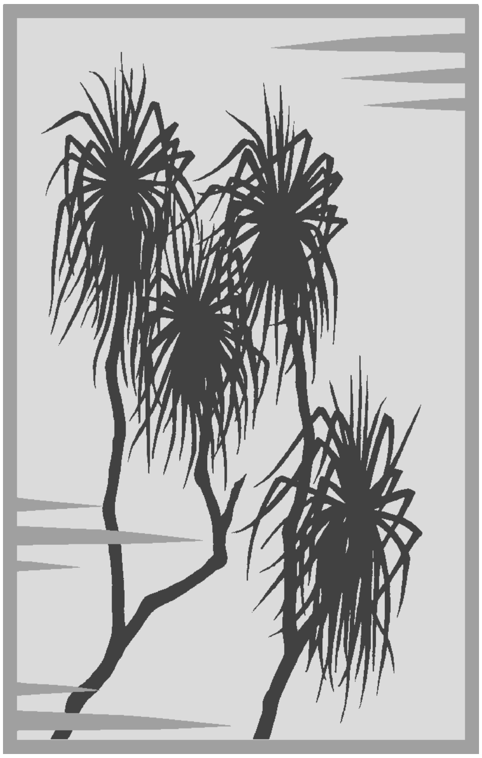
Australian Government

Department of Sustainability, Environment, Water, Population and Communities

Supervising Scientist

SUPERVISING SCIENTIST



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2010–2011

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

The Hon Tony Burke MP
Minister for Sustainability, Environment, Water, Population and Communities
Parliament House
CANBERRA ACT 2600

21 October 2011

Dear Minister

In accordance with subsection 36(1) of the *Environment Protection (Alligator Rivers Region) Act 1978* (the Act), I submit to you the thirty-third Annual Report of the Supervising Scientist on the operation of the Act during the period of 1 July 2010 to 30 June 2011.

Yours sincerely

Alan Hughes
Supervising Scientist

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Photos (from top left): Opening EnviroTox 2011; ARRTC fieldtrip; Minister Burke visiting SSD; resetting the radon decay product monitor; collecting bedload from the trial landform; biomass sampling; inset: sieving sediment for macroinvertebrate collection; IAEA Fellow visiting Ranger mine; water flea; using the ASD FieldSpecPro spectrometer; measuring tree height at vegetation analogue site; Magela Creek downstream pontoon; collecting sediment samples Ranger retention pond 2; Alligator Rivers Region tidal mudflats; placing radon cups on the trial landform; laboratory work at Jabiru Field Station; schoolchildren learning about waterbugs; snail tanks at the Jabiru Field Station.

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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; and
- 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 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, and current plans will see mining of the Ranger 3 deposit cease in 2012 with milling of stockpiled ore expected to continue through until 2020. A proposal to include a heap leach facility at Ranger was lodged in 2009 but was formally withdrawn by ERA in August 2011.

As the time of mine closure and rehabilitation draws closer, the work of the Supervising Scientist includes engagement with stakeholders in discussions and research activities associated with operations, rehabilitation and closure of the Ranger site.

Work has continued in developing improvements to the Supervising Scientist's surface water monitoring program. This program is relevant to both the operational and rehabilitation phases of mining.

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

Monitoring programs by ERA, the NT Department of Resources and SSD continue to indicate that there is no evidence of seepage from the base of the Ranger tailings storage facility (TSF) impacting on Kakadu National Park. ERA has installed additional monitoring bores around the TSF at the request of stakeholders, including SSD. Installation and commissioning of monitoring bores in the vicinity of the TSF continues into 2011–12.

At Ranger mine the 2010–11 wet season was the third largest on record with rainfall of 2457 mm recorded. The high rainfall resulted in increased inventories of water accumulating on site. From 28 January until 15 June 2011 ERA ceased production at Ranger in order to restrict inputs to the process water system to only those attributable to incident rainfall. This initiative avoided the need to invoke a contingency response to transfer process water to the active mine pit, Ranger 3, in order to comply with authorised maximum operating levels in the process water system.

Delays in sourcing and commissioning an effective process water treatment facility mean that the process water inventory at the mine remains an acute focus. As an interim process water management strategy, raising of the walls of the tailings storage facility by four metres commenced in October 2010 and continued throughout the reporting period. Changes to the maximum operating level of the dam will require formal regulatory assessment and approval in order to make use of the increase in tailings and process water capacity created by this construction.

The SSD surface water quality monitoring program continues to be improved with refinements to the operation of continuous monitoring of pH, electrical conductivity (EC) and turbidity in Magela and Gulungul Creeks upstream and downstream of Ranger mine. The SSD 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. This event-based sampling has enhanced the capability of the monitoring program by allowing collection of samples outside of normal working hours or when conditions in the creeks are unsafe for manual grab sampling. SSD discontinued its routine surface water grab sampling program in the 2010–11 wet season in favour of the more conservative event-based program, although some manual grab samples were collected for research and quality assurance purposes. SSD's surface water monitoring results are posted weekly on the internet throughout the wet season.

The principal biologically-based toxicity monitoring approach for 2010–11 was in situ monitoring using freshwater snails, with test organisms deployed in containers floating in the creek water. This program was extended from Magela Creek to include Gulungul Creek during and since the 2009–10 wet season.

Determination of radionuclide levels in mussels from Mudginberri Billabong has been a continuing element of the SSD monitoring program downstream of Ranger. Results for samples collected in October 2010 contained above-average radium 226 content. This is attributed to lower soft body weights of the molluscs this season and not to mine related events. It is concluded that the levels of uranium and radium in mussels collected downstream of Ranger continue to pose no risk to human or ecological health.

Ecotoxicology research programs in progress include determination of responses for a variety of organisms to pulse exposures for a range of magnesium concentrations and durations. Previous work has confirmed a strong correlation between magnesium and EC in Magela Creek. Use of EC as a surrogate for magnesium has the obvious advantage of being suitable for direct measurement rather than relying on sampling and analysis at a remote laboratory.

An eight hectare trial landform was constructed by ERA during late 2008 and early 2009 adjacent to the north-western wall of the tailings storage facility at Ranger mine. SSD is involved in erosion studies on the trial landform to assist in longer-term modelling of the performance of the ultimate landform created during rehabilitation of the site.

The Jabiluka project remains in long-term care and maintenance, and the next stage of the project is a matter for discussion between ERA and the area's traditional owners.

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

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

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 as the post works monitoring progresses.

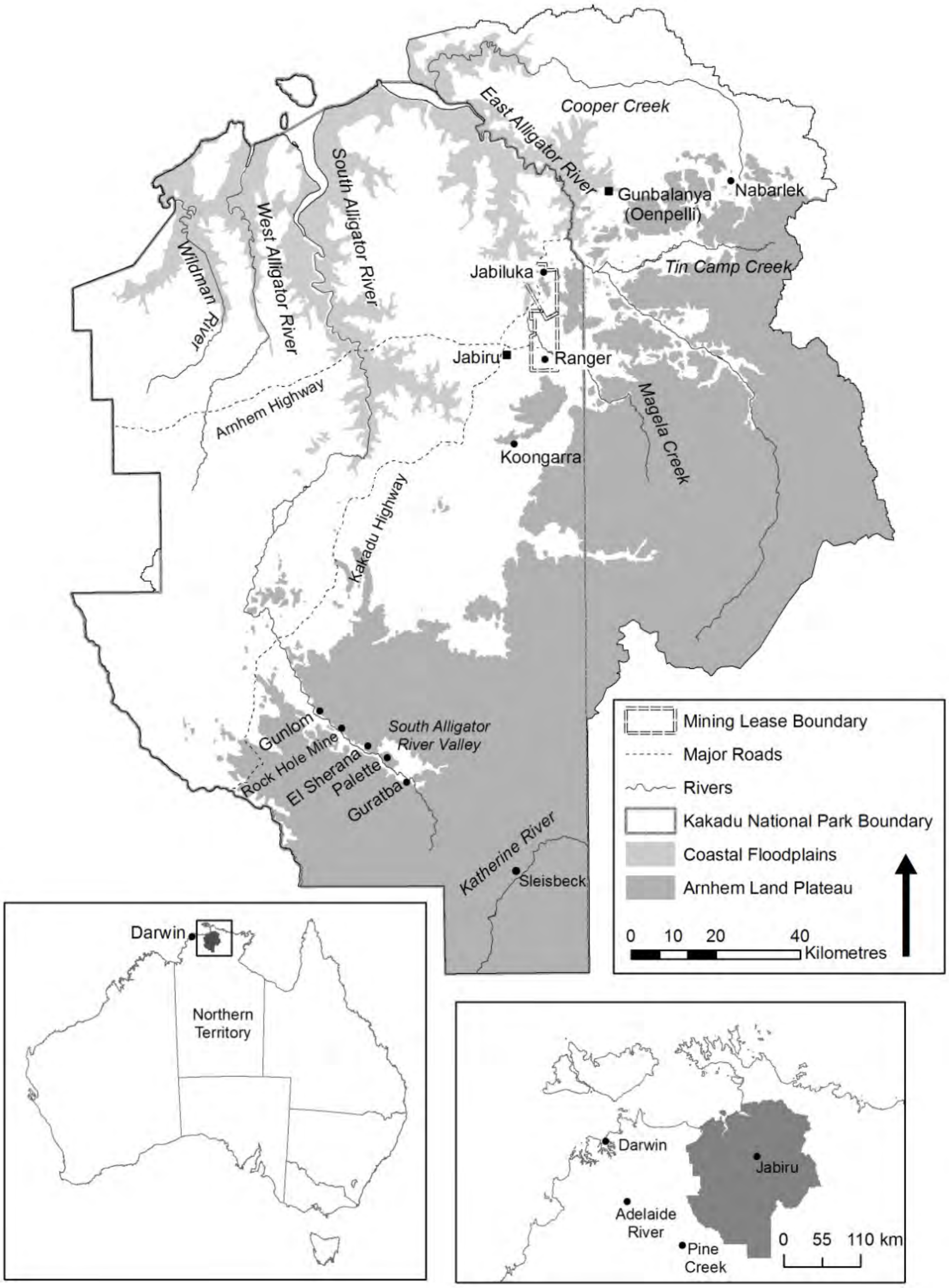
The Alligator Rivers Region Technical Committee (ARRTC) continues to play a vital role in assessing the science used in making judgements about the protection of the environment from the impacts of uranium mining. Professor David Mulligan and Mr Andrew Johnston, with areas of expertise in plant ecology and rehabilitation and in radiation protection respectively were appointed in early 2010–11. Dr Terry Hillman and Mr Ray Evans resigned from the committee during the year, creating vacancies for independent members with expertise in freshwater ecology and hydrogeology respectively.

During the reporting period, SSD provided advice to the Approvals and Wildlife Division (AWD) of the department on referrals submitted in accordance with the EPBC Act for proposed new and expanding uranium mines and assisted AWD with compliance audits against approval conditions.

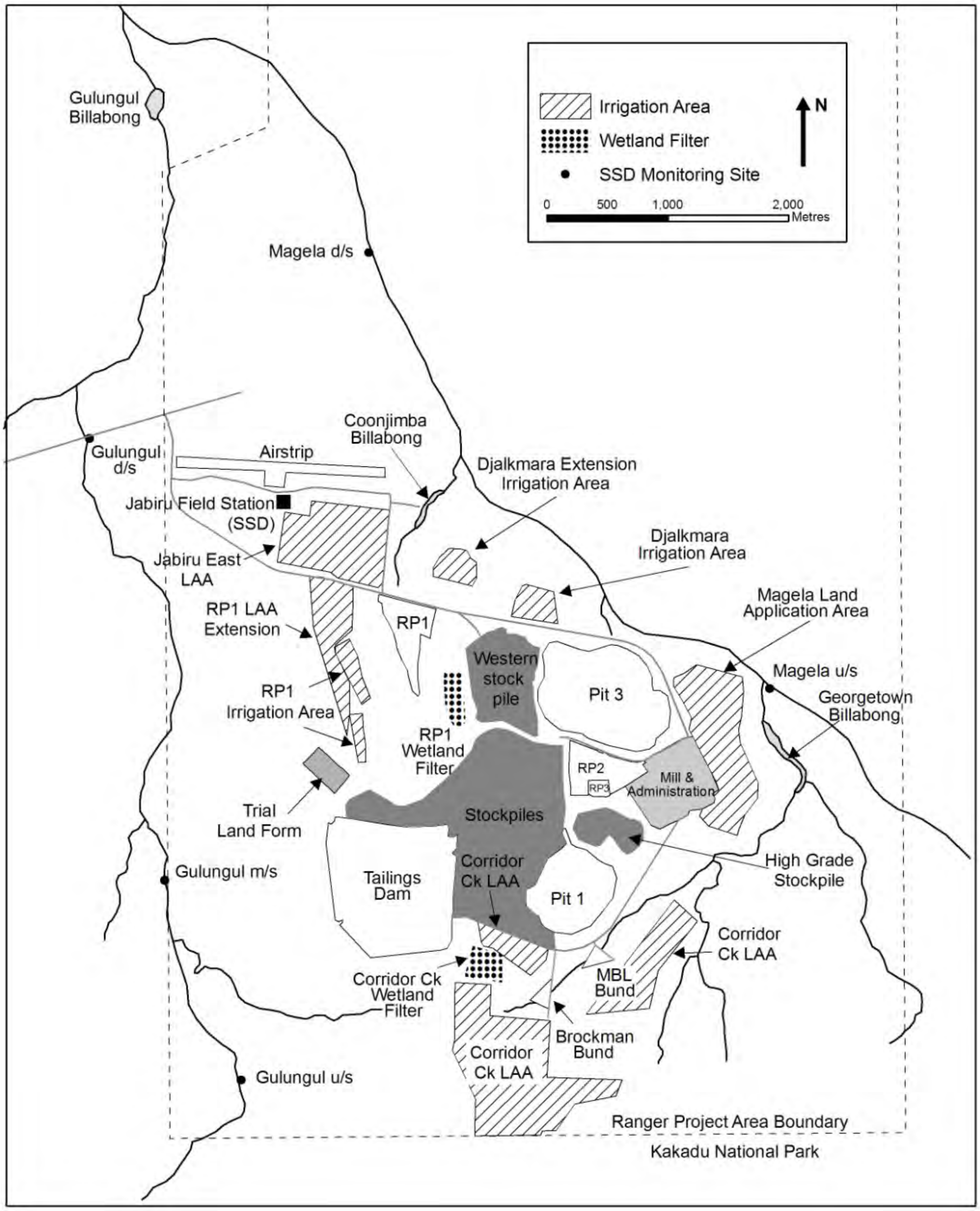
Funds were provided in the 2009–10 Federal Budget for a four-year program to progress and implement environmental maintenance activities, conduct appropriate environmental monitoring programs and develop contemporary site rehabilitation strategies at Rum Jungle under a national partnership agreement between the Northern Territory and the Australian Government. The Rum Jungle Technical Working Group (RJTWG) comprises representatives from the NT Department of Resources, NT Department of Natural Resources, Environment, the Arts and Sport, Australian Government Department of Resources, Energy and Tourism, the Northern Land Council and SSD. SSD has contributed to the work of the RJTWG during the reporting period.

