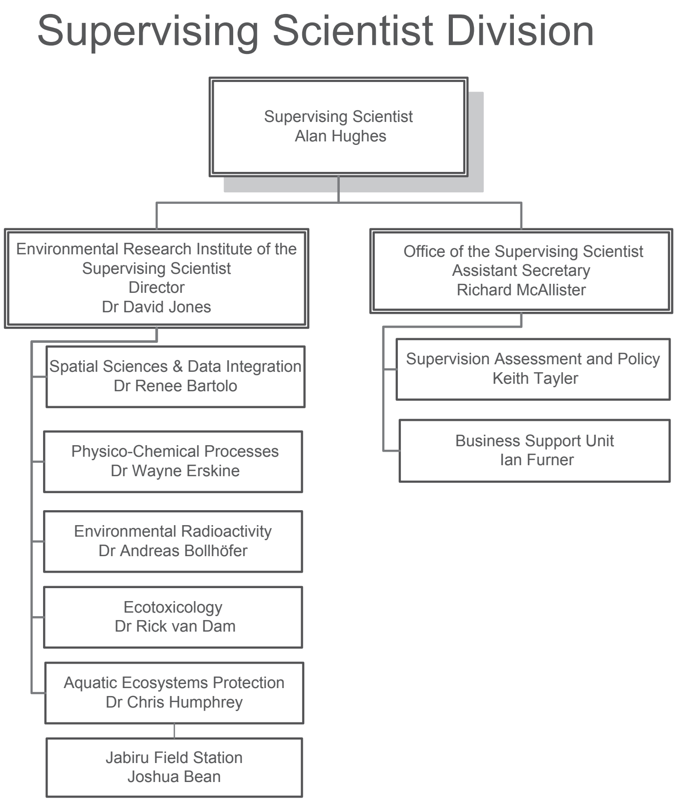


**Figure 7.1** Organisational structure of the Supervising Scientist Division

The ***oss*** is responsible for supervision, assessment, policy, information management and corporate support activities. Mr Richard McAllister, Assistant Secretary, was the ***oss*** Branch Head until April 2013 when he assumed the role of acting Supervising Scientist. The position of Assistant Secretary ***oss*** has been vacant since April 2013.

***Eriss*** is responsible for scientific research and monitoring activities and was headed by Dr David Jones until his retirement in November 2012, when Dr Rick Van Dam assumed the role of acting head of ***eriss***.

Average staffing numbers for 2011–2012 and 2012–2013 are given in Table 7.1.

**TABLE 7.1 STAFFING NUMBERS (1) AND LOCATIONS**

| | 2011–2012 | 2012–2013 |
|---|---|---|
| Darwin | 43 | 40 |
| Jabiru | 7 | 7 |
| Total | 50 | 47 |

(1) Average full time equivalent from 1 July to 30 June

### 7.1.3 Workforce management

SSD has a well established human resource management framework that strives to achieve continuous improvement in workforce capability, retention of staff and achievement of business outcomes. The framework is supported by a proactive performance development scheme with targeted learning and development aligned to achieving business outcomes.

The SSD Investors in People (IiP) program is an important part of the framework. The IiP program is led by a representative Action Group with participation from management and staff from each work program. The group meets regularly to discuss human resource issues with the aim of reviewing, developing and promoting new initiatives and strategies that contribute to improved performance and workforce capability.

The SSD leadership group encourages and supports staff to build capability through on-the job training, coaching and mentoring, delivering papers at scientific conferences, and attendance at identified training courses, conferences and internal seminars. Staff are also provided opportunities to act in higher level positions – this prepares them for advancement and supports the Division's succession plan. Through the Performance Development Scheme, staff identify training requirements to help deliver their work plan outcomes. Courses for project management, performance management, diversity in the workplace, work, health and safety, electronic records management and specialist software applications have been held in-house to assist with staff development. SSD staff have access to Canberra-based seminars and information sessions. Locally-hosted seminars, in addition to the SSD Internal Seminar Series, provide staff with a range of topics relevant to SSD business activities.

SSD is also committed to the training and development of indigenous and non-indigenous trainees. SSD acts as a host employer and provides on-the-job training and mentoring whilst trainees enrol and complete a qualification in a course aligned with their on-the-job duties. During 2012-13 SSD engaged a new school base apprentice completing a Certificate II in Business; had one trainee successfully complete a Certificate IV in Business and obtain an on-going position with SSD; and engaged a new trainee who is also completing a Certificate IV in Business. SSD has also supported the continuation of a trainee to complete their Certificate III in Lands Conservation and Management during 2012–13.

The SSD Jabiru Field Station was nominated as a finalist for the GTNT Host Employers Awards for 2012 for their commitment in developing and training young local indigenous trainees.

Facilitation of continuous improvement is achieved through the implementation of periodic staff surveys enabling the Department and each Division within the portfolio to gain insight into staff perceptions on the Department's performance against various workplace indicators. SSD has addressed staff concerns through development and implementation of a Divisional Improvement Plan that incorporated strategies to:

- improve communication and respect in the workplace
- promote health, wellbeing and work life balance initiatives
- encourage effective performance management
- recognise staff contribution.

Effective communication has also been an integral part of achieving outcomes set by the organisation. SSD continued to produce a fortnightly staff newsletter, *Newsbrief*, that attracts a wide range of internal contributors and readership. Management and staff participate in regular structured meetings that ensure information flow within the organisation is maintained. Healthy lifestyle and social activities coordinated by IiP representatives and Social Club members also enable staff to network in an informal manner.

During 2012-13, the health and wellbeing program offered staff access to vaccinations for influenza, hepatitis and tetanus, team pedometer challenges and meditation and relaxation classes. Internal health and wellbeing seminars on the department's EAP program, mental health awareness and stress management have been well attended by staff. SSD has also supported Cancer Council fund raising events to raise awareness on cancer associated health risks.

## 7.2 Work Health and Safety

SSD continued to maintain a strong commitment to Work Health and Safety (WHS) during 2012–2013 following the introduction of the new WHS Act on 1 January 2012. SSD has gradually transitioned to the new WHS terminology and is progressively replacing references to OHS with WHS in policies, procedures and general operations. SSD again achieved a 'zero harm' rating for another year with no workplace compensation claims submitted since February 2010. The SSD WHS Manager was also seconded to other areas of the department to assist with development of WHS policies and procedures.

The Work Health and Safety Committee (WHSC) met regularly and was responsible for reviewing and updating a number of guidelines including the WHS management plan, boat handling procedures, crocodile safety, fieldwork operations, movement of dangerous goods and the chemical management plan.

All Health and Safety Representatives (HSRs) attended the Comcare accredited training to ensure qualifications were current with the new WHS legislation.

All senior managers (accompanied by a HSR) conducted WHS site inspections (which occur every three months) to ensure they take an active role in WHS and to enhance their understanding of workplace hazards and the safety concerns of staff. Identified potential hazards not addressed within a specified time at the work group level are subject to a formal escalation process. This has significantly improved the times for resolution of hazards with over 95% of tasks completed within 30 days and the balance monitored and risk managed.

In 2012–13, safety education for staff focused on:

- flu vaccinations
- materials handling equipment operation
- preventing bullying and harassment
- handling and packaging dangerous goods
- 4WD training for all terrain vehicle operation
- Workplace Contact Officers (WCO)

Quarterly reports were provided to the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) in conformance with requirements to confirm SSD's general control, safety and management plans of radioactive and non radiation source holdings.

## 7.3 Finance

SSD is part of the Australian Government Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) and full financial statements for the Department are contained in the Department's annual report (www.environment.gov.au/about/publications/annual-report/index.html).

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

**TABLE 7.2 SUMMARY OF DIRECT PROGRAM EXPENSES**

| PBS Outcome 5 | 2011–2012 | 2012–2013 |
|---|---|---|
| **Program 5.2 – Environmental Regulation** * | $9 224 731 | $9 192 765 |
| Total* | $9 224 731 | $9 192 765 |

* Excludes departmental corporate overheads of $4 942 246 in 11–12 and $5 012 737 in 12–13.

# 7.4 Facilities

## 7.4.1 Darwin facility

The majority of SSD staff are situated at the SEWPaC Darwin facility adjacent to the Darwin International Airport. This facility consists of office accommodation and laboratories. During the year major works to install a dehumidification system to rectify long standing problems with air-conditioning and moisture intrusion into the laboratories were finally completed.


**Figure 7.2**
Dehumidification unit installed and functioning

The office space, library and amenities are shared with Parks Australia, which is also part of the Department of Sustainability, Environment, Water, Population and Communities.

## 7.4.2 Jabiru Field Station

The primary function of the JFS is to support the activities of the SSD in the Alligator Rivers Region. JFS staff are a multi-disciplinary team that implement environmental monitoring programs, community extension activities, local administrative and financial management, and the management of assets and minor plant at JFS and related temporary accommodation. The JFS Manager has overall responsibility for managing the Field Station as well as supervisory and inspection responsibilities.

Infrastructure works undertaken by JFS in 2012–13 include: installation of new monitoring pontoon in Georgetown billabong; conversion of old conference kitchenette into a sediment laboratory and set up of radon exhalation experiment.

**Figure 7.3** The new sediment laboratory at Jabiru Field Station.

## 7.5 Information management

Information management activities provided support to staff based in Darwin and the Jabiru Field Station through library services and the co-ordination of records management. In addition to the provision of routine services, library activities have focused on further reducing the SSD Library collection and working towards integration of the collection into the Department's catalogue and eventual decommissioning of the current SSD Library. Records management activities included paper file creation and maintenance, destruction of records in accordance with National Archives procedures, and transfer of selected records to commercial storage. During 2012-13 SSD has been working closely with the department to move to an electronic document record keeping system for all SSD records.

## 7.6 Interpretation of Ranger Environmental Requirements

Section 19.2 of the Environmental Requirements of the Commonwealth of Australia for the Operation of the Ranger Uranium Mine provides for the publication of explanatory material agreed to by the major stakeholders to assist in the interpretation of provisions of the Environmental Requirements. No explanatory material was published during 2012–13.

## 7.7 Ministerial directions

There were no Ministerial Directions issued to the Supervising Scientist under Section 7 of the *Environment Protection (Alligator Rivers Region) Act 1978* during 2012–13.

## 7.8 Environmental performance

SSD contributes to the Department's sustainability objectives through a range of measures aimed at continuously improving the environmental performance of our business operations and minimising any associated environmental impacts. The Division reports on its environmental performance in the Department's 2012–13 Annual Report.

### 7.8.1 Environmental Management System

The Department has committed to extend the scope of its Environmental Management System (EMS) and associated certification to SSD in the future. In the interim, SSD's operations are conducted in a manner consistent with the Department's aim to minimise the ecological footprint on the environment. This involves a range of strategies including complying with legal and other agreements, actively promoting sustainable work practices, preventing pollution as result of work practices, focus on continuous improvement, public reporting of environmental performance as part of the Department's annual report and procurement and use of sustainable goods and services.

## 7.9 Animal experimentation ethics approvals

***eriss*** seeks the approval of Charles Darwin University's Animal Ethics Committee (AEC) to undertake scientific experiments involving vertebrate animals. The Animal Welfare Branch of the Northern Territory Government grants the ***eriss*** premises a licence to use animals for research purposes. This licence includes the laboratories in Darwin and Jabiru, as well as field work conducted in the Alligator Rivers Region. Since April 2011, the CDU AEC has begun issuing permits to persons involved or employed by a licensee conducting a teaching or research program.

A final report for the project 'Larval fish for toxicity tests at ***eriss***' (ref no 97016) was submitted to CDU AEC and approved on 2 August 2012. A renewal application for this project (now A12028) was granted in September 2012 and a progress report will be submitted in September 2013. Individual permits for ***eriss*** staff conducting research with fish were also granted at this time but two new staff members applied for licences during July 2013. This project is due for renewal during August 2014 and the individual permits are valid for two years. The number of fish used in toxicity tests at ***eriss*** was reported in July 2013 to the Northern Territory Government, as part of our licence requirements granted by them permitting the use of animals for research purposes.

The project 'Monitoring mining impact using the structure of fish communities in shallow billabongs' (A12007) was not undertaken for the 2012–13 wet season and as such no fish were sampled. Fish were observed for the project 'Fish community sampling in channel billabongs around Ranger mine using boat visual census'. Approvals for these projects were granted by CDU AEC on 22 February 2012 and will expire on 22 February 2014. Individual permits for ***eriss*** staff conducting research with fish were also granted at this time. Progress reports for these two projects were submitted on 8 February 2013 and approved on 27 February 2013.

Table 7.3 provides information on new applications, renewals of approvals and approval expiries for projects during 2012–13.

**TABLE 7.3 ANIMAL EXPERIMENTATION ETHICS APPROVALS**

| Project title | Ref no | Initial submission | Approval/latest renewal | Expiry |
|---|---|---|---|---|
| Larval fish toxicity testing at ***eriss*** | A12028 (previously 97016) | 26 May 1997 | 2 August/ September 2012 | 2 September 2014 |
| Monitoring mining impact using the structure of fish communities in shallow billabongs | A12007 (previously A09001) | 25 Sep 2000 | 27 Feb 2013 | 22 Feb 2014 |
| Fish community sampling in channel billabongs around Ranger mine using boat visual census | A11034 | 22 Feb 2012 | 27 Feb 2013 | 22 Feb 2014 |

# APPENDIX 1 ARRTC KEY KNOWLEDGE NEEDS: URANIUM MINING IN THE ALLIGATOR RIVERS REGION

## Overall objective

To undertake relevant research that will generate knowledge leading to improved management and protection of the ARR and monitoring that will be sufficiently sensitive to assess whether or not the environment is protected to the high standard demanded by the Australian Government and community.

## Background

In assessing the Key Knowledge Needs for research and monitoring in the Alligator Rivers Region, ARRTC has taken into account current mining plans in the region and the standards for environmental protection and rehabilitation determined by the Australian Government. The assumptions made for uranium mining operations in the region are:

- mining of uranium at Ranger is expected to cease in about 2012. This will be followed by milling until about 2020 and final rehabilitation expected to be completed by about 2026;
- Nabarlek is decommissioned but has not reached a status where the NT Government will agree to issue a Revegetation Certificate to the mine operator. Assessment of the success of rehabilitation at Nabarlek is ongoing and may provide valuable data for consideration in the design and implementation of rehabilitation at Ranger;
- Jabiluka will remain in a care and maintenance condition for some years. ERA, the project owner, has stated that further mining will not occur without the agreement of the traditional owners; and
- grant of an exploration title at Koongarra is required under the terms of the *Aboriginal Land Rights (Northern Territory) Act 1976* before the mining company can apply for a mining title. As such, any future activity at Koongarra is subject to the agreement of the traditional owners and the Northern Land Council.