I would like to offer my personal thanks to all the staff of the Supervising Scientist Division for their continued enthusiasm and efforts during the year. The commitment and professionalism of the division's staff remain vital factors in the division being able to fulfil its role in environmental protection.

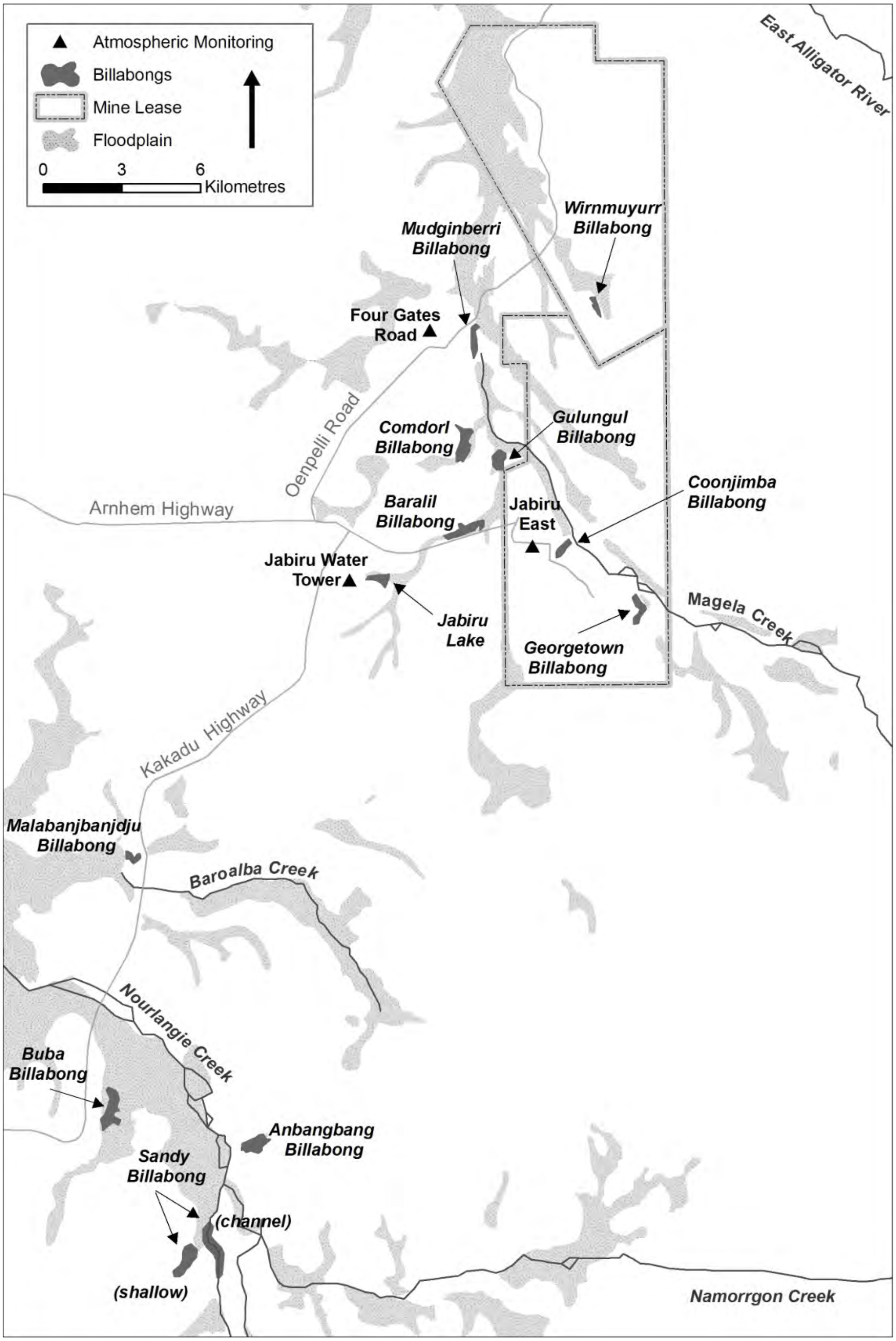
Alan Hughes
Supervising Scientist



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

ABBREVIATIONS

ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARR	Alligator Rivers Region
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
CERF	Commonwealth Environmental Research Facility
DRET	Department of Resources, Energy and Tourism
DoR	NT Department of Resources (formerly Department of Regional Development, Primary Industry, Fisheries and Resources**)**
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
G8210009	Magela Creek d/s (downstream) gauging station
GAC	Gundjeihmi Aboriginal Corporation
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
KKN	Key Knowledge Needs (prepared by ARRTC)
LAA	Land Application Area
MCUGT	Magela Creek u/s (upstream) site (formerly described as MCUS)
MTC	Minesite Technical Committee
NLC	Northern Land Council
NRETAS	NT Department of Natural Resources, Environment, the Arts and Sport
oss	Office of the Supervising Scientist
POSS	Parks Operational Support Section
POT	Parks Operation and Tourism Branch
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)
RPI	Routine Periodic Inspection
SEWPAC	Department of Sustainability, Environment, Water, Population and Communities
SSAR	Supervising Scientist annual report
SSD	Supervising Scientist Division
TSF	Tailings Storage Facility
UEL	Uranium Equities Limited

GLOSSARY

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.
airborne gamma survey	Aerial measurements of the terrestrial gamma radiation using a large volume sodium iodide (NaI) detector on board an aircraft.
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.
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.
bund	Embankment or wall designed to retain contents (usually liquids) in the event of leakage or spillage from a storage facility.

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.
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.
dose coefficient	The committed tissue equivalent dose or committed effective dose Sievert [Sv] per unit intake Becquerel [Bq] of a radionuclide. See definition of Sievert and Becquerel.
dose constraint	The International Commission on Radiation Protection (ICRP) defines dose constraint as '*a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation*' for assessing site remediation options.
early detection	Measurable early warning biological, physical or chemical response in relation to a particular stress, prior to significant adverse affects occurring on the system of interest.
ecogenomic	The use of short DNA sequences to identify the species in an environmental sample.
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.
GC2	Georgetown Creek 2 (ERA monitoring site)
GCMBL	Georgetown Creek Median Bund Leveline (ERA monitoring site)
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.
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.
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.
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).
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.
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).
MOL	Maximum Operating Level. The maximum level at which a liquid containing impoundment can be operated.
MCUGT	Current acronym for the upstream station u/s (formerly described as MCUS).
ore	A type of rock that bears minerals, or metal, which can be extracted.
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.
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.
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.
radiologically anomalous area	Area that displays significantly above background levels of radioactivity.
radionuclide	An atom with an unstable nucleus that loses its excess energy via radioactive decay. There are natural and artificial radionuclides. Natural radionuclides are those in the uranium (^{238}U), actinium (^{235}U) and thorium (^{232}Th) decay series for example, which are characteristic of the naturally occurring radioactive material in uranium orebodies.

radium	A radioactive chemical element that is found in trace amounts in uranium ores.
radon	Colourless, odourless, tasteless, naturally-occurring radioactive noble gas formed from the decay of radium.
Sievert (Sv)	Name for equivalent dose and effective dose 1 Sievert = 1 Joule·kg^{-1}. In contrast to the Gray, the Sievert takes into account both the type of radiation and the radiological sensitivities of the organs irradiated, by introducing dimensionless radiation and tissue weighting factors, respectively.
sonde	A water quality instrument that is immersed in water for measuring (typically) electrical conductivity, pH, turbidity and dissolved oxygen.
speciation (of an element)	The forms in which an element exists within a particular sample or matrix.
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).
tube stock	Young seedlings (usually wrapped in plastic tube or in stored in punnets) that have been germinated in a plant nursery.
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.

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.[1] 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 work of the Supervising Scientist. The branch also conducts research into the sustainable use and environmental protection of tropical rivers and their associated wetlands.

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[1] Following machinery of government changes on 14 September 2010, the department's name was changed from Department of the Environment, Water, Heritage and the Arts to the Department of Sustainability, Environment, Water, Population and Communities in line with the restructure of its portfolio responsibilities.

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 the department's Outcome 1:

> The conservation and protection of Australia's terrestrial and marine biodiversity and ecosystems through supporting research, developing information, supporting natural resource management, regulating matters of national environmental significance and managing Commonwealth protected areas

Outcome 1 is divided into five Outputs. During the 2010–11 financial year, the Supervising Scientist contributed to Program 1.2: Environmental regulation, information and research.

Further details on SSD activities during 2010–11 contributing to Program 1.2 are provided in Chapters 2, 3 and 5 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 indigenous people living in the Alligator Rivers Region. Further details on SSD communications activities during 2010–11 are provided in Chapter 5.

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, extending into western Arnhem Land. The World Heritage listed Kakadu National Park lies entirely within the Alligator Rivers Region.

The Ranger, Jabiluka and Koongarra 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.

Ranger is currently the only operational uranium mine in the Region. 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.

Development of the Koongarra uranium deposit is subject to traditional owner approval as required under the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976*. There are also a number of former uranium mines in the South Alligator River Valley that operated during the 1950s and 1960s. The Australian Government has funded the rehabilitation of a number of these former mines over the past four years.

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.

Current ERA planning is for mining at Ranger to cease in 2012 with processing of stockpiled ore to continue until 2020.

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 indigenous 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, discovered in 1970, is located about 25 km south-west of Ranger in the South Alligator River catchment. The Koongarra Project Area was added to the Kakadu World Heritage Area by the World Heritage Committee on 27 June 2011.

1.4.5 South Alligator Valley mines

During the 1950s and 1960s, several 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 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.

During 2010–11, SSD continued to assist Parks Australia with the implementation of the $7.3 million four year project for rehabilitation of abandoned uranium mining sites in the valley, announced by the Australian Government in May 2006. Further details on SSD involvement in this project are provided in Section 2.5.1 of this annual report.

2 ENVIRONMENTAL ASSESSMENTS OF URANIUM MINES

2.1 Supervision process

The Supervising Scientist utilises a structured program of audits and inspections, in conjunction with the Northern Territory Government and the Northern Land Council, 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.

2.1.1 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 Supervising Scientist Division 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. Each MTC is made up of representatives from the Northern Territory Department of Resources (DoR – which provides the Chair), the Office of the Supervising Scientist (***oss***), the Northern Land Council (NLC) and the relevant mining company. A representative from the Gundjeihmi Aboriginal Corporation is invited to attend each Ranger and Jabiluka MTC meeting. Other organisations or experts may be co-opted from time to time as required to assist MTC members.

2.1.2 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 Ranger mine, Jabiluka project area and Nabarlek mine. ***oss*** staff also participate in audits of exploration operations throughout the ARR.

Routine Periodic Inspections (RPI) take place monthly at Ranger, being the only operating minesite 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 environmental management as well as an opportunity for the inspection team to discuss environmental management issues with staff on site. These discussions may include any unplanned events or reportable incidents and any associated follow-up actions. The inspection team is made up of representatives from ***oss***, DoR and the NLC.

The rehabilitated former abandoned minesites locations at South Alligator Valley are also inspected at least once annually.

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

The annual environmental audits of Ranger and Jabiluka occur in April or May to assess each site under 'end of wet season' conditions. 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 and the annual environmental audit is conducted later in the year.

The audit outcomes are described later in this annual report.

2.1.3 Assessment of reports, plans and applications

The Authorisations for Ranger mine and the Jabiluka project area 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 DoR, which then considers applications after ***oss*** and the NLC 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 Minister.

The main reports and plans assessed by the Supervising Scientist during 2010–11 included:

- Ranger Amended Plan of Rehabilitation No 36
- Ranger Mine Water Management Plan
- Ranger Mine and Jabiluka Project Annual Environmental Reports
- Ranger Mine and Jabiluka Project Wet Season Reports
- Ranger Mine Annual Tailings Dam Inspection Report
- Ranger Mine and Jabiluka Radiation Protection Monitoring Program quarterly and annual reports
- Jabiluka Project Plan of Rehabilitation No 14
- ERA weekly environmental monitoring data and quarterly reports submitted in accordance with the Authorisations
- Applications by the mining companies for amendments to their Authorisations.

2.2 Ranger

2.2.1 Developments

On 28 January 2011 ERA advised stakeholders of a 12 week suspension of processing plant operations to stop any further processing-related inputs to the tailings storage facility (TSF) during the wet season. Higher than average rainfall meant that water levels in the TSF were higher than predicted for that time of year. The plant was shut down as a precautionary measure to ensure that levels in the TSF remained below the authorised operating limit. On 12 April 2011 ERA advised stakeholders that it had extended the mill shut-down until late July 2011. ERA commenced cold commissioning of the plant on 15 June 2011 with a view to resuming production in the mill in early July 2011.

On 25 February 2011 the Northern Territory Minister granted ERA permission to utilise the contingency wet season process water storage capacity between 52.5mRL (RL – relative level) and 53mRL in the TSF and between 14mRL and 15mRL in Pit 1 providing all inputs to the process water circuit other than incident rainfall ceased. The water level in the TSF reached the maximum operating limit (MOL) of RL52.5m on 26 February 2011, and reached 14mRL in Pit 1 on 9 March 2011. Process water in the TSF and Pit 1 ultimately reached maximum levels of 52.89mRL and 14.85mRL, respectively. The design crest level of the TSF is 54mRL, although the true crest level is slightly greater than this around 54.3mRL. The maximum operating level of the dam is 53mRL. If ERA had exceeded this level it was required to transfer water from the TSF directly to Pit 3 to ensure levels remained at or below 53mRL. SSD received regular updates on process water levels at Ranger throughout the wet season and provided advice to ERA on proposed process water management strategies.

The shutdown of the mill in the first quarter of 2011 resulted in a significant reduction in the volume of ore treated and the amount of U_3O_8 produced. The Ranger mill produced 2679 tonnes of uranium oxide (U_3O_8) during 2010–11 from 1 307 130 tonnes of treated ore (Table 2.1). 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 2.2.