This scenario is considered to be a reasonable basis on which to base plans for research and monitoring, but such plans may need to be amended if mining plans change in the future. ARRTC will ensure the research and monitoring strategy is flexible enough to accommodate any new knowledge needs.

The Australian Government has specified Primary and Secondary environmental objectives for mining at Ranger in the Ranger Environmental Requirements. Similar standards would be expected for any future mining development at Jabiluka or Koongarra.

Specifically, under the Ranger Environmental Requirements (ERs):

> The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:
>
> (a) maintain the values for which Kakadu National Park was inscribed on the World Heritage List
>
> (b) maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (ie the wetlands within Stages I and II of Kakadu National Park)
>
> (c) protect the health of Aboriginals and other members of the regional community, and
>
> (d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

With respect to rehabilitation at Ranger, the Ers state that:

> The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.

The Ers go on to specify the major objectives of rehabilitation at Ranger as follows:

> (a) revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of 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
>
> (b) stable radiological conditions on areas impacted by mining so that the health risk to members of the public, including traditional owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area
>
> (c) erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas

A secondary environmental objective applies to water quality and is linked to the primary Ers. This ER states:

> The company must not allow either surface or ground waters arising or discharging from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.

While there are many possible different structures that could be used to specify the Key Knowledge Needs, ARRTC has chosen to list the knowledge needs under the following headings:

- Ranger – current operations
- Ranger – rehabilitation
- Jabiluka
- Nabarlek
- General Alligator Rivers Region

# 1 Ranger – Current operations

## 1.1 Reassess existing threats

### 1.1.1 Surface water transport of radionuclides

Using existing data, assess the present and future risks of increased radiation doses to the indigenous population eating bush tucker potentially contaminated by the mining operations bearing in mind that the current traditional owners derive a significant proportion of their food from bush tucker.

### 1.1.2 Atmospheric transport of radionuclides

Using existing data and atmospheric transport models, review and summarise, within a risk framework, dose rates for members of the general public arising from operations at the Ranger mine.

## 1.2 Ongoing operational issues

### 1.2.1 Ecological risks via the surface water pathway

Off-site contamination during mine operation (and subsequent to decommissioning – refer KKN 2.6.1) should be placed in a risk-based context. A conceptual model of the introduction, movement and distribution of contaminants, and the resultant biotic exposure (human and non-human) has been developed, and the ecological risks (ie probability of occurrence x severity of consequence) of some of the contaminant/pathway sub-models have been estimated. This process should be completed for all the contaminant/pathway sub-models, noting, however, that the level of effort for each needs to be proportionate to the level of concern of the issue. It is critical that robust risk assessment methodologies are used, and that they explicitly incorporate uncertainty in both the assessment and subsequent decision making processes. Where ecological risk is significant, additional information may be required (eg mass-balance and concentration dynamics, consideration of possible interactive effects, field data). Further, knowledge gaps preventing reasonable estimation of potential risks (ie with unacceptable uncertainty) must be filled.

The Magela floodplain risk assessment framework developed to estimate and compare mining and non-mining impacts should be revisited periodically, and updated to the current risk profile. It should be revised in the event that either **(i)** the annual monitoring program or other sources indicate that the inputs from mining have significantly increased relative to the situation in 2005, or **(ii)** an additional significant contaminant transport pathway from the minesite is identified, or **(iii)** there is a change in external stressors that could result in a significant increase in likelihood of impacts from the site.

### 1.2.2 Land irrigation

Investigations are required into the storage and transport of contaminants in the land irrigation areas particularly subsequent to decommissioning. Contaminants of interest/concern in addition to radionuclides are magnesium, 144ecquere and manganese. Results from these investigations should be sufficient to quantify the role of irrigation areas as part of satisfying KKN 1.2.1, and form the basis for risk management into the future.

### 1.2.3 Wetland filters

The key research issue associated with wetland filters in relation to ongoing operations is to determine whether their capacity to remove contaminants from the water column will continue to meet the needs of the water management system in order to ensure protection of the downstream environment. Aspects of contaminant removal capacity include (i) instantaneous rates of removal, (ii) temporal performance – including time to saturation, and (iii) behaviour under 'breakdown' conditions – including future stability after closure. Related to this is a reconciliation of the solute mass balance particularly for the Corridor Creek System (see KKN 1.2.5).

### 1.2.4 Ecotoxicology

Past laboratory studies provide a significant bank of knowledge regarding the toxicity of two of the major contaminants, uranium and magnesium, associated with uranium mining in the ARR. Further studies are scheduled to assess (i) the toxicity of manganese and, potentially, ammonia (in the event that permeate produced by process water treatment will contain potentially toxic ammonia concentrations), and (ii) the relationship between dissolved organic matter and uranium toxicity. This knowledge should continue to be synthesised and interpreted, within the existing risk assessment framework (refer KKN 1.2.1), as it comes to hand.

An additional issue that needs to be addressed is the direct and indirect effects on aquatic biota of sediment arising from the mine site. In the first instance, a conceptual model needs to be developed (building on the relevant components of the conceptual model developed under KKN 1.2.1) that describes the movement of sediment within the creek system, including the associated metal-sediment interactions and biological implications. Studies likely to arise from the outcomes of the conceptual model include:

- the effects of suspended sediment on aquatic biota;
- the relationship between suspended sediment and key metals, and how this affects their bioavailability and toxicity; and

- the effects of sediment-bound metals to benthic biota, including, initially, a review of existing information on uranium concentrations in sediments of waterbodies both on- and off the Ranger site, and uranium sediment toxicity to freshwater biota.

Whilst of relevance at present, the above issues will be of additional importance as Ranger progresses towards closure and rehabilitation (refer KKN 2.6.1). Finally, the need for studies to assess the toxicity of various mine waters (treated and untreated) in response to specific supervisory/regulatory or operational requirements is likely to continue.

#### 1.2.5 Mass balances and annual load limits

With the expansion of land application areas and the increase in stockpile sheeting that has occurred in concert with the expansion of the footprints of the waste rock dumps and low grade ore stockpiles, it is becoming increasingly important to develop a solute mass balance for the site – such that the behaviour of major solute source terms and the spatial and temporal contribution of these sources to water quality in Magela Creek can be clearly understood. Validated grab sample and continuous data records are needed to construct a high reliability solute mass balance model.

Related to mass balance is the issue of specifying allowable annual load limits from the site – as part of the site's regulatory requirements. The technical basis for these load limits needs to be reviewed since they were originally developed decades ago. There has since been significantly increased knowledge of the environmental geochemistry of the site, a quantum increase in knowledge about ecotoxicological sensitivity of the aquatic systems and updated data on the diet profile of traditional owners.

### 1.3 Monitoring

#### 1.3.1 Surface water, groundwater, chemical, biological, sediment, radiological monitoring

Routine and project-based chemical, biological, radiological and sediment monitoring should continue, together with associated research of an investigative nature or necessary to refine existing, or develop new (promising) techniques and models. A review of current water quality objectives for Ranger should be conducted to determine if they are adequate for future water management options for the whole-of-site, including the closure and rehabilitation phase (KKN 2.2.1 and KKN 2.2.2).