TABLE 2.1 RANGER PRODUCTION ACTIVITY FOR 2009–2010 BY QUARTER

	1/07/2010 to 30/09/2010	1/10/2010 to 31/12/2010	1/01/2011 to 31/03/2011	1/04/2011 to 30/06/2011	Total
Production (drummed tonnes of U_3O_8)	911	1165	517	86	2679
Ore treated (‘000 tonnes)	531	515	171	88	1305

TABLE 2.2 RANGER PRODUCTION ACTIVITY FOR 2005–2006 TO 2009–2010

	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011
Production (drummed tonnes of U_3O_8)	5261	4926	5678	4222	2679
Ore treated (‘000 tonnes)	2136	2001	2042	2283	1305

2.2.1.1 On-site activities

Ranger Heap Leach Project

In March 2009 ERA submitted a referral under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) for the construction of a heap leach facility to treat low grade ore at Ranger. This referral was determined to be a controlled action and to be assessed by an environmental impact statement (EIS) managed under a bilateral agreement by the Northern Territory Government. Subsequent to this reporting period, in early August 2011, ERA considered the proposal to be unviable due to the current economic situation and stakeholder concerns and withdrew the proposal.

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. In May 2009 this proposal was deemed not to be a controlled action and would not require further assessment under the EPBC Act. After submission and review of several draft versions of the application, a final version was submitted to the Minesite Technical Committee on 24 June 2011. Satisfied that all aspects of this application have been adequately addressed by ERA, SSD advised the Northern Territory Government of its support for the approval of this application on 30 June 2011.

TSF wall raise to RL58m

In October 2010, ERA notified the MTC of its intent to raise the height of the TSF walls to RL57m. This was later revised to lift the walls to a maximum height of RL58m. ERA proposed that lifting the walls to RL58m would provide sufficient process water storage to support operations, enable environmental protection from significant rainfall events, allow Pit 1 closure activities to continue as planned, and provide time for detailed design, construction and commissioning of the brine concentrator in 2013. ERA is required to submit a separate application to raise the MOL of the TSF, which is expected to be provided to MTC members in Q3 2011.

Calciner replacement

ERA provided an outline of the process followed to replace and dispose of the original calciner from the processing plant. The information provided to SSD included a hazard assessment and disposal options for the calciner. Works to replace the original calciner were completed during August 2010 under the supervision of the Radiation and Hygiene team on site. ERA disposed of the calciner in Pit 1 and stakeholders confirmed the disposal of the vessel during a routine periodic inspection.

Water Management Activities

ERA submitted a range of proposals to the Supervising Authority to manage the increased pond and process water inventories resulting from the higher than average rainfall experienced at Ranger during the 2010–11 wet season. SSD participated in a working group convened by ERA that held weekly teleconferences to discuss site water levels and management strategies throughout the wet season.

TSF MOL to dry season storage capacity

An application for the contingency use of storage capacity in the TSF to the dry season MOL of 53mRL and to the top of the Pit 1 seepage limiting barrier at 15mRL was submitted to the MTC on 16 February 2011. Under the current authorisation ERA is permitted to store process water to a maximum level of RL53m from 1 May to 31 November and 52.5mRL during the period from 1 December to 30 April the following year, and to 14mRL in Pit 1. SSD provided conditional support for the application on 24 February 2011. The application was approved by the Northern Territory Minister on 25 February 2011.

Pit 1 to RL15.9m

ERA consulted with stakeholders, including SSD, on a proposal to store process water in Pit 1 to RL15.9m. The proposal outlined a strategy to pump process water from the TSF to Pit 1 to a maximum height of RL15.9m. Storing water to this height in Pit 1 would have exceeded the height of the seepage limiting barrier installed along the western boundary of the pit, but not exceeded the lowest standing water level in groundwater bores monitored around the pit. Following consultation with Geoscience Australia, SSD provided conditional support of the proposal to ERA and the Northern Territory Government. With the onset of the dry season ERA withdrew the proposal on 27 April 2011 and no approval was issued.

Pond water treatment brines to RP2

ERA conducted a review of the quality of pond water treatment plant brines to determine if the brines could be directed to RP2 without environmental impact. This review was undertaken as part of a site wide water management strategy to reduce inputs to the process water circuit. Brines are normally directed to the TSF in accordance with the approvals for operation of the water treatment plants. The review determined that the brine stream was of a quality to allow it to be directed to RP2 for a set period without long-term impact to the overall quality of water in RP2. ERA submitted an application to the MTC to direct brines to RP2 on 22 February 2011. SSD supported this application as an interim measure but reserved endorsement for this as a permanent water management strategy until the long-term effects on RP2 water quality have been demonstrated. The application received interim approval by the Northern Territory Government on 25 February 2011.

Wet season process water treatment

ERA submitted an application on 4 March 2011 to operate the process water treatment plant (WTP1) during the wet season to assist in disposal of process water. Under the approval issued by the NT Minister for Resources in 2005, ERA is authorised to release treated water from the process water treatment plant during the dry season only. ERA proposed to operate the process water treatment plant and direct treated water to cell 1 of the Corridor Creek wetland filter where it would be mixed with treated water from the Osmoflow treatment plant (WTP2). Additional dilution from rainfall inputs would reduce ammonia concentrations to below the approved limit of 2 mg/L. On 7 March 2011 SSD provided support for this application subject to a number of conditions relating to the monitoring and reporting of ammonia.

Softened water to RP2

In addition to other water management strategies proposed by ERA over the 2010–11 wet season, on 16 March 2011 ERA sought approval to direct process water softened by the high density sludge processor (HDS) to RP2 and/or Pit 3 prior to further treatment through the water treatment plants. Under normal operating conditions, water treated through the HDS continues through the process water treatment plant (WTP1) for pH adjustment and further treatment by ultra filtration/reverse osmosis (UF/RO). ERA proposed to pump water from the HDS directly to RP2 and/ or Pit 3 for up to 6 months or until such time that Pit 3 was successfully dewatered. SSD reviewed this initial application and additional supporting information was requested relating to performance of the HDS and water quality in RP2. SSD provided feedback to the Northern Territory Government on 20 April 2011 that included a range of conditions to be applied to any approval issued by the regulator. These conditions specified that the approval should only be issued for a trial not extending beyond the 2011 dry season. Amongst other recommended approval conditions, SSD specified maximum values for electrical conductivity (EC), calcium, aluminium and manganese that were not to be exceeded through the addition of the partially treated process water to the pond water system. On 30 May 2011 ERA notified stakeholders of its withdrawal of this application and as such no approval was issued by Northern Territory Government.

2.2.2 On-site environmental management

2.2.2.1 Water management

All water on site is managed in accordance with the Water Management Plan which is updated annually and subject to assessment by the Minesite Technical Committee (MTC) before approval. The 2010–11 Water Management Plan was submitted for approval by ERA on 1 October 2010. SSD endorsed the plan on 4 January 2011 and the document was formally approved by the Northern Territory Department of Resources (DoR) on 6 January 2011. The plan describes the systems for routine and contingency management of the three categories of water on site, process, pond and potable.

Water management remains a critical issue at Ranger mine. As shown in Figure 2.1, the 2010–11 wet season was the third largest on record with a total of 2457 mm recorded at Jabiru Airport to 30 June 2011, compared with an annual average of 1584 mm. Consequently, both the pond and process water inventories have increased compared with this time last year.

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 untreated process water to the surrounding environment during the reporting period.

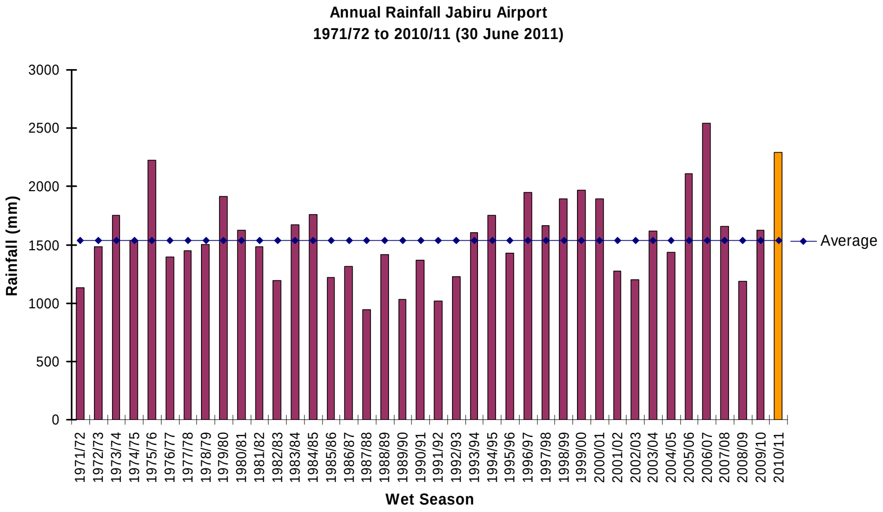


Figure 2.1 Annual rainfall Jabiru Airport 1971–72 to 2010–11 (data from Bureau of Meteorology)

The Process Water Treatment Plant (WTP1) was commissioned in late 2009 and utilised for treatment and discharge of process water permeate to the Corridor Creek wetland filter throughout Q4 2009. During this reporting period, WTP1 was used to treat pond and process water. A total of 1618 ML was treated through WTP1 to produce 1039 ML of permeate, which reported to the Corridor Creek wetland filter.

ERA commenced a lift of the TSF crest to RL58m in October 2010. At the end of the reporting period ERA was preparing information and supporting studies for an application to increase the MOL of the TSF in line with the crest raise.

On the 30 June 2011, the process water inventory was 10 694 ML, of which 10 384 ML was stored in the TSF. This represents an increase of 804 ML over the previous year's total of 9890 ML.

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 by quality. The pond water system consists primarily of Retention Pond 2 (RP2), Retention Pond 3 (RP3) and Pit 3. Water from RP2, RP3 and Pit 3 may not be released without prior treatment through wetland filtration and/or irrigation. At the end of the reporting period 4133 ML was contained within the system representing an increase of 2848 ML over the previous year. The increased pond water inventory is due to high rainfall experienced on the site during the extended 2010–11 wet season.

Runoff from sheeted stockpiles into the Corridor Creek wetland filter generated from the first 200 mm of rainfall 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 that occurs in the early stages of the wet season, from freshly mined rock.

Methods of disposal of pond water

Passive release water

Rainfall runoff discharges from the Ranger site during the wet season primarily via Corridor Creek and Coonjimba Creek with much 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. RP1 wetland filter was used during the 2010 dry season to polish water prior to irrigation to the RP1 and RP1 extension land application areas. Due to chemical changes in the feed water to the wetland filter and reduced filter performance in recent years, ERA has committed to cease use of RP1 wetland filter in future years. The Corridor Creek wetland filter receives runoff from specially prepared sheeted areas of low grade and waste rock stockpiles. The surfaces of these stockpile areas are compacted to minimise infiltration and hence contribution of additional water to the RP2 pond water system via seepage. An interception trench has been installed around the western perimeter of the western stockpile to capture seepage and redirect stockpile runoff away from RP1. This measure has resulted in an improvement to water quality in RP1. Water is passively released from RP1 via the sluice gate when the water level in RP1 exceeds the height of the spillway. In Corridor Creek, passive release of waters retained upstream of ERA monitoring site GC2 occurred throughout the 2010–11 wet season.

Managed release water

Controlled discharge of RP1 via siphons/pumping over the weir occurred from January through to mid-April 2011 to reduce the overall pond water inventory during periods of higher flow in Magela Creek. ERA manually controls the discharge of runoff water via four sluice gates along the Ranger access road. Release from these gates occurred on several occasions during the 2010–11 wet season.

ERA was granted interim approval through the Water Management Plan for the discharge of RP1 water to Magela Creek from the MG001 site over the 2010–11 wet season. Discharge occurred periodically throughout the 2010–11 wet season under high flow conditions in Magela Creek and a total volume of approximately 424 ML of RP1 water was released via MG001.

Pond water treatment

The two water treatment plants were in operation throughout the reporting period, with WTP1 being offline during September and October 2010, and early February 2011. The Osmoflow water treatment plant (WTP2) treated 1990 ML of pond water during the reporting period to produce 1418 ML of permeate. Treated permeate was discharged to the Corridor Creek wetland filter and from there passively released to Magela Creek via ERA monitoring sites GCMBL and GC2. As stated above, ERA gained approval for the temporary storage of water treatment plant brines in RP2 during the 2010–11 wet season.

Land application areas

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 disposal. Jabiru East and RP1 land application areas were operational during the 2010 dry season. Corridor Creek and RP1 land application areas are being utilised during the 2011 dry season.

2.2.2.2 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 from the milling and processing of ore from Pit 3 ceased in December 2008 when tailings reached the maximum permitted level of RL12m. All inputs to the TSF ceased during the 2011 mill shut down period to ensure the maximum operating level of process water in the TSF did not exceed 53mRL. After the mill is recommissioned and processing resumes, tailings will be discharged to the TSF via a floating discharge pipe that is moved regularly to achieve an even deposition of tailings across the footprint of the dam.

The average density of tailings in Pit 1 at June 2011 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 reported to be 1.0 t/m^3.

2.2.2.3 Audit and Routine Periodic Inspections (RPIs)

Eleven inspections and one audit were undertaken at Ranger during the 2010–11 reporting period. Findings from the May 2010 environmental audit were reviewed throughout the following RPIs and an acceptable outcome was achieved for all but one finding. This item remains outstanding. An audit of selected sections of the Ranger Authorisation 0108-12 as well as several incident recommendations was undertaken in May 2011. RPIs were carried out for each other month of the 2010–11 reporting year with the exception of May. Table 2.3 shows the focus areas for the audit and RPIs for the year.

Audit outcomes

Closeout of findings from the May 2010 environmental audit

The May 2010 audit of the Ranger Radiation Management Plan delivered 8 significant findings, ranked:

- 2 x category 2 non-conformance
- 6 x conditional

These findings were followed up via the monthly RPI process with all conditional and one category 2 non-conformance corrective actions implemented to achieve an acceptable rating prior to the 2011 audit. Corrective actions to adequately address the second category 2 non-conformance, relating to the system for managing controlled area vehicles on site, were not finalised prior to the 2011 audit.

Since the 2010 audit stakeholders have been engaged in ongoing discussions with ERA regarding improvements to the system to manage controlled area vehicles on site. Two incidents involving controlled area vehicles leaving site were reported to stakeholders during 2011 indicating that the system to manage controlled area vehicles still requires improvement. During the Routine Periodic Inspections (RPI) following the 2010 audit stakeholders were kept informed of progress made by ERA to address this non-conformance. At the MTC of 12 May 2011, ERA presented a proposal to improve the system for managing controlled area vehicles by installing an electronic tagging and sensor system at the gatehouse to prevent controlled area vehicles from leaving site. At the time of the 2011 audit an effective system to ensure controlled area vehicles do not leave site was still not in place, one year on from the original audit finding in 2010. This category 2 non-conformance was therefore escalated to a category 1 non-conformance and will remain as an outstanding finding against the 2010 audit until adequately addressed.

TABLE 2.3 AUDIT AND RPI

Date	Foci
20 July 2010	Mill and plant area, GCMBL, Corridor Creek land application area, western stockpile seepage interception trench, RP1 spillway, Pit 3
17 August 2010	CCD overflow incident, raffinate line, product packing, tailings transfer pumps
21 September 2010	TSF ring road contamination investigation, TSF ring road drains and on-line monitoring, tailings pumping area, process water header tank, ammonia storage area, western stockpile seepage interception barrier
20 October 2010	Primary crusher, radiation source storage, controlled area vehicles, airport land clearing, Magela boat ramp and pontoon installation
17 November 2010	Contingency process water pump – TSF to Pit 3, Corridor Road sump and bund, RP2 spillway, JELAA bund, drill core storage
14 December 2010	TSF ring road, swale drains and sumps, other sumps including Sed2B, CB2, western stockpile seepage trench and sumps, landfill and hydrocarbon remediation facility, assessment of completed findings from May 2010 audit
18 January 2011	Heavy vehicle workshop drainage and oil/water separator, fine crushing area, Magela exploration area, MG001 discharge point, Jabiru East core storage area
15 February 2011	Power station, incident follow-up, verbal update on water levels across site and progress of existing actions and audit findings *Reduced agenda due to inclement weather and access conditions on Arnhem Highway*
15 March 2011	Release plan calculator, water treatment plants, trial landform, 2010 audit findings, processing plant maintenance schedule
19 April 2011	General maintenance works, solvent extraction, CCDs, tailings pump, Magela land application area exploration, Pit 3
16–18 May 2011	Audit : Schedules 5, 6 and 7 of Authorisation 0108-12, recommendations from DRET Minister following potable water contamination incident, recommendations from NT Government following compressed air contamination incident
14 June 2011	Jabiru East land application area, waste hydrocarbon storage, bulk fuel unloading, turbo burning yard, TSF lift, crusher scrubber sump, location of proposed TSF lift clay borrow pit, location of proposed exploration decline portal

May 2011 environmental audit

The 2011 environmental audit of Ranger mine was held on 16–18 May 2011. The audit team was made up of representatives from the NLC, DoR and ***OSS***. The subject of the 2011 audit was Schedules 5, 6, 7 and Annex C of Ranger Authorisation 0108-12, recommendations included in the 2004 letter from DRET Minister McFarlane to ERA CEO following the 2004 potable water incident and Northern Territory Government recommendations following 2004 ADU contamination in product packing (compressed air incident).

Eighty commitments were audited against the ranking system shown in Table 2.4. Use of this ranking system ensures the outcomes of the Ranger auditing process are consistent with other mines in the Northern Territory.

TABLE 2.4 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.

The following significant findings were determined from the 80 commitments audited:

- 4 x category 2 non-conformances
- 3 x conditional

A number of observations were made throughout the audit and reported to ERA in the closing meeting and in the audit report. All other findings were ranked as acceptable or not verified.

The category 2 non-conformances are outlined below.

Prior to December 1 each year the operator shall provide sufficient evidence that capacity and contingency exists within the process circuit to contain a wet season equivalent or *greater than the largest wet season on record or a season of 1 in 1000 year return interval, whichever is the greater, without exceeding RL53.0m AHD in the tailings dam.*

The document provided on 1 December 2010 did not provide sufficient evidence that capacity and contingency existed within the process circuit. This document, along with subsequent responses by ERA to stakeholder information requests, were not of satisfactory quality, nor were they provided in a timely manner, given the situation at the time the document was submitted. Although not part of the process water circuit, the use of Pit 3 (ie pond water circuit) has been approved as a contingency storage for process water approaching or exceeding RL53m in the TSF, in the current and previous versions of the Water Management Plan. With Pit 3 available as the ultimate contingency, there was a low risk of the release of process water to the surrounding environment although this contingency is generally considered to be undesirable.

All mine site employees shall attend an induction course, which shall explain the environment protection and monitoring programs, radiation protection and responsibilities, Aboriginal culture, and the plan of management of Kakadu National Park.

ERA was not able to demonstrate that all mine site employees and contractors had attended a mine site induction within the prescribed timeframe.

All excavated material shall be managed such that there is no detrimental environmental impact outside the Ranger Project Area, and that environmental impacts within the Ranger Project Area are as low as reasonably achievable.

Calibration records showed that the primary calibration of the discriminator was not completed in January 2011 in line with the manufacturers requirements.

ERA should ensure that staff who undertake radiation clearance procedures are adequately trained in all practical aspects of radiation clearance, should review its procedures for the monitoring of the movement of vehicles on site and should ensure that all vehicles that have been in controlled areas are checked for radiation clearance certificates at the Security Gate.

Two incidents of controlled area vehicles leaving the site through the gatehouse were reported to stakeholders in 2011. This criterion was graded as a category 2 non conformance as these vehicles were not subject to a radiation clearance and as such were not issued with a clearance certificate.

The 3 conditional findings related to the following:

- landfill management
- minimising the volume of contaminated water required to be managed on site
- non-return valves within the potable water circuit.

oss will continue to follow up on all identified non-conformances and ensure the close-out of corrective actions through the RPI process.

2.2.2.4 Minesite Technical Committee

The Ranger Minesite Technical Committee met eight times during 2010–11, including two out-of-session special MTCs. Dates of meetings and issues discussed are shown in Table 2.5.

Significant agenda items discussed at MTCs included updates from ERA on site activities including the heap leach and exploration decline projects, updates from the Ranger Closure Criteria Working Group, the Radiation Management Plan and process water management strategies. The Ranger Closure Criteria Working Group reconvened in June 2008. Terms of reference have been established for the group, which is working to develop and agree upon closure criteria for Ranger. The working group met 4 times during 2010–2011.

TABLE 2.5 RANGER MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items in addition to standing items
8 July 2010	Application to optimise the radiation and atmospheric monitoring program, Information and Compliance policies and procedures, RP1 releases upstream of Coonjimba and MG001, clay borrow failure, radiation reporting, western stockpile, and provision of monitoring data.
9 September 2010	Heap Leach EIS and exploration decline application, Annual Plan of Rehabilitation no.35, Jabiru East Accommodation Village, radiation reporting, RP1 spillway and GC2 control structures.
14 October 2010	Special MTC: Process water management strategy update, action plan, alternatives and contingencies, status of covered evaporators, brine concentrator, TSF lift, Pit 1 closure, tailings transfer to Pit 3
11 November 2010	RP1 release to MG001, TSF ring road materials, TSF groundwater issues, Water Management Plan, TSF wall raise, discrepancy with the lease boundaries, rock material for boat ramp construction
13 January 2011	Mining Management Plan requirement, groundwater radium and uranium data, release criteria and trigger values for Gulungul catchment, process water capacity and contingency for 2010/11 wet season
11 March 2011	Authorisation requirements for process water capacities, recommendations from the TSF review (Weaver report), contingency process water storage in TSF and Pit 1, temporary storage of pond water treatment plant brines in RP2, wet season operation of the process water treatment plant, best practice water sampling, maximum operating level of the TSF
12 May 2011	Heap Leach EIS and exploration decline applications, Annual Plan of Rehabilitation no.36, storage of process water in Pit 1 to RL15.9m, requirement for non-return valves, Schedule 5.2 of the Authorisation, controlled area vehicles
23 June 2011	Special MTC: Ranger Water Management Strategy, overview of water management and planning, major studies, brine concentrator

2.2.2.5 Authorisations and approvals

There were no changes to the Ranger Authorisation during the reporting period. The current version of the Authorisation (0108-12) was issued on 18 December 2009.

2.2.2.6 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, ***oss*** 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 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 routine periodic inspection (see section 2.1.2), the inspection team reviews the previous month's environmental incident report summary (EIRS) and any open issues. Where incidents are considered to have any potential environmental significance or represent repetitions of a class of occurrences, an on-site review is scheduled as a part of the routine inspection protocol.

oss determined that no incidents that occurred during the reporting period were of a serious enough nature to warrant a separate independent investigation, however, the following incidents were followed up as part of the routine periodic inspections.

Jabiru airstrip clearing

In October 2010 ERA cleared land at the Jabiru airstrip to conform to the requirements of the Civil Aviation Safety Authority. During the works ERA informed Stakeholders that approximately 1.3 ha of vegetation was cleared beyond the Ranger project area. Upon investigation it was discovered that due to a datum discrepancy the Ranger project area boundary was incorrectly identified on some Government mapping products and consequently the vegetation clearing works had actually occurred inside the Ranger project area boundary. No vegetation outside of the Ranger project area had been cleared. SSD followed up on the lease boundary discrepancies and the matter is now being discussed through the MTC.

Controlled area vehicles leaving site

Two incidents of controlled area vehicles leaving site were reported to stakeholders during the reporting period. The first occurred on 24 November 2010 and involved a contractor driving a controlled area vehicle to the car park to collect work tools. After being identified and returned to site, the vehicle was assessed and determined to not have any loose contamination present on the outside or underside surfaces of the vehicle and there was no evidence that contaminated material fell off the vehicle whilst in the car park. The second incident was reported to stakeholders on 6 April 2011 and involved a clean controlled area vehicle driving offsite to the Jabiru airport. Upon return to site, the Radiation and Hygiene

Team assessed the vehicle and confirmed that it was clean and no sources of contaminated material were deposited on the road whilst the vehicle was offsite. Following the second incident SSD wrote to DoR to request that ERA undertake a best practicable technology assessment of options to address the system of controlled area vehicles leaving site. ERA presented the findings of their assessment and a timeframe for implementation to the MTC on 12 May 2011.

Disposal of product to Pit 1

On 6 May 2011 ERA advised that material intended for re-introduction to the processing plant (following the shut down period) had been inadvertently disposed of in Pit 1. Three drums had been filled with material to be processed and were included in a pallet of drums disposed of in Pit 1 as part of plant clean-up works. ERA advised the relevant authorities that only one of the three drums of processing material was able to be recovered from Pit.

Spool failure and tailings leak

In July 2010 ERA reported a 150 L leak of tailings slurry from the plant, which sprayed outside the controlled area bund following a failure of a pump discharge spool. A similar incident was again reported on 8 September 2010 whereby a pump discharge spool developed a hole and sprayed process slurry over a bund wall and onto the surrounding area.

On 27 June 2011 ERA reported a leak of tailings from an expansion joint on tailings line pump B. Approximately 10L of tailings seeped through the gap between the bund and screens surrounding the area, which was then contained and cleaned up. Tailings did not leave the mine area in any of these incidents.

SSD followed up on these incidents 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.

2.2.3 Off-site environmental protection

2.2.3.1 Surface water quality

Under the Authorisation, ERA is required to monitor and report on water quality in Magela and Gulungul Creeks adjacent to 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, DoR and NLC). 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 in Magela and Gulungul Creeks, and biological monitoring in Magela and Gulungul Creeks as well as other reference creeks and waterbodies in the region. Key results (including time-series charts of key variables of water quality) are reported by the Supervising Scientist through the wet season on the Internet at www.environment.gov.au/ssd/monitoring/index.html. The highlights of the monitoring results are summarised below.

Chemical and physical monitoring of Magela Creek

During 2010–11, SSD modified its routine wet season monitoring program, with continuous monitoring of EC, turbidity, pH and water temperature coupled with event-triggered automatic sampling replacing weekly grab sampling as the primary water quality monitoring method. This change substantially enhanced SSD's ability to independently detect changes in water quality through time. In addition to continuous monitoring, manual grab samples are taken every two weeks from Magela Creek for radium analysis and every four weeks for measurement of physicochemical parameters (pH, EC, turbidity) and analysis of key mine-related solutes, for quality assurance purposes. Map 2 shows the location of the upstream and downstream monitoring sites and key Ranger Mine features.

From early November 2010, until mid December, flow in Magela Creek was intermittent with a peak flow of 3.4 cumecs occurring on 29 November 2010. During this period the probes at the Magela Creek upstream station were periodically out of the water resulting in no data reporting for the period between 11 and 24 November 2010. The probes at the Magela Creek downstream monitoring station (MCDW) reported for the whole of this period but were frequently in stagnant water resulting in a stepped response in EC to individual flushing events (Figure 2.2).

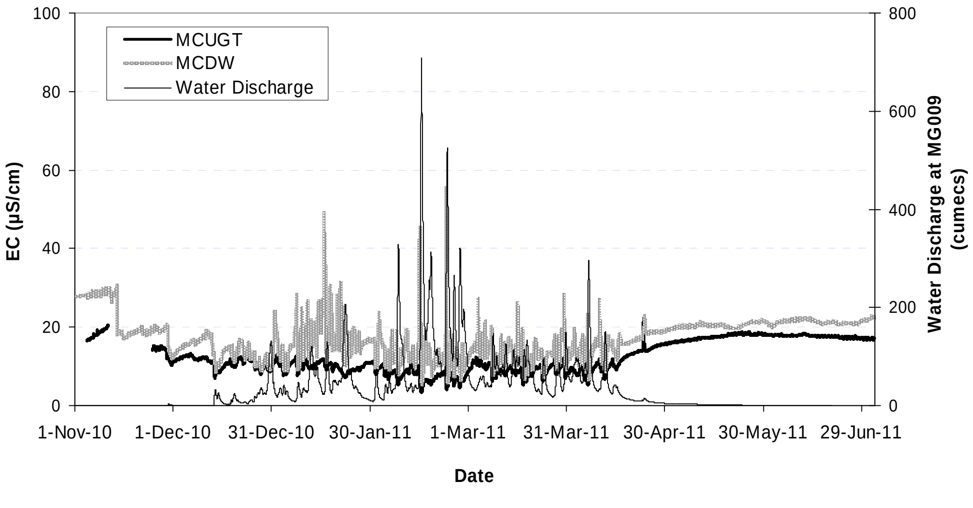


Figure 2.2 Electrical conductivity and discharge measurements in Magela Creek between November 2010 and July 2011

Flow remained very low until mid-December 2010 when flows increased due to rainfall events, which resulted in several peaks in turbidity at both the upstream and downstream monitoring stations (Figure 2.3) typical of first flush conditions. During December 2010, EC remained < 20 µS/cm at both monitoring stations except for a small peak of 23.3 µS/cm at MCDW on 31 December 2010. Several more small EC peaks were recorded during early

January 2011, but these were all below the statistically derived EC guideline value for grab samples.