ARRTC supports the design and implementation of a risk-based radiological monitoring program based on a robust statistical analysis of the data collected over the life of Ranger necessary to provide assurance for indigenous people who source food items from the Magela Creek system downstream of Ranger.

# 2 Ranger – Rehabilitation

## 2.1 Reference state and baseline data

### 2.1.1 Defining the reference state and baseline data

There is a requirement to define the baseline data/reference state that existed at the Ranger site prior to development. This will inform the process of the development of closure criteria which is compatible with the Environmental Requirements. The knowledge need is to develop and perform analysis to generate agreed reference data that cover the range of pre-mining and operational periods.

## 2.2 Landform

### 2.2.1 Landform design

An initial design is required for the proposed final landform. This would be based upon the optimum mine plan from the operational point of view and it would take into account the broad closure criteria, engineering considerations and the specific criteria developed for guidance in the design of the landform. This initial landform would need to be optimised using the information obtained in detailed water quality, geomorphic, hydrological and radiological programs listed below.

Current and trial landforms at Ranger and at other sites such as Nabarlek should be used to test the various models and predictions for water quality, geomorphic behaviour and radiological characteristics at Ranger. The detailed design for the final landform at Ranger should be determined taking into account the results of the above research programs on surface and ground water, geomorphic modelling and radiological characteristics.

### 2.2.2 Development and agreement of closure criteria from the landform perspective

Closure criteria from the landform perspective need to be established at both the broad scale and the specific. At the broad scale, agreement is needed, particularly with the traditional owners and within the context of the objectives for rehabilitation incorporated within the Ers, on the general strategy to be adopted in constructing the final landform. These considerations would include issues such as maximum height of the landform, the maximum slope gradient (from the aesthetic perspective), and the presence or absence of lakes or open water. At the specific scale, some criteria could usefully be developed as guidance for the initial landform design such as slope length and angle (from the erosion perspective), the minimum cover required over low grade ore, and the minimum distance of low grade ore from batter slopes. Specific criteria are needed that will be used to assess the success of landform construction. These would include, for example, maximum radon exhalation and gamma dose rates, maximum sediment delivery rates, maximum constituent concentration rates in runoff and maximum settling rates over tailings repositories.

### 2.2.3 Water quality in seepage and runoff from the final landform

Existing water quality monitoring and research data on surface runoff and subsurface flow need to be analysed to develop models for the quality of water, and its time dependence, that would enter major drainage lines from the initial landform design. Options for adjusting the design to minimise solute concentrations and loads leaving the landform need to be assessed.

There is a need to develop and analyse conceptual models of mine related turbidity and salinity impacts following closure. These models could be analysed in a variety of ways as a precursor to the development of a quantitative model of potential turbidity and salinity impacts offsite caused by surface and subsurface water flow off the rehabilitated mine site. This analysis should explicitly acknowledge knowledge uncertainty (eg plausible alternative conceptual models) and variability (eg potential for Mg/Ca ratio variations in water flowing off the site) and explore the potential ramifications for the off-site impacts. (see also KKN 2.6.1)

### 2.2.4 Geomorphic behaviour and evolution of the landscape

The existing data set used in determination of the key parameters for geomorphological modelling of the proposed final landform should be reviewed after consideration of the near surface characteristics of the initial proposed landform. Further measurements of erosion characteristics should be carried out if considered necessary. The current site-specific landform evolution models should be applied to the initial proposed landform to develop predictions for long term erosion rates, incision and gullying rates, and sediment delivery rates to the surrounding catchments. Options for adjusting the design to minimise erosion of the landform need to be assessed. In addition, an assessment is needed of the geomorphic stability of the Ranger mine site with respect to the erosional effects of extreme events.

### 2.2.5 Radiological characteristics of the final landform

The characteristics of the final landform from the radiological exposure perspective need to be determined and methods need to be developed to minimise radiation exposure to ensure that restrictions on access to the land are minimised. Radon exhalation rates, gamma dose rates and radionuclide concentrations in dust need to be determined and models developed for both near-field and far-field exposure.

The use of potential analogue sites for establishing pre-mining radiological conditions at Ranger should be further investigated to provide information on parameters such as pre-mining gamma dose rates, radon exhalation rates, and levels of radioactivity in dust. This information is needed to enable estimates to be made of the likely change in radiation exposure when accessing the rehabilitated site compared to pre-mining conditions.

## 2.3 Groundwater dispersion

### 2.3.1 Containment of tailings and other mine wastes

The primary method for protection of the environment from dispersion of contaminants from tailings and other wastes will be containment. For this purpose, investigations are required on the hydrogeological integrity of the pits, the long-term geotechnical properties of tailings and waste rock fill in mine voids, tailings deposition and transfer (including TD to Pit 3) methods, geochemical and geotechnical assessment of potential barrier materials, and strategies and technologies to access and 'seal' the surface of the tailings mass, drain and dispose of tailings porewater, backfill and cap the remaining pit void.

### 2.3.2 Geochemical characterisation of source terms

Investigations are needed to characterise the source term for transport of contaminants from the tailings mass in groundwater. These will include determination of the permeability of the tailings and its variation through the tailings mass, strategies and technologies to enhance settled density and accelerate consolidation of tailings, and porewater concentrations of key constituents.

There is a specific need to address the existence of groundwater mounds under the tailings dam and waste rock stockpiles. Models are needed to predict the behaviour of groundwater and solute transport in the vicinity of these mounds and options developed for their remediation to ensure that on-site revegetation can be achieved and that off-site solute transport from the mounds will meet environmental protection objectives. Assessment is also needed of the effectiveness (cost and environmental significance) of paste and cementation technologies for increasing tailings density and reducing the solubility of chemical constituents in tailings.

### 2.3.3 Aquifer characterisation and whole-of-site model

The aquifers surrounding the tailings repositories (Pits 1 & 3) need to be characterised to enable modelling of the dispersion of contaminants from the repositories. This will involve geophysics surveys, geotechnical drilling and groundwater monitoring and investigations on the interactions between the deep and shallow aquifers.

### 2.3.4 Hydrological/hydrogeochemical modelling

Predictive hydrological/hydrogeological models need to be developed, tested and applied to assess the dispersion of contaminants from the tailings repositories over a period of 10 000 years. These models will be used to assess whether all relevant and appropriate factors have been considered in designing and constructing an in-pit tailings containment system that will prevent environmental detriment in the long term.

## 2.4 Water treatment

### 2.4.1 Active treatment technologies for specific mine waters

Substantial volumes of process water retained at Ranger in the tailings dam and Pit 1 must be disposed of by a combination of water treatment and evaporation during the mining and milling phases of the operation and during the rehabilitation phase. Research priorities include treatment technologies and enhanced evaporation technologies that can be implemented for very high salinity process water. A priority should be evaluation of the potential impact of treatment sludge and brine streams on long term tailings chemistry in the context of closure planning and potential post closure impacts on water quality.

### 2.4.2 Passive treatment of waters from the rehabilitated landform

Sentinel wetlands may form part of the final landform at Ranger. Research on wetland filters during the operational phase of mining will provide information relevant to this issue. Research is needed to establish the effect of wet-dry seasonal cycling on contaminant retention and release, since this aspect will influence design criteria and whether such wetlands should be maintained as ephemeral or perennial waterbodies There is also the need to assess the long-term behaviour of the physical and biotic components of the wetlands, their ecological health, and the extent of contaminant accumulation (both metals and radionuclides) in the context of potential human exposure routes.