On 15–16 January, EC peaked at 50 μS/cm during a 12 hour event, with EC remaining above the guideline of 43 μS/cm for 2.5 hours during this time. Uranium concentrations in automatic samples collected during this EC event remained below 0.3 μg/L, less than 5% of the 6.0 μg/L uranium limit (Figure 2.4). Manganese peaked at 19.3 μg/L during the beginning of this event (Figure 2.5), which lies within the historic grab sample range for Mn for this site (2.08–48.1 μg/L) and is below the guideline of 26 μg/L. Magnesium and sulfate concentrations closely followed the EC continuous monitoring peak with concentrations peaking at 3.4 mg/L and 12.6 mg/L, respectively. These concentrations are less than 0.5 mg/L greater than the historic grab sample ranges for these analytes at this monitoring site.

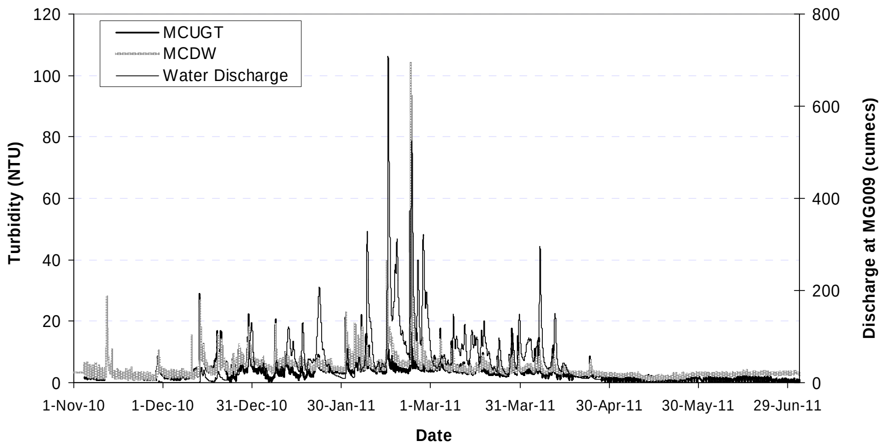


Figure 2.3 Turbidity and discharge measurements in Magela Creek between November 2010 and July 2011

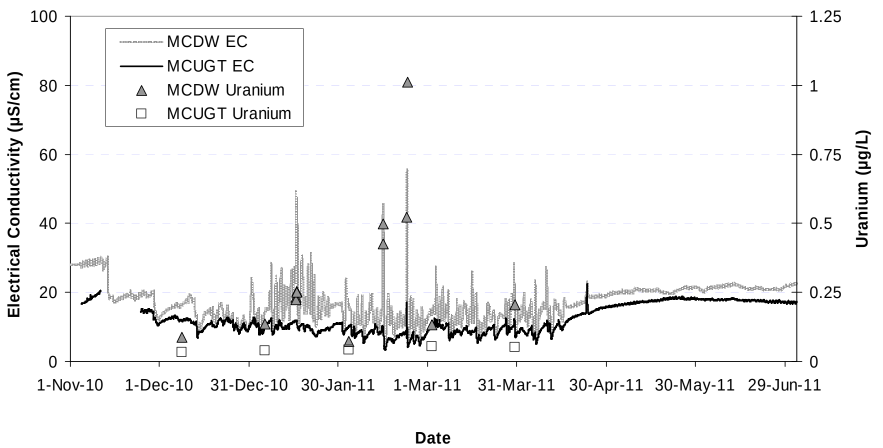


Figure 2.4 Electrical conductivity and total uranium concentrations in Magela Creek between November 2010 and July 2011

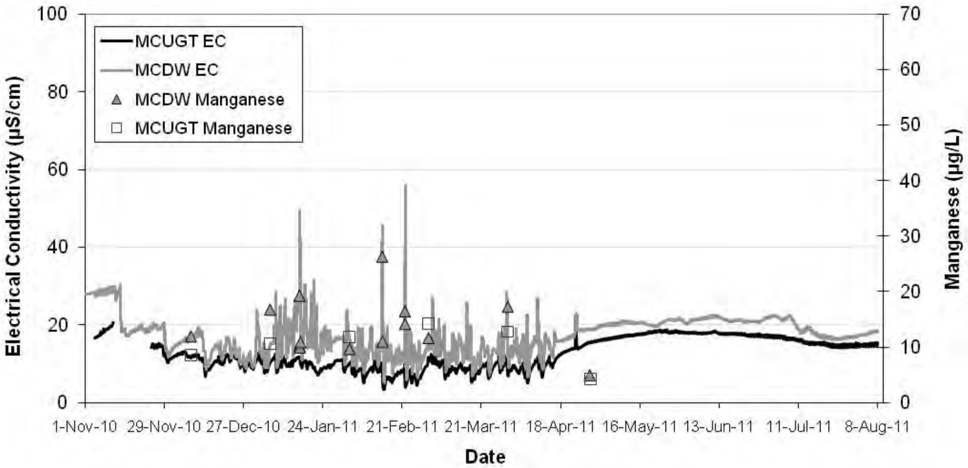


Figure 2.5 Electrical conductivity and total manganese concentrations in Magela Creek between November 2010 and July 2011

EC levels were stable at the upstream monitoring site through late January and early February, and showed some minor fluctuations at MCDW with a maximum EC of around 30 µS/cm.

On 13–14 February EC peaked at 46 µS/cm during a 14 hour period with EC remaining above the guideline of 43 µS/cm for 1.7 hours during this time. Two samples were collected by autosampler, containing uranium and manganese concentrations up to 0.498 µg/L and 26.3 µg/L respectively. Concentrations of magnesium (3.4 mg/L) and sulfate (11.8 mg/L) closely follow the EC (Figures 2.6 & 2.7). As the EC declined on 14 February in advance of a peak in Magela Creek discharge of 709 cumecs there was a turbidity peak of 42 NTU at MCDW (Figure 2.3).

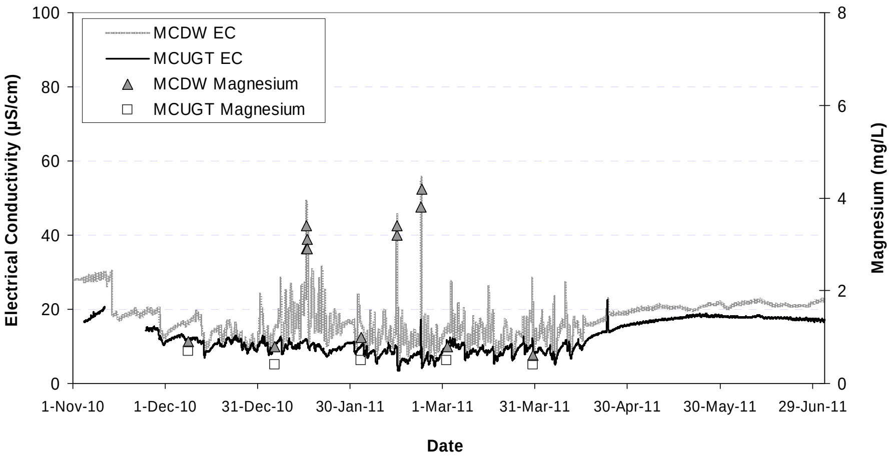


Figure 2.6 Electrical conductivity and total magnesium concentrations in Magela Creek between November 2010 and July 2011

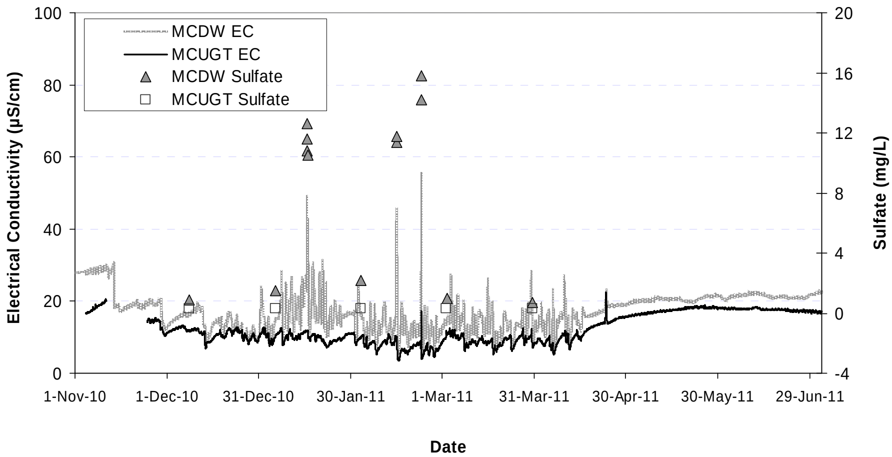


Figure 2.7 Electrical conductivity and total sulfate concentrations in Magela Creek between November 2010 and July 2011

On 22 February the MCDW EC peaked at 57 µS/cm during a 4 hour event with EC remaining above the guideline of 43 µS/cm for 1.75 hours during this time. Two autosamples were triggered, which contained uranium and manganese concentrations up to 1.01 µg/L and 16.5 µg/L respectively. This would equate to a filtered uranium value of between 0.6-0.8 µg/L, as compared with the limit of 6 µg/L. Concentrations of the major ions magnesium and sulfate were 4.2 mg/L and 15.8 mg/L, respectively.

As the EC decreased due to an increase in flow, there was a peak in turbidity. The turbidity peak occurred following a 190 mm rainfall event and is likely to be due to surface runoff from areas both on and off the mine site.

Water levels decreased during March with EC and turbidity being relatively stable. This continued through April with EC remaining below 30 µS/cm. A brief increase in flow was noted on 6 April in response to a 22 mm rainfall event. A local rainfall event on 23 April caused minor peaks in EC and turbidity at both monitoring sites. SSD completed an investigation into a low magnitude EC spike noted at the SSD upstream site in the early hours of 22 February 2011 (Figure 2.8), which was not detected at the ERA site further upstream (Figure 2.8). Such an occurrence had not been observed before and it was important to investigate the source of the EC in the context of the robustness of our upstream reference site and the data produced.

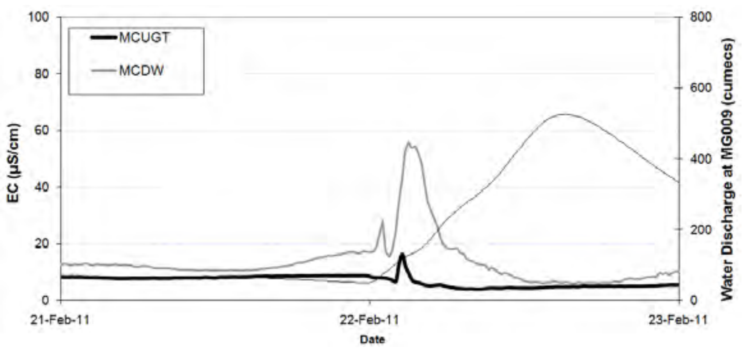


Figure 2.8 Magela Creek continuous monitoring data for the period 21–23 February 2011

A field inspection showed that discharge flow from Georgetown Billabong had over-topped the bar dividing the exit channel from the billabong and Magela Creek, thereby registering an elevated EC response at SSD upstream monitoring station. This was caused by an unusual localised high intensity rainfall event which delivered approximately 170 mm in just over 2 hours. This caused a rapid increase in discharge from the Georgetown catchment prior to flows having risen in Magela Creek. Without the hydraulic dam effect of high flow in Magela Creek, flows from Georgetown Billabong were able to push into the Magela central channel over the top of the channel divide. The effect quickly diminished as flow in Magela Creek increased.

Given that such incidents are very rare, and their occurrence easily identified, SSD does not consider relocation of the upstream monitoring station to be warranted.

Recessional flow conditions became established in Magela Creek in late April. These conditions are typified by a falling hydrograph, with EC stabilising and rising slowly as groundwater input becomes the dominant contributor to flow.

Continuous monitoring continues until cease to flow is agreed by stakeholders or until the multi-probes are out of water and cannot be lowered any further, regardless of continuous flow still occurring between the upstream and downstream monitoring locations.

Overall, the water quality measured in Magela Creek for the 2010–11 wet season is comparable to previous wet seasons, with the results indicating that the aquatic environment in the creek has remained protected from mining activities (Figure 2.9).

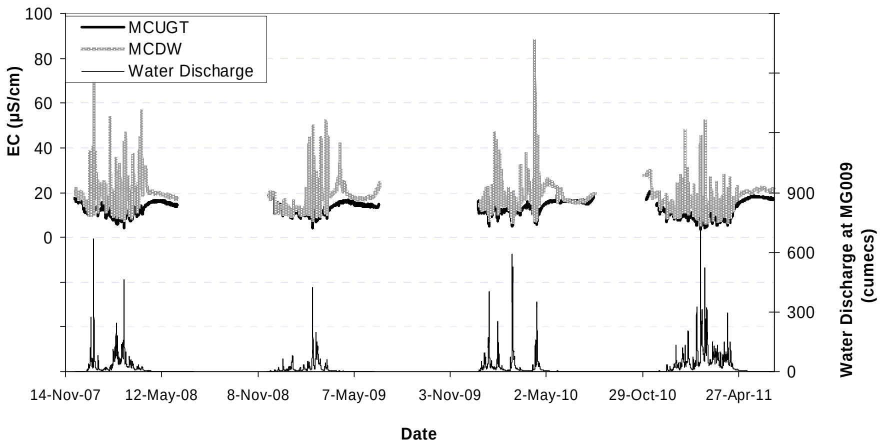


Figure 2.9 Electrical conductivity measurements and discharge (lower trace) in Magela Creek between December 2007 and July 2011 (this chart uses 1 hour mean values)

Radium in Magela Creek

Radium-226 (^{226}Ra) results for the 2010–11 wet season can be compared with previous wet season data back to 2001–02 (Figure 2.10).

The data from sample composites (weekly collected samples were combined from 2006–07 onwards to give monthly averages) show that the levels of ^{226}Ra are very low in Magela Creek, including downstream of the Ranger mine. The anomalous ^{226}Ra activity concentration of 8.8 mBq/L 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 result has previously been explained in the 2004–05 Supervising Scientist annual report.

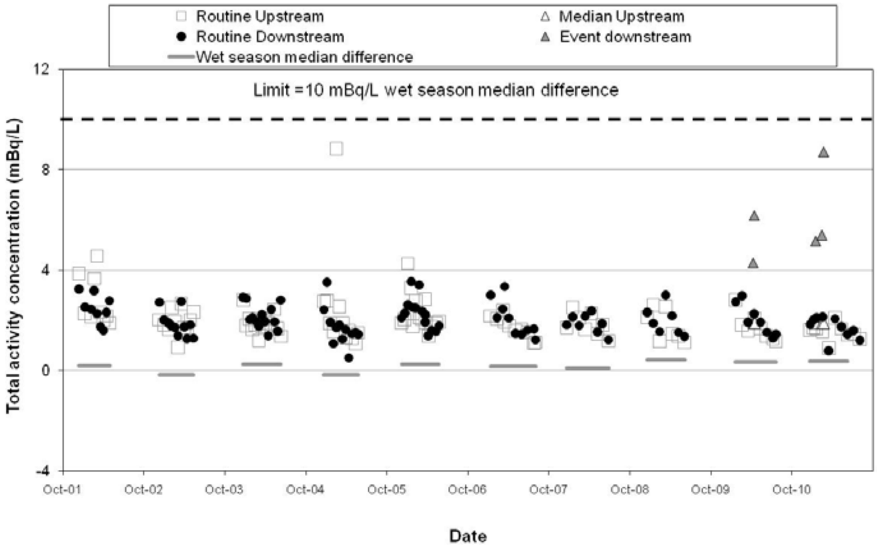


Figure 2.10 Radium-226 in Magela Creek 2001–2011

Composite samples from MCDW were collected by autosampler during EC-triggered events on 15–16 January 2011, and 14 and 22 February 2011. However, there were no upstream samples collected since there was no EC pulse upstream to trigger the autosampler. To enable an activity difference to be calculated the median of all previous upstream routine ^{226}Ra results (2001–2010) was used as a reference.

Since 2011, radium analyses of composites from samples collected by autosampler during EC-triggered events have been included in the radium analysis and dose estimate. The higher radium concentrations seen in Figure 2.10 are a consequence of our new automated sampling method which enables us to capture these EC events. These events are short-lived and their impact on seasonal ^{226}Ra loads is likely to be small. Including these values provides a more conservative estimate of dose.

The limit value for total ^{226}Ra activity concentrations has been defined for human radiological protection purposes and is based on the difference between upstream and downstream ^{226}Ra activities. The median of the upstream data ^{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. This difference value should not exceed 10 mBq/L.

Wet season median differences (shown by the grey horizontal lines in Figure 2.10) from 2001 to 2011 are close to zero, indicating that the majority of ^{226}Ra at both sites in Magela Creek is coming from natural sources of Ra in the catchment.

Chemical and physical monitoring of Gulungul Creek

Flow was first observed at the Gulungul Creek downstream monitoring station (GCDS) on 14 December 2010. Continuous monitoring commenced on 15 December 2010 when flow was established and water depths in the creek were sufficient for deployment of the monitoring multi-probes. Water levels gradually increased due to successive rainfall events, which resulted in peaks in turbidity at both monitoring stations. Peaks in turbidity during late December 2010 and early January 2011 are primarily associated with increasing water levels within the creek and localised rainfall events.

EC increased from the end of December and peaked at the upstream (GCUS) and GCDS monitoring stations at 27.7 µS/cm on 4 and 5 January 2011, respectively. EC peaks were recorded at both the upstream and downstream monitoring sites between 7 and 11 January 2011 (see insert in Figure 2.11). However, the magnitude of the EC increase was much greater at GCDS. Continuous monitoring data from SSD's Gulungul Creek Mid (GCMid) monitoring station (not shown) suggests the source of the increased EC lies between GCMid and GCDS.

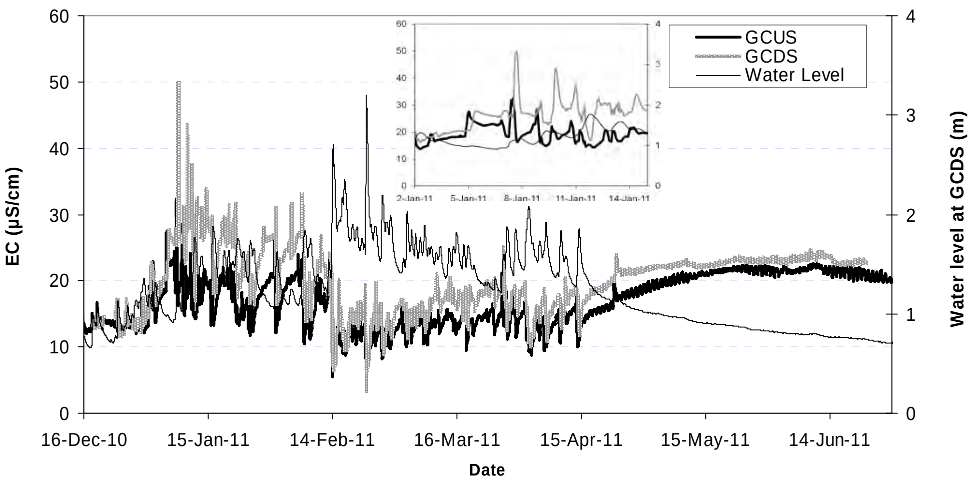


Figure 2.11 Electrical conductivity and water level in Gulungul Creek between December 2010 and July 2011. GCUS is Gulungul Creek upstream of the mine and GCDS is Gulungul Creek downstream of the mine.

Uranium concentrations from samples collected by autosampler at GCDS during these EC events remained below 0.6 µg/L, less than 10% of the 6.0 µg/L uranium limit for Magela Creek (Figure 2.12). Manganese concentration peaked at 17.8 µg/L (Figure 2.13), which lies within the historic grab sample range for this site (0.68–18.1 µg/L). Magnesium and sulfate concentrations closely followed the EC continuous monitoring peak (Figures 2.14 & 2.15). Investigations by ERA suggest the source of the increased EC is salts leached from the fresh rock used in recent TSF wall raises. Recent improvements that have been made to the water management system around the base of the TSF means that water shed from the western and southern walls of the TSF is now being contained in constructed ponds and pumped back to the pond water system.

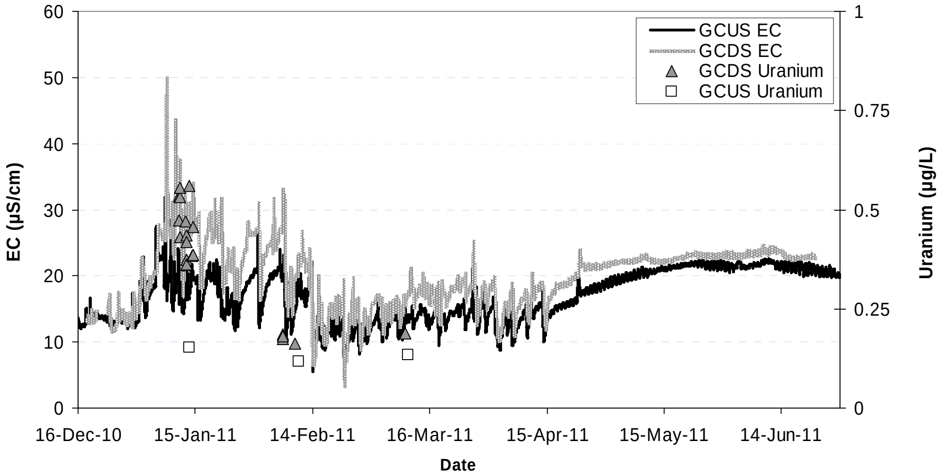


Figure 2.12 Electrical conductivity and total uranium concentrations in Gulungul Creek between December 2010 and July 2011

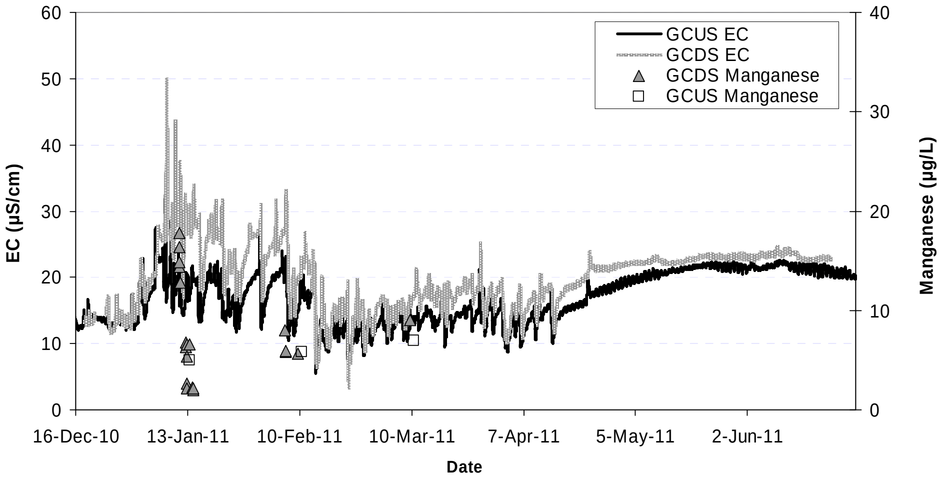


Figure 2.13 Electrical conductivity and total manganese concentrations in Gulungul Creek between December 2010 and July 2011

A rise in EC levels at both monitoring sites occurred in late January and early February as water levels decreased. Turbidity peaks which occurred at the upstream site on 15 and 24 January 2011 were also observed at the downstream site but at a much lower magnitude. This type of behaviour is consistent with that typically observed in the upper catchment of small creeks. On 14 February there was a turbidity peak of 84 NTU at GCUS in advance of a peak in water level due to heavy rainfall (Figure 2.16). At GCDS the turbidity remained relatively low, peaking at 15 NTU. During this time EC decreased at both monitoring points to <10 µS/cm. During late February and March EC gradually increased as flow decreased.

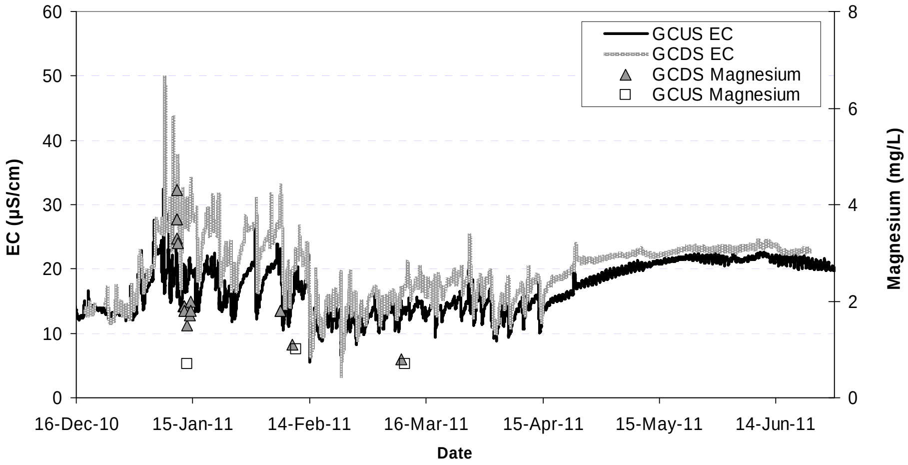


Figure 2.14 Electrical conductivity and total magnesium concentrations in Gulungul Creek between December 2010 and July 2011

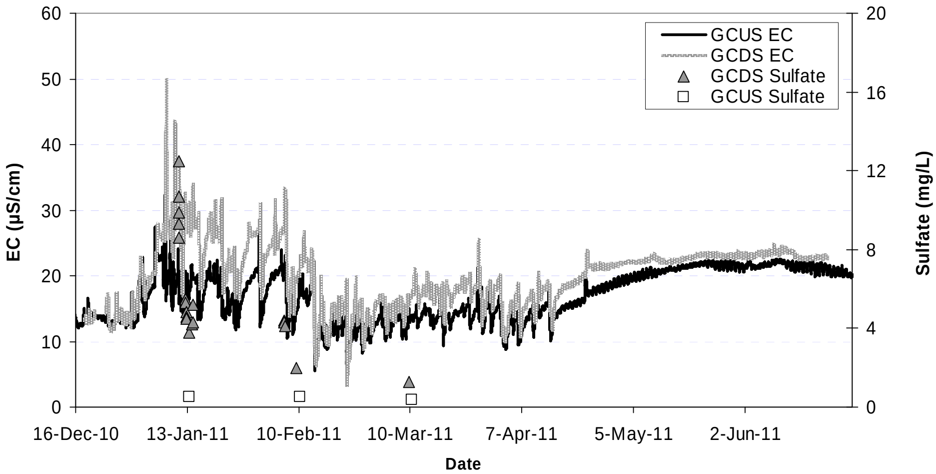


Figure 2.15 Electrical conductivity and total sulfate concentrations in Gulungul Creek between December 2010 and July 2011

During early April, EC at GCDS remained comparable with the upstream site and below 20 µS/cm. Turbidity likewise remained relatively low and stable. A local rainfall event on 23 April caused minor peaks in EC and turbidity at both monitoring sites.

Recessional flow conditions became established in Gulungul Creek in late April. These conditions are typified by a falling hydrograph with EC stabilising and rising slowly as groundwater input becomes the dominant contributor to flow.

Monitoring ceased for the season in Gulungul Creek in the week of the 22nd of June as the sensors became exposed, requiring their removal.

Overall, the water quality measured in Gulungul Creek for the 2010–11 wet season is comparable with results from previous wet seasons and indicates that the aquatic environment in the creek has remained protected from mining activities (Figure 2.17).