## 2.5 Ecosystem establishment

### 2.5.1 Development and agreement of closure criteria from ecosystem establishment perspective

Closure criteria need to be established for a range of ecosystem components including surface water quality, flora and fauna. The environmental requirements provide some guidance but characterisation of the analogue ecosystems will be an important step in the process. Consultation on closure criteria with the traditional owners has commenced and it is important that this process continues as more definitive criteria are developed.

### 2.5.2 Characterisation of terrestrial and aquatic ecosystem types at analogue sites

Identification and characterisation of analogue ecosystems (target habitats) can assist in defining the rehabilitation objective and developing robust, measurable and ecologically-based closure criteria. The concept of using analogue ecosystems for this purpose has been accepted by ARRTC and the traditional owners. Substantial work has been undertaken on the Georgetown terrestrial analogue ecosystem while there is also a large body of information available on aquatic analogues, including streams and billabongs. Future work on the terrestrial analogue needs to address water and nutrient dynamics, while work on the aquatic analogue will include the development of strategies for restoration of degraded or removed natural waterbodies, Coonjimba and Djalkmara, on site.

### 2.5.3 Establishment and sustainability of ecosystems on mine landform

Research on how the landform, terrestrial and aquatic vegetation, fauna, fauna habitat, and surface hydrology pathways will be reconstructed to address the Environmental Requirements for rehabilitation of the disturbed areas at Ranger is essential. Trial rehabilitation research sites should be established that demonstrate an ability by the mine operator to be able to reconstruct terrestrial and aquatic ecosystems, even if this is at a relatively small scale. Rehabilitation establishment issues that need to be addressed include species selection; seed collection, germination and storage; direct seeding techniques; propagation of species for planting; fertiliser strategies and weathering properties of waste rock. Rehabilitation management issues requiring investigation include the stabilisation of the land surface to erosion by establishment of vegetation, return of fauna; the exclusion of weeds; fire management and the re-establishment of nutrient cycles. The sustainable establishment and efficiency of constructed wetland filters, reinstated waterbodies (eg Djalkmara Billabong) and reconstructed waterways also needs to be considered (see KKN 2.3.2).

### 2.5.4 Radiation exposure pathways associated with ecosystem re-establishment

Radionuclide uptake by terrestrial plants and animals on the rehabilitated ecosystem may have a profound influence on the potential utilisation of the land by the traditional owners. Significant work has been completed on aquatic pathways, particularly the role of freshwater mussels, and this now forms part of the annual monitoring program. The focus is now on the terrestrial pathways and deriving concentration factors for Bushtucker such as wallabies, fruits and yams. A project investigating the contemporary diet of traditional owners has commenced and needs to be completed. Models need to be developed that allow exposure pathways to be ranked for currently proposed and future identified land uses, so that identified potentially significant impacts via these pathways can be limited through appropriate design of the rehabilitation process.

## 2.6 Monitoring

### 2.6.1 Monitoring of the rehabilitated landform

A new management and monitoring regime for the rehabilitated Ranger landform needs to be developed and implemented. It needs to address all relevant aspects of the rehabilitated landform including ground and surface water quality, radiological issues, erosion, flora, fauna, weeds, and fire. The monitoring regime should address the key issues identified by the ecological risk assessment of the rehabilitation phase (KKN 2.7.1).

### 2.6.2 Off-site monitoring during and following rehabilitation

Building upon the program developed and implemented for the operational phase of mining, a monitoring regime is also required to assess rehabilitation success with respect to protection of potentially impacted ecosystems and environmental values. This program should address the dispersion of contaminants by surface water, ground water and via the atmosphere. The monitoring regime should address the key issues identified by the ecological risk assessment of the rehabilitation phase (KKN 2.7.1).

## 2.7 Risk assessment

### 2.7.1 Ecological risk assessments of the rehabilitation and post rehabilitation phases

In order to place potentially adverse on-site and off-site issues at Ranger during the rehabilitation phase within a risk management context, it is critical that a robust risk assessment framework be developed with stakeholders. The greatest risk is likely to occur in the transition to the rehabilitation phase, when active operational environmental management systems are being progressively replaced by passive management systems. A conceptual model of transport/exposure pathways should be developed for rehabilitation and post rehabilitation regimes and the model should recognise the potential that some environmental stressors from the mine site could affect the park and vice versa. Implicit in this process should be consideration of the effects of extreme events and climate change.

Conceptual modelling should be followed by a screening process to identify and prioritise key risks for further qualitative and/or quantitative assessments. The conceptual model should be linked to closure criteria and post-rehabilitation monitoring programs, and be continually tested and improved. Where appropriate, risk assessments should be incorporated into decision making processes for the closure plan. Outputs and all uncertainties from this risk assessment process should be effectively communicated to stakeholders.

### 2.8 Stewardship

The concept of Stewardship (including ownership and caring for the land) is somewhat broader and applies to all phases of, in this case, uranium mining. In this context it is considered to be the post closure phase of management of the site, ie after relinquishment of the lease. If the rehabilitation phase is successful in meeting all objectives then this stewardship will effectively comprise an appropriate level of ongoing monitoring to confirm this. Should divergence from acceptable environmental outcomes be detected then some form of intervention is likely to be required. The nature, responsibility for, and duration of, the monitoring and any necessary intervention work remains to be determined.

## 3 Jabiluka

### 3.1 Monitoring

#### 3.1.1 Monitoring during the care and maintenance phase

A monitoring regime for Jabiluka during the care and maintenance phase needs to be implemented and regularly reviewed. The monitoring program (addressing chemical, biological, sedimentalogical and radiological issues) should be commensurate with the environmental risks posed by the site, but should also serve as a component of any program to collect baseline data required before development such as meteorological and sediment load data.

### 3.2 Research

#### 3.2.1 Research required prior to any development

A review of knowledge needs is required to assess minimum requirements in advance of any development. This review would include radiological data, the groundwater regime (permeabilities, aquifer connectivity etc), hydrometeorological data, waste rock erosion, assess site-specific ecotoxicology for uranium, additional baseline for flora and fauna surveys.

## 4 Nabarlek

### 4.1 Success of revegetation

#### 4.1.1 Revegetation assessment

Several assessments of the revegetation at Nabarlek have been undertaken; the most recent being completed by ***eriss***. There is now general agreement that the rehabilitated areas require further work. Revised closure criteria are currently being developed through the mine-site technical committee and these should be reviewed by relevant stakeholders, including ARRTC. The required works should then be completed on site with further monitoring leading to the relinquishment of the lease.

#### 4.1.2 Development of revegetation monitoring method

A methodology and monitoring regime for the assessment of revegetation success at Nabarlek needs to be developed and implemented. Currently, resource intensive detailed vegetation and soil characterisation assessments along transects located randomly within characteristic areas of the rehabilitated landform are being undertaken. Whilst statistically valid, these assessments cover only a very small proportion of the site. Remote sensing (satellite) data are also being collected and the efficacy of remote sensing techniques for vegetation assessment in comparison to ground survey methods should continue. The outcomes of this research will be very relevant to Ranger.

### 4.2 Assessment of radiological, chemical and geomorphic success of rehabilitation

#### 4.2.1 Overall assessment of rehabilitation success at Nabarlek

The current program on erosion, surface water chemistry, groundwater chemistry and radiological issues should be continued to the extent required to carry out an overall assessment of the success of rehabilitation at Nabarlek. In particular, all significant radiological exposure pathways should be identified and a comprehensive radiation dose model developed. Additional monitoring of ground water plumes is required to allow assessment of potential future groundwater surface water interaction and possible environmental effects.

## 5 General Alligator Rivers Region

### 5.1 Landscape scale analysis of impact

#### 5.1.1 Develop a landscape-scale ecological risk assessment framework for the Magela catchment that incorporates, and places into context, uranium mining activities and relevant regional landscape processes and threats, and that builds on previous work for the Magela floodplain

Ecological risks associated with uranium mining activities in the ARR, such as current operations (Ranger) and rehabilitation (Nabarlek, Jabiluka, future Ranger, South Alligator Valley), should be assessed within a landscape analysis framework to provide context in relation to more diffuse threats associated with large-scale ecological disturbances, such as invasive species, unmanaged fire, cyclones and climate change. Most key landscape processes occur at regional scales, however the focus will be on the Magela catchment encompassing the RPA. A conceptual model should first be developed to capture links and interactions between multiple risks and assets at multiple scales within the Magela catchment, with risks associated with Ranger mining activities made explicit. The spatially explicit Relative Risk Model will be used to prioritise multiple risks for further qualitative and/or quantitative assessments. The conceptual model and risk assessment framework should be continually tested and improved as part of Best Practice. Where appropriate, risk assessments should be incorporated into decision making processes using advanced risk assessment frameworks such as Bayesian Networks, and all uncertainties made explicit. This risk assessment process should integrate outputs from KKN 1.2.1 (risks from the surface water pathway – Ranger current operations) and the new KKN 2.6.1 (risks associated with rehabilitation) to provide a landscape-scale context for the rehabilitation of Ranger into Kakadu National Park, and should be communicated to stakeholders.

## 5.2 South Alligator River valley rehabilitation

### 5.2.1 Assessment of past mining and milling sites in the South Alligator River valley

SSD conducts regular assessments of the status of mine sites in the SAR valley, provides advice to Parks Australia on technical issues associated with its rehabilitation program and conducts a low level radiological monitoring program. This work should continue.

## 5.3 Develop monitoring program related to West Arnhem Land exploration activities

### 5.3.1 Baseline studies for biological assessment in West Arnhem Land

ARRTC believes there is a need to determine a baseline for (a) rare, threatened and endemic biota and (b) indicator species or groups such as macroinvertebrates in areas where advanced exploration or proposed mining projects are identified and in line with the current approvals process under the *Aboriginal Land Rights Act***.**

## 5.4 Koongarra

### 5.4.1 Baseline monitoring program for Koongarra

In line with the current approvals process under the *Aboriginal Land Rights Act*, a low level monitoring program should be developed for Koongarra to provide baseline data in advance of any possible future development at the site. Data from this program could also have some relevance as a control system for comparison to Ranger, Jabiluka and Nabarlek.

*Note: The Koongarra Project Area was added to the Kakadu World Heritage Area by the World Heritage Committee on 27 June 2011, and this KKN will need to be revisited pending the possible re-incorporation of the area into Kakadu National Park.*

# APPENDIX 2 PUBLICATIONS FOR 2012–13

## Published[15]

Boyden J, Joyce K, Boggs G & Wurm P 2013. Object-based mapping of native vegetation and para grass (*Urochloa mutica*) on a monsoonal wetland of Kakadu NP using a Landsat 5 TM Dry-season time series. *Journal of Spatial Science* 58 (1), 53–77.

Coulthard TJ, Hancock GR & Lowry JBC 2012. Modelling soil erosion with a downscaled landscape evolution model. *Earth Surfaces Processes and Landforms*, 37 (10) 1046–1055.

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Erskine WD & Saynor MJ 2012. Landslide impacts on suspended sediment sources following an extreme event in the Magela Creek catchment, northern Australia In *Erosion and sediments yields in the changing environment.* Eds AL Collins, V Golosov, AJ Horowitz, X Lu, M Stone, DE Walling & X Zhang, Proceedings of a symposium held at the Institute of Mountain Hazards and Environment, CAS-Chengdu, China, 11–15 October 2012, IAHS Publication 356, 138-145.

Erskine WD & Saynor MJ 2013. Hydrology and bedload transport relationships for sand-bed streams in the Ngarradj Creek catchment, northern Australia. *Journal of Hydrology* 483 (2013), 68–79.

Frostick A, Jones D &Turner K 2012. Review of solute selection for water quality and bioaccumulation monitoring at a northern Australian uranium mine. In *Proceedings: International Mine Water Association Symposium*, Bunbury, Western Australia, September 29 to October 4, 2012, eds CD McCullough, MA Lund & L Wyse, International Mine Water Association, 91–100.

Hancock GR, Willgoose GR & Lowry J (in press). Transient landscapes: gully development and evolution using a landscape evolution model. *Stochastic Environmental Research and Risk Assessment*.

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Howard BJ, Beresford NA, Copplestone D, Telleria D, Proehl G, Fesenko S, Jeffree RA, Yankovich TL, Brown JE, Higley K, Johansen MP, Mulye H, Vandenhove H, Gashchak S, Wood MD, Takata H, Andersson P, Dale P, Ryan J, Bollhöfer A, Doering C, Barnett CL & Wells C 2012. The IAEA handbook on radionuclide transfer to wildlife. *Journal of Environmental Radioactivity* 121, 55–74.

Humphrey C, Jones D, Frostick A & Chandler L 2012. Deriving surface water quality closure criteria for natural waterbodies adjacent to an Australian uranium mine. In *Proceedings: International Mine Water Association Symposium*, Bunbury, Western Australia, September 29 to October 4, 2012, eds CD McCullough, MA Lund & L Wyse, International Mine Water Association, 159–165.

Jones DR 2012. Water in mining: challenges for the Australian and international mining industry. In *Proceedings: International Mine Water Association Symposium*, Bunbury, Western Australia, September 29 to October 4, 2012, eds CD McCullough, MA Lund & L Wyse, International Mine Water Association, 10A-10I.

Medley P 2012. Variability of procedural blanks leads to greater uncertainty in assessing detection limits for the measurement of polonium-210. In *Ninth International Conference on Methods and Applications of Radioanalytical Chemistry (MARC IX)*, 25–30 March 2012, Kailua-Kona, Hawaii, DOI 10.1007/s10967-012-2179-y.

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Bollhöfer A, Doering C, Pfitzner J, Medley P & Fox G 2012. Assesment of the radiological exposure pathways at the Rum Jungle Lake Reserve, Northern Territory, Australia. Paper presented at *37th Australasian Radiation Protection Society (ARPS) conference*, 14–17 October 2012, Sydney Australia.

Bollhöfer A, Schlosser C, Ross O, Satorius H & Schmid S 2012. Atmospheric Kr-85 activity concentrations measured close to the ITCZ in the Southern Hemisphere. Paper presented at *12th South Pacific Environmental Radioactivity Association (SPERA) conference*, 16–19 October 2012, Sydney Australia.

Bollhöfer A, Doering C 2013. BRUCE: A tool for calculating radionuclide transfer factors for Northern Australian bushfoods. Paper presented at the 1st Interim Technical Meeting of MODARIA Working Group 8, 27 May 2013, Vienna, Austria.