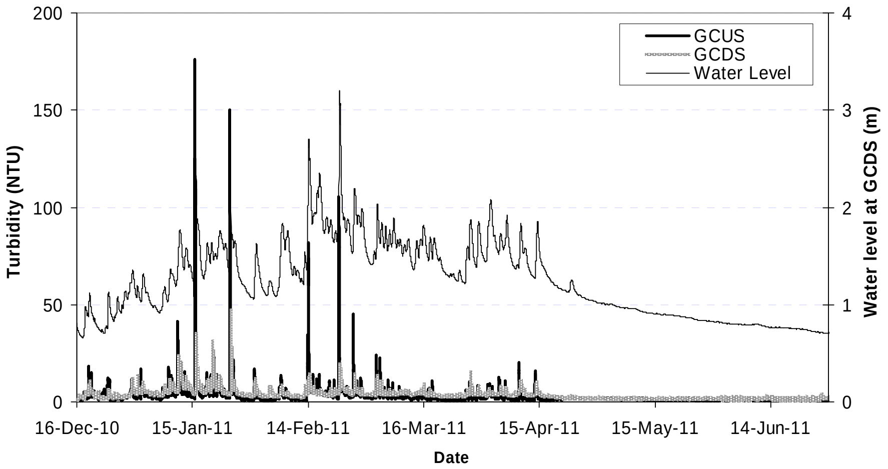


Figure 2.16 Turbidity and water level in Gulungul Creek between December 2010 and July 2011

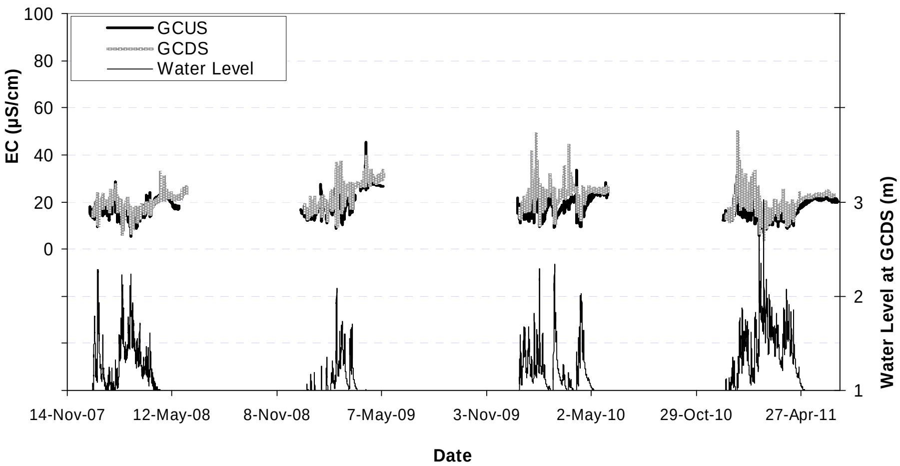


Figure 2.17 Electrical conductivity measurements and discharge (lower trace) in Gulungul Creek between December 2007 and July 2011 (this chart uses 1 hour mean values)

2.2.3.2 Biological monitoring in Magela Creek

Research conducted by the Environmental Research Institute of the Supervising Scientist (***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: early detection and assessment of overall ecosystem-level responses.

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 bioavailability of mine-derived solutes (metals and radionuclides) in aquatic biota.

For *ecosystem-level responses*, benthic macroinvertebrate and fish community data from 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 2010–11 reporting period are summarised below.

In situ toxicity monitoring

In this form of monitoring, effects of waters dispersed from the Ranger minesite on receiving waters are evaluated using responses of aquatic animals exposed in situ to creek waters. The response measured is reproduction (egg production) by the freshwater snail, *Amerianna cumingi*. Each test runs over a four-day exposure period. 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. 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 2008–09 wet season, this method was replaced by an in situ testing method 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). 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. Results of testing conducted in Gulungul Creek in the 2009–10 wet season were reported in the Supervising Scientist's Annual report for 2009–10 (section 3.2) while results for the 2010–11 wet season are described in section 3.4, Toxicity monitoring in Magela and Gulungul Creeks, of this report.

Fortnightly testing was conducted in each creek in the 2010–11 wet season, alternating each creek on a weekly basis (as such, testing was never conducted in both creeks in the same week.)

The first of ten toxicity monitoring tests commenced in Magela Creek on 17 December 2010, once moderate creek flows were established. Tests were then conducted every other week over the 2010–11 wet season with the final test commencing on 29 April 2011. In Gulungul Creek, a total of nine tests were conducted, alternating with the Magela tests. The first Gulungul test commenced on 20 December 2010 and the final test was started on 5 May 2011. Results for both creeks are plotted in Figure 2.18 with egg production at upstream and downstream sites, and differences in egg production between the sites, being displayed.

Analysis of Magela Creek results

After each wet season, the 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. For wet seasons from 1991–92 to 2008–09, egg numbers at the downstream site have been slightly greater than those measured at the upstream control site with a mean upstream-downstream difference value of -5.8 (Figure 2.18A&B). This contrasts to the 2009–10 wet season when for the first time, Analysis Of Variance (ANOVA) testing found a significant difference between the difference data for that year (mean difference value of -22.3) and that from previous wet seasons, because of the unusually higher downstream egg production (see Figure 2.18B).

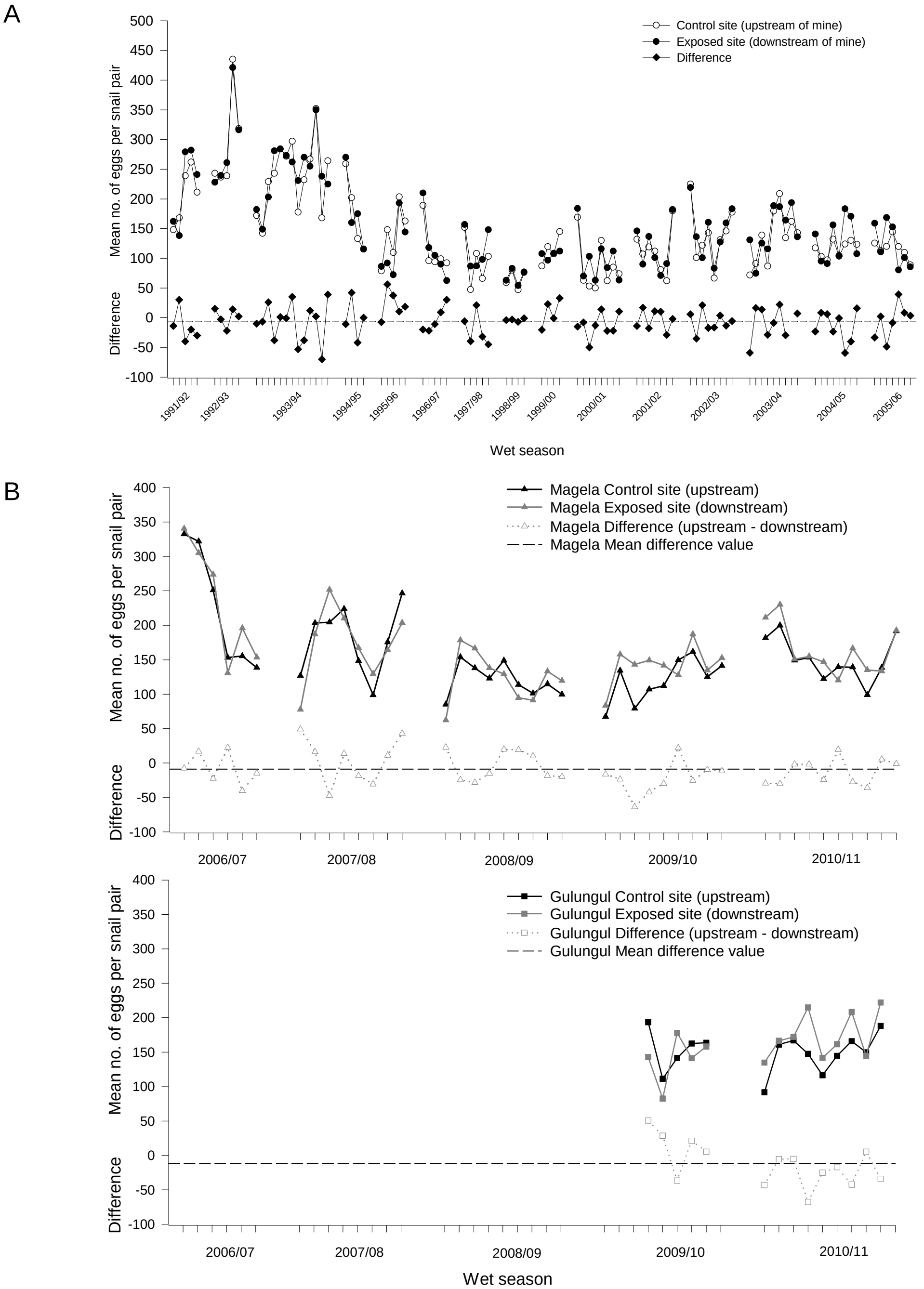


Figure 2.18 Time-series of snail egg production data from toxicity monitoring tests conducted in A: Magela Creek using creekside tests, and B Magela and Gulungul creeks using in situ tests

An assessment of the 2009–10 data (see last annual report) was not able to attribute any specific cause for this result and it remains the subject of ongoing investigation (see section 3.4 Toxicity monitoring in Magela and Gulungul Creeks). The results for the 2010–11 season showed that, on average, egg numbers at the downstream site were again greater than those measured at the upstream control site (Figure 2.18B), with a mean upstream-downstream difference value of -12.8, a value intermediate between that observed in previous wet seasons and the value reported in 2009–10 (Figure 2.18A&B).

Given the statistically significant result observed in 2010 for Magela test results, a number of different statistical tests were applied to the 2010–11 wet season test results. These are described in Table 2.6, together with results of ANOVA testing.

TABLE 2.6 RESULTS OF ANOVA TESTING COMPARING UPSTREAM-DOWNSTREAM DIFFERENCE VALUES FOR MEAN SNAIL EGG NUMBER FOR DIFFERENT ‘BEFORE VERSUS AFTER’ WET SEASON SCENARIOS

Statistical comparison	Probability value (*P*)	Significance
2009–10 compared with all previous seasons	0.046	at 5% level
2010–11 compared with all previous seasons	0.408	NS
2010–11 compared with previous seasons excl 2009-10	0.299	NS
2010–11 + 2009–10 compared with previous seasons	0.043	at 5% level

NS – not significant

The results indicate that the 2011 data continue the trend towards relatively higher downstream egg production that was also observed in 2010 (also evident in Figure 2.18B). Thus, when combined with 2010 data, the 2010 and 2011 seasons’ data are significantly different from previous seasons (Table 2.6). However, and as noted above, the magnitude of higher downstream egg production found in 2011 is not as marked as that observed in 2010. When the 2011 data are compared with previous seasons with the omission of 2010 data, there is no significant difference between the test results for the two time periods (Table 2.6). As noted above, detailed analyses are in progress to examine the possible causes of any recent trends towards higher downstream egg production in Magela Creek and these results will be reported in future annual reports.

Analysis of Gulungul Creek results

Results for Gulungul Creek also show snail egg production at the downstream site was consistently higher than at the upstream site in 2010–11, with eight of the nine tests producing a negative difference value (Figure 2.18B). These results are in contrast to those observed during the previous (2009–10) season when four out of the five tests conducted in Gulungul Creek resulted in positive difference values (indicating higher upstream egg production). Confirming this observation, ANOVA testing found a significant difference between the upstream-downstream difference data for 2011 compared with difference data for 2010

($P < 0.05$). In section 3.4 of this report, the higher variability of egg production in Gulungul Creek, compared with that in Magela Creek, is noted. This higher variability appears to be associated with similar and higher (natural) variability in water quality observed between sites and between years in Gulungul Creek compared with water quality variation in Magela Creek (section 3.4 Toxicity monitoring in Magela and Gulungul Creeks).

The toxicity monitoring dataset for Gulungul Creek is currently too small to attribute any mine-related cause of the significant difference in between-site egg production observed between 2011 and 2010. Gulungul Creek toxicity monitoring data are being used with those from Magela Creek to develop an improved understanding of the contributions of different environmental factors to variations in snail egg production in the two creek systems (section 3.4). This understanding will improve the ability to distinguish between natural and mine-related contributions to the toxicity monitoring results.

Bioaccumulation in freshwater mussels

Local indigenous people harvest aquatic food items, in particular mussels, from Mudginberri Billabong, 12 km downstream of the Ranger mine (Map 3). Hence it is essential that they are fit for human consumption and that concentrations of metals and/or radionuclides in tissue and organs of aquatic biota attributable to mine-derived inputs from Ranger remain within acceptable levels. Enhanced body burdens of mine-derived solutes in biota could also potentially reach limits that may harm the organisms themselves, as well as provide early warning of bioavailability of these dispersed constituents to the creek system. Hence the bioaccumulation monitoring program serves an ecosystem protection role in addition to the human health aspect.

Uranium and radium bioaccumulation data were obtained intermittently from Mudginberri Billabong between 1980 and 2000. Between 2000 and 2008, mussels were collected annually and fish every two years, respectively, from Mudginberri (the potentially impacted site, sampled from 2000 onwards) and Sandy Billabongs (the control site, sampled from 2002 onwards). Results from monitoring and two research projects (conducted in 2007 and 2008 and reported in previous annual reports) showed that radionuclide burdens in mussels from Mudginberri Billabong were generally about twice as high compared with mussels from the reference Sandy Billabong. However, of all sites investigated along the Magela channel, Mudginberri Billabong mussels exhibit the lowest radium loads, age-for-age. It has been concluded (documented in previous annual reports) that the differences in mussel radionuclide activity loads between Mudginberri and Sandy Billabong mussels are due to natural catchment rather than any mining influence. Nine years of monitoring of the levels of radionuclides and metals in fish had not shown any issues of potential concern with regards to bioaccumulation. Consequently, the effort on the bioaccumulation component of the monitoring program has been reduced to analysing annually a bulk sample of mussels for radionuclides and metals, while the two yearly fish sampling program has been discontinued. The fish bioaccumulation program will be restarted in the event it is shown that levels of metals being input from the mine (via the water quality monitoring program) increase above the current condition.

Uranium in freshwater mussels

Uranium concentrations in freshwater mussels, water and sediment samples collected annually from Mudginberri and Sandy Billabongs are shown in Figure 2.19.

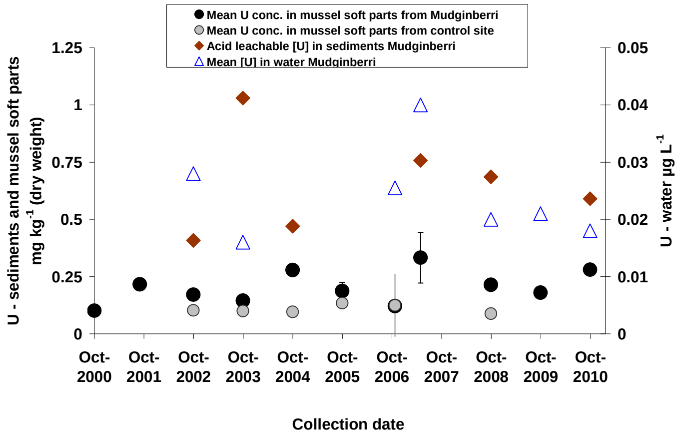


Figure 2.19 Mean concentrations of U measured in mussel soft-parts, sediment and water samples collected from Mudginberri and Sandy Billabongs since 2000

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. Notwithstanding some bioaccumulation with age, uranium in mussels is reported to have a short biological half-life, a conclusion that is supported by the data in Figure 2.19. The lack of any increase in concentration of U in mussel tissues through time, with essentially constant levels observed between 1989 and 1995 (previous reports) and consistently low levels from 2000 to the last sample taken in October 2010, indicates absence of any mining influence.