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Doering C, Pfitzner J, Cahill R & Bollhöfer A 2012. Radon progeny monitoring and public dose estimates in the vicinity of the Ranger uranium mine. Paper presented at the *37th Australasian Radiation Protection Society (ARPS) Conference*, 14–17 October 2012, Sydney, Australia.

16 Presentations to conferences and symposia that have been externally published in 2012–13 are included in Appendix 2, Published.

Doering C & Saey P 2012. Analysis of 7Be data from five Australian IMS radionuclide particulate stations over 12 years. Paper presented at the *12th South Pacific Environmental Radioactivity Association (SPERA) Conference*, 16–19 October 2012, Sydney, Australia.

Harford A, Hogan A, Jones D & van Dam R 2012. Ecotoxicology of highly treated mine waters. Paper presented at the *International Mine Water Conference*. 1–4 October 2012, Bunbury Australia.

Harford A, Hogan A, Jones D & van Dam R 2012. Stuck in the goop! Difficulties in assessing the environmental risk of organic flocculants. Paper presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

Hogan A, Trenfield M, Cheng K, Harford A, Costello C & van Dam R 2012. And the winner is: Filtration, for successfully isolating unicellular algae from pulse exposure waters. Poster presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

Humphrey C 2013. Training presentations at *Water quality and the environment: Master class*, Australian Water Association, 13–14 March 2013, Melbourne Vic. (Names of co-authors and other contributors to individual presentations available on request.)

- An overview of key features of the revision of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
- Decision frameworks and integrated assessments using weight of evidence
- Developing site-specific Guidelines
- Proposal for an improved (eco)regionalisation and ecosystem classification schema for aquatic ecosystems in the revised Guidelines
- Proposals for revising monitoring, assessment and reporting advice contained in the WQ and M&R Guidelines
- Biological monitoring and assessment: approaches and possible new directions
- Some issues associated with seasonal systems and temporary waters

Medley P 2012. Developing and calibrating a method for analysis of Pb-210 via Liquid Scintillation Counting: A technical perspective. Paper presented at *12th South Pacific Environmental Radioactivity Association (SPERA) conference*, 16–19 October 2012, Sydney Australia.

Sinclair A, Tayler K, van Dam R & Hogan A 2013. From leading practice technology to regulation – the development of a framework for regulating short-term pulse exposures to mine water. Paper presented at *12th Australia Institute of Mining and Metallurgy (AUSIMM) International Uranium conference*, 11-12 June 2013, Darwin Australia.

Trenfield M, Ng J, Noller B, Markich S & van Dam R. 2012. Dissolved organic carbon reduces the bioavailability and toxicity of uranium to the unicellular eukaryote *Euglena gracilis*. Poster presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

van Dam R, Harford A, Trenfield M, Markich S, Humphrey C, Hogan A & Stauber J 2012. Updating water quality guidelines for uranium – Standardising measures of toxicity and incorporating the influence of dissolved organic carbon. Paper presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

Woodworth J, Hack L, van Dam R & Fox D 2012. Teething troubles with consulting in ecotoxicology. Paper presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

# APPENDIX 4 LIST OF ERISS RESEARCH PROJECTS, 2012–13

| Project Code | Project Title | Work group* |
|---|---|---|
| ***Completed*** | | |
| RES-2005-001 | Pre-mining radiological analogue for Ranger | EnRad |
| RES-2007-008 | An ecological risk assessment of the major weeds on the Magela Creek Floodplain, Kakadu National Park | SSDI |
| RES-2008-005 | Effects of Mg pulse exposures on tropical freshwater species | Ecotox |
| RES-2009-012 | Communication of contaminant pathway conceptual models for Ranger uranium mine | SSDI |
| RES-2010-012 | Re-analysis of existing uranium freshwater chronic toxicity data to calculate low effect concentrations | Ecotox |
| ***Continuing*** | | |
| MON-1995-002 | Toxicity monitoring research in Magela and Gulungul creeks | AEP |
| RES-1996-002 | Radionuclide uptake in traditional aboriginal foods | EnRad |
| RES-2000-003 | Radiological assessment of the South Alligator River Valley | EnRad |
| RES-2005-002 | Development of surface water quality (solutes) closure criteria for Ranger billabongs using macroinvertebrate community data | AEP |
| RES-2005-003 | Use of analogue plant communities as a guide to revegetation and associated monitoring of the post-mine landform at Ranger | AEP |
| RES-2006-003 | Assessing the impact of extreme rainfall events on the geomorphic stability of the rehabilitated Ranger landform using the CAESAR landscape evolution model | PCP |
| RES-2007-002 | Loads of suspended sediment, metals and radionuclides in Magela and Gulungul creeks | PCP |
| RES-2007-004 | Assessing landslips in the Upper Magela Catchment | PCP |
| RES-2008-001 | Characterisation of contamination at Land Application Areas at Ranger uranium mine | EnRad |
| RES-2008-002 | Development and implementation of a remote sensing framework for environmental monitoring within the Alligator Rivers Region (focus on the Magela Floodplain) | SSDI |
| RES-2009-002 | The toxicity of uranium (U) to sediment biota of Magela Creek backflow billabong environments | Ecotox |

| | | |
|---|---|---|
| RES-2009-003 | Effects of fine suspended sediment on billabong limnology (development of turbidity closure criteria) | AEP |
| RES-2009-004 | Radon exhalation from the Ranger uranium mine trial landform | EnRad |
| RES-2009-009 | Geological provinence of fine suspended sediment within the Magela Creek catchment | SSDI |
| RES-2009-011 | Ranger trial landform erosion and chemistry studies | PCP |
| RES-2010-007 | Assessing the geomorphic stability of the Ranger trial landform | SSDI |
| RES-2012-001 | Effect of manganese on tropical freshwater species | Ecotox |
| RES-2012-002 | Dose rates to non-human biota | EnRad |
| RES-2012-004 | Model geomorphic stability of Ranger Pit 1 landform | SSDI |
| RES-2012-008 | Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine | EnRad |
| RES-2012-011 | Magela Creek floodplain vegetation mapping | SSDI |
| ***Commenced*** | | |
| RES-2012-012 | Ranger rehabilitation & closure ecological risk assessment: Phase 1, problem formulation | SSDI |
| RES-2012-014 | Investigating changes in the sensitivity of *Moinodaphnia macleayi* to uranium | Ecotox |
| RES-2012-015 | The effect of multiple Mg pulses on tropical freshwater species with an emphasis on recovery and carry over toxicity | Ecotox |

* AEP: Aquatic Ecosystems Protection; Ecotox: Ecotoxicology; EnRad: Environmental Radioactivity; PCP: Physico-chemical Processes; SSDI: Spatial Sciences and Data Integration.

# GLOSSARY OF TERMS, ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| 1s – 7s | When referring to ore and stockpiles, indicates the amount of extractable uranium in the ore (grade). At Ranger, 1s indicates the lowest grade (waste) and 7s indicates the highest grade ore. |
| AAPA | Aboriginal Areas Protection Authority |
| Airborne gamma survey | Aerial measurements of the terrestrial gamma radiation using a large volume sodium iodide (NaI) detector on board an aircraft. |
| ALARA | As low as reasonably achievable |
| alpha radiation (α) | A positively charged helium ($He^{2+}$) nucleus (two protons + two neutrons) that is spontaneously emitted by an energetically unstable heavy atomic nucleus (such as $^{226}Ra$ or $^{238}U$). |
| 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. |
| 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* (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. |
| Becquerel (Bq) | SI unit for the activity of a radioactive substance in decays per second [$s^{-1}$]. |
| Beta radiation (β) | A high energy electron or positron emitted when an unstable atomic nucleus (such as $^{90}Sr$ or $^{40}K$) loses its excess energy. |
| Bioaccumulation | Occurs when the rate of uptake by biota of a chemical substance, such as metals, radionuclides or pesticides is greater than the rate of loss. These substances may be taken up directly, or indirectly, through consumption of food containing the chemicals. |
| Bioavailable | The proportion of the total present (in water, sediment, soil or food) of metals and radionuclides, that can be taken up by biota (see also bioaccumulation). |

| | |
|---|---|
| Biodiversity (biological diversity) | The variety of life forms, including plants, animals and micro-organisms, the genes they contain and the ecosystems and ecological processes of which they are a part. |
| Biological assessment | Use and measurement of the biota to monitor and assess the ecological health of an ecosystem. |
| Biological community | An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another. |
| BoM | Bureau of Meteorology |
| bund | Embankment or wall designed to retain contents (usually liquids) in the event of leakage or spillage from a storage facility. |
| Closure criteria | Performance measures used to assess the success of mine-site 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). |
| Damp-proof course | A waterproof barrier comprising bitumen and aluminium. |
| DataSonde | A DataSonde is a multi-parameter sensor for monitoring water quality in ground and surface waters. |
| Direct seeding | Vegetation is established by broadcasting seed across the area to be revegetated. |
| Dissolved organic carbon | Natural organic material from plants and animals that has broken down and is able to pass through a very fine (0.45 micrometre) filter. |
| 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. |
| DRET | Department of Resources, Energy and Tourism |
| early detection | Measurable early warning biological, physical or chemical response in relation to a particular stress, prior to significant adverse effects occurring on the system of interest. |
| Electrical conductivity (EC) | A measure of the total concentration of salts dissolved in water. |

| | |
|---|---|
| EIS | Environmental Impact Statement |
| EMS | Environmental Management System |
| ERA | Energy Resources of Australia Ltd |
| ERAES | ERA Environmental Strategy (formerly EWLS) |
| *eriss* | Environmental Research Institute of the Supervising Scientist |
| ERs | Environmental Requirements |
| IWMP | Interim water management pond |
| flume | A channel control structure with known cross-sectional area used to measure flow rate of runoff water. |
| Fulvic acid | A component of dissolved organic carbon that is especially reactive and forms strong complexes with metals. Fulvic acids account for a large part of the dissolved organic matter in natural water. |
| G8210009 | Magela Creek downstream gauging station |
| GAC | Gundjeihmi Aboriginal Corporation |
| gamma radiation (γ) | High energy electromagnetic radiation emitted by excited nuclei (for example after an alpha or beta decay) in their transition to lower-lying nuclear levels. |
| GC2 | Georgetown Creek 2 (ERA monitoring site) |
| GCDS | Gulungul Creek Downstream (downstream monitoring site) |
| GCMBL | Georgetown Creek Mine Bore L (ERA monitoring site) |
| GCMID | Gulungul Creek Midstream (midstream monitoring site) |
| GCUS | Gulungul Creek Upstream (upstream monitoring site) |
| grab sampling | Collection of a discrete water sample for chemical analysis |
| Gray (Gy) | Name for absorbed dose 1 Gray = 1 Joule·$kg^{-1}$. The absorbed dose gives a measure for the energy imparted by ionising radiation to the mass of the matter contained in a given volume element. |
| GTB | Georgetown Billabong |
| 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 (eg soil or water) or organism (eg fish tissue) by transport, degradation or transformation. |
| Hydstra | Hydrology data management software package. |
| IAEA | International Atomic Energy Agency |

| | |
|---|---|
| IC50 | The concentration of a compound that causes a 50% inhibition in a particular response (eg growth, reproduction) of an organism relative to that of a control organism (ie an organism not exposed to the compound). |
| 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. |
| IWMP | Interim Water Management Pond |
| KKN | Key Knowledge Needs |
| LAA | Land Application Area |
| land application | A method for management of excess accumulated water by spray irrigation. The method depends on the evaporation from spray droplets, and from vegetation and ground surfaces once it reaches them. |
| Laterite | In the Ranger mine context, laterite is a local term used to describe well weathered rock and soil profile material that consists primarily of a mixture of sand and silt/clay size particles. It may or may not exhibit characteristics of a fully-developed laterite profile. |
| LC50 | The concentration of a compound that causes the death of 50% of a group of organisms relative to that of a control group of organisms (ie a group of organisms not exposed to the compound). |
| LiDAR | Light Detection and Ranging |
| LLAA | Long-lived alpha activity |
| MCDW | Magela Creek Downstream West (downstream monitoring site) |
| MCUGT | Magela Creek Upstream Georgetown (upstream monitoring site) |
| MOL | Maximum Operating Level. The maximum level at which a liquid containing impoundment can be operated. |
| mRL | Reduced Level metres |
| MTC | Minesite Technical Committee |
| Near Infrared | 0.7 to 1.3 µm |
| NERP | National Environmental Research Program |
| NLC | Northern Land Council |
| NRETAS | Department of Natural Resources, Environment, the Arts and Sport |
| 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 |
| permeate | The higher purity stream produced by passage of water through a reverse osmosis (RO) treatment process. |
| 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. |
| POSS | Parks Operational Support Section |
| POT | Parks Operations and Tourism Branch |
| potable water | Water suitable for human consumption. |
| 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.<br>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. |
| Radon (Rn) | Colourless, odourless, tasteless, naturally-occurring radioactive noble gas formed from the decay of radium. |
| RJTWG | Rum Jungle Technical Working Group |
| RL | Relative Level. The number after RL denotes metres above or below a chosen datum (also known as Reduced Level) |
| RP1 | Retention Pond 1 |
| RP5 | Retention Pond 5 |
| RP6 | Retention Pond 6 |
| RPI | Routine Periodic Inspection |

| | |
|---|---|
| SEWPAC | Department of Sustainability, Environment, Water, Population and Communities |
| Sievert (Sv) | Unit for equivalent dose and effective dose 1 Sievert = 1 Joule·$kg^{-1}$.<br>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. |
| solute load | Total mass of a solute delivered over a defined period of time. |
| speciation (of an element) | The forms in which an element exists within a particular sample or matrix. |
| SSD | Supervising Scientist Division |
| stable lead isotopes | Lead has four stable isotopes, three of which, $^{206}Pb$, $^{207}Pb$ and $^{208}Pb$, are end members of the natural uranium, actinium and thorium decay series, respectively. $^{204}Pb$ is primordial only. |
| tailings | A slurry of ground rock and process effluents left over once the target product, in this case uranium, has been extracted from mineralised ore. |
| thoriferous | Containing thorium. |
| 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 |
| tube stock | Young seedlings (usually wrapped in plastic tubes or in stored in punnets) that have been germinated in a plant nursery. |
| UEL | Uranium Equities Ltd |
| uraniferous | Containing uranium. |
| uranium oxide | An oxide of uranium which occurs naturally or is produced by a uranium extraction process. This is the product from the Ranger mine. |
| water treatment plant (WTP) | The process system that removes undesirable chemicals, materials, and biological contaminants from water thereby decreasing its ability to harm the environment. |

# INDEX


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