^{226}Ra and ^{210}Pb in mussels (Mudginberri Billabong)

The average annual committed effective dose from radiation due to mussel consumption is calculated for a 10-year old child who eats 2 kg (wet weight) of mussel flesh from Mudginberri Billabong, using the activity concentrations of ^{226}Ra and ^{210}Pb measured in mussel flesh. The average of all collections from 2000 to 2010 is 0.180 mSv. Figure 2.20 shows the doses estimated for the individual years, and the median, 80 and 95 percentiles for all collections.

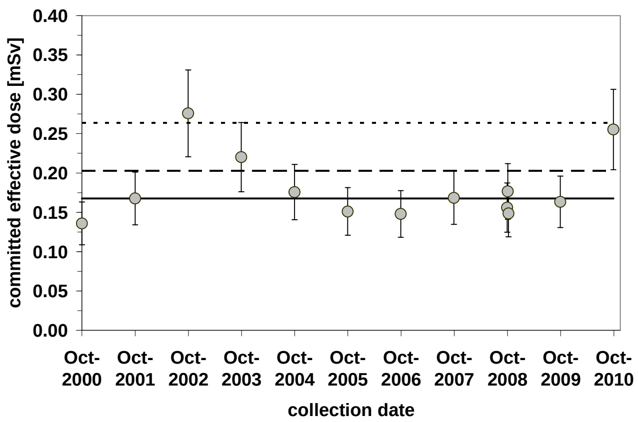


Figure 2.20 Annual committed effective doses (point data) from ^{226}Ra and ^{210}Pb for a 10 year old child eating 2 kg of mussels collected at Mudginberri Billabong. The median for all the data (solid line), the 80th percentile (dashed line) and 95thpercentile (dotted line) are shown for reference.

Activity concentrations of ^{226}Ra and ^{210}Pb in mussels are age-dependent (see previous annual reports) and are also related to growth rates and in particular seasonal soft body weights. Consequently, ^{226}Ra and ^{210}Pb activity concentrations in mussels can vary depending on the timing of collection. As can be seen, annual committed effective doses from the consumption of mussels collected in 2010 are higher than in the previous 6 years, but still lower than the 95th percentile. This higher value is caused by higher concentrations of ^{226}Ra in mussel flesh, potentially due to lower soft body weights of the mussels collected in 2010. Despite the higher value in 2010, committed effective doses due to ingestion of these mussels continue to be of no concern to human health.

The ^{226}Ra in mussels originates from natural catchment sources, rather than any mining influence, as confirmed by the wet season median difference for ^{226}Ra activity concentrations measured in Magela Creek (downstream minus upstream) being close to zero (see discussion above).

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 '0%' 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 2010, and data from the paired sites in the two 'exposed' streams, Magela and Gulungul Creeks, for 2011, have been completed with results shown in Figure 2.21. 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 previous 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, only samples from Magela and Gulungul Creeks from the 2010–11 wet season were available for analysis. Without comparable data from the two control streams, it is not possible to run ANOVA testing for 2011, only a statistical test for the previous (2010) season, the last season for which a complete dataset is available for all control and exposed creeks. However, other statistical testing and assessment of the 2011 data for Magela and Gulungul creeks are available, as described below.

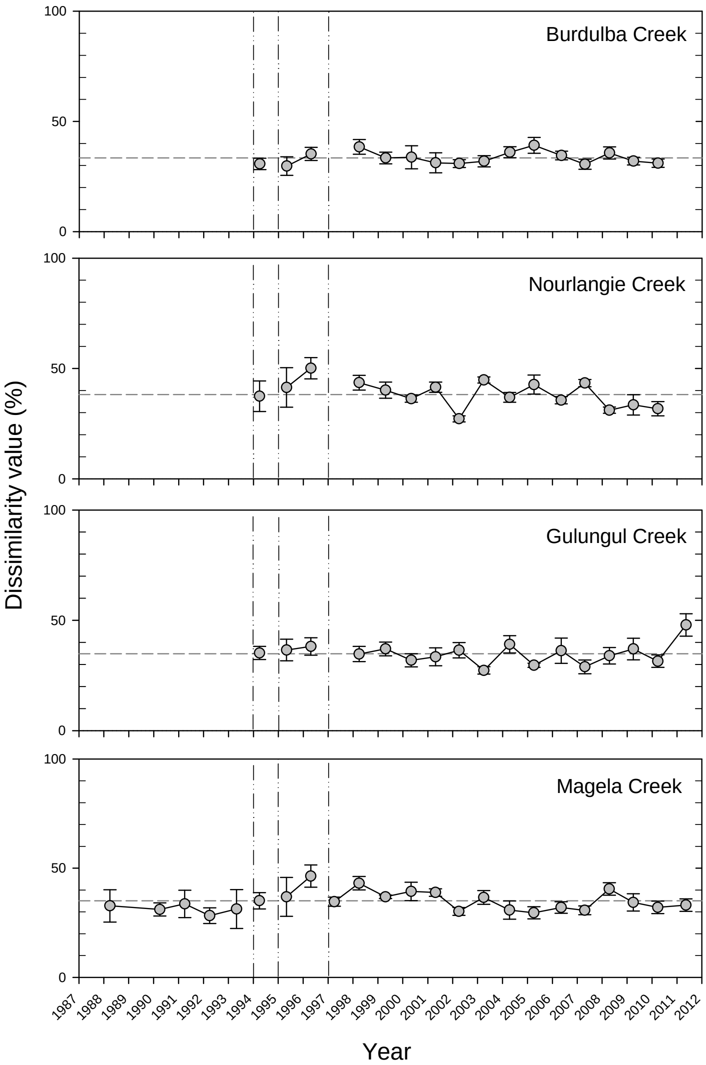


Figure 2.21 Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger mine for the period 1988 to 2011. The dashed vertical lines delineate periods for which a different 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.

Inferences that may be drawn from the data shown in Figure 2.21 are weakened because there are no baseline (pre 1980) data upon which to assess whether or not significant changes have occurred as a consequence of mining. Notwithstanding, a four-factor ANOVA based upon replicate, paired-site dissimilarity values and using the factors Before/After (BA; fixed), Control/Impact (CI; fixed), Year (nested within BA; random) and Site (nested within CI; random) showed no significant difference between the control and exposed streams in the change (in dissimilarity) from values derived from earlier years (back to 1998) to those from 2010 (ie the BA x CI interaction is not significant). While the Year x Site (BA CI) interaction is significant in the same analysis ($p = 0.014$), this simply indicates that dissimilarity values for the different streams – regardless of their status (Before, After, Control, Impact) – show differences through time. The dissimilarity plots shown in Figure 2.21 corroborate these results for data up to an including 2010, showing reasonable constancy in the mean dissimilarity values for each stream across all years.

For the 2011 dissimilarity data for Magela and Gulungul Creeks (Figure 2.16), a sharp rise in dissimilarity for Gulungul Creek can be observed. Closer examination of the data is required to assess whether or not this result may be associated with a possible mining impact. To do this, abundances of the numerically-dominant taxa were compared between the upstream and downstream sites over time to determine what types of shifts in taxa abundances may have occurred recently. In addition, the dissimilarity indices used in Figure 2.21 were 'mapped' using multivariate ordination techniques to depict the relationship of the community sampled at any one site and sampling occasion with all other possible samples. The ordination can assist in determining whether the upstream and/or downstream Gulungul communities have changed or are aberrant compared to the other communities sampled over time.

Figure 2.22 depicts the 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 2011), relative to Magela and Gulungul Creek upstream (control) sites for 2011, and all other control sites sampled up to 2010 (Magela and Gulungul upstream sites, all sites in Burdulba and Nourlangie). Samples close to one another in the ordination indicate a similar community structure. The ordination indicates that Gulungul Creek communities from the upstream site differ from communities from other sites and times (Figure 2.22). Conversely, data-points associated with the 2011 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.

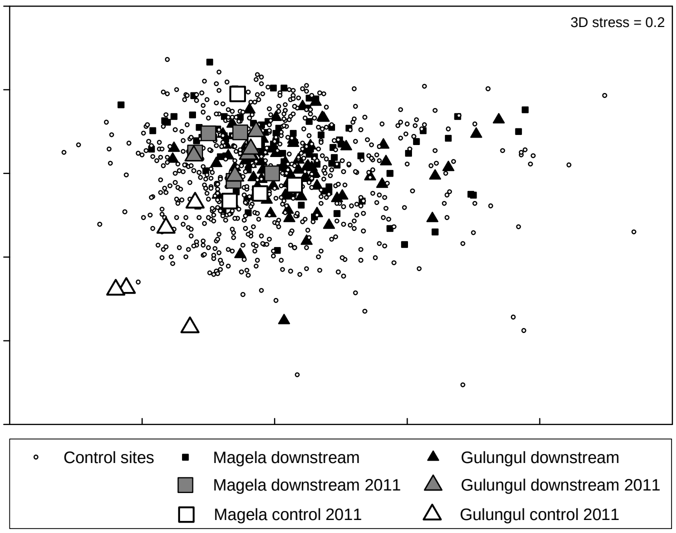


Figure 2.22 Ordination plot of macroinvertebrate community structure data from sites sampled in several streams in the vicinity of Ranger mine for the period 1988 to 2011. Data from Magela and Gulungul Creeks for 2011 are indicated by the enlarged symbols.

ANOSIM testing (ANalysis Of SIMilarity, effectively an analogue of the univariate ANOVA) was used to determine if Magela and Gulungul sites in 2011 were significantly different from control sites in multivariate space. ANOSIM conducted on replicate data showed that while the 2011 group is overlapping, it is clearly different from other sample points and the degree of separation is significant ($P<0.05$). Further examination of the data indicated that this result was associated with the 2011 Gulungul data, where the upstream and downstream sites were significantly separated in ordination space ($P <0.05$).

Abundances of numerically-dominant taxa were examined between Gulungul upstream and downstream sites over time. This analysis found that, historically and typically, there are a greater proportion of taxa at the Gulungul upstream site with a preference for high velocity waters associated with this location in the creek (ie so-termed ‘flow-dependent’ taxa). While this remained the pattern in 2011, the abundances of these taxa at the upstream site in 2011 were unusually high compared with values found in previous years and were about three times the abundances observed at the downstream site in 2011 (results not shown here). Given that dissimilarity values are sensitive to taxa abundances, this discrepancy in macroinvertebrate abundances between the Gulungul sites in 2011 can explain the separation of Gulungul upstream sample points observed in the ordination (Figure 2.22) and the increase in mean dissimilarity observed in the paired-site dissimilarity plot (Figure 2.21). The habitat and flow conditions prevailing at the upstream Gulungul site in 2011 have yet to be examined closely to better interpret these results.

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 2011 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 using non-destructive sampling methods applied in ‘exposed’ and ‘control’ locations. Two billabong types are sampled: deep channel billabongs studied every year, and shallow lowland billabongs dominated by aquatic plants which are studied every two years. Details of the sampling methods and sites were provided in the 2003–04 Supervising Scientist annual report (Supervising Scientist 2004, chapter 2, section 2.2.3). These programs were reviewed in October 2006 and the refinements to their design detailed in the 2006–07 and 2007–08 Supervising Scientist annual reports (shallow and channel billabong fish communities respectively).

For both deep channel and shallow lowland billabongs, comparisons are made between a directly-exposed billabong (Mudginberri) in the Magela Creek catchment downstream of Ranger mine versus control billabongs from an independent catchment (Nourlangie Creek and Wirnmuyurr Creek). The 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 ‘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) was determined using multivariate dissimilarity indices calculated for each annual sampling occasion. A plot of the dissimilarity values from 1994 to 2011 is shown in Figure 2.23.

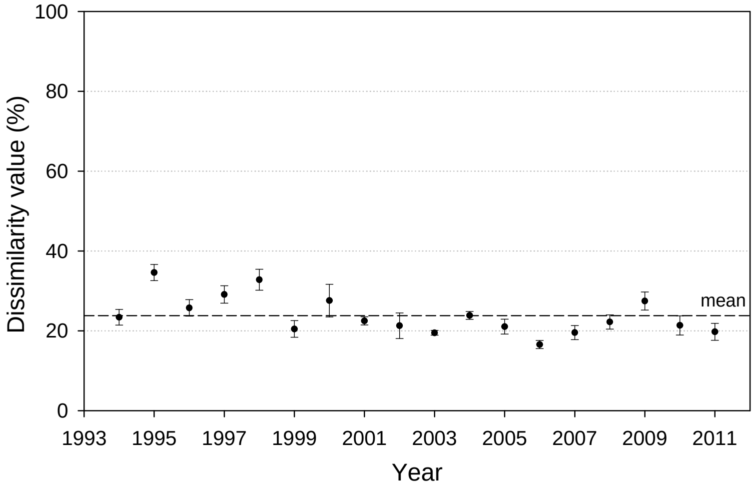


Figure 2.23 Paired control-exposed dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in Mudginberri ('exposed') and Sandy ('control') Billabongs in the vicinity of the Ranger Mine over time. Values are means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of transect data between the two waterbodies.

In previous reports, possible causes of trends in the annual paired-site dissimilarity measure over time have been advanced and assessed. Because the dissimilarity measure is most influenced by numerically-abundant fish species, it was possible to demonstrate that fluctuations in the measure over time were directly associated with longer-term changes in abundance in Magela Creek of the chequered rainbowfish (*Melanotaenia splendida inornata*), the most common fish species in this creek system (the 2003–04 Supervising Scientist annual report, chapter 2, 35–38). Thus, effort has been directed at understanding the possible causes of interannual variations in the abundance of this fish species in Magela Creek.

In the Supervising Scientist annual report for 2008–09, a negative correlation between annual rainbowfish abundance in Mudginberri Billabong and the magnitude of wet season discharge (total for the wet season, January total and February total) was observed in Magela Creek. The negative relationship between rainbowfish in Mudginberri Billabong and wet season discharge identified in 2008–09 has been tested and remains significant (total for the wet season $p=0.014$, January total $p=0.009$ and February total $p=0.014$). This is supported by an examination of Figure 2.24 which shows the relatively low abundances of rainbowfish in Mudginberri Billabong in 2011 in relation to well-above annual discharge in Magela Creek for that wet season. The reduced rainbowfish abundances after larger wet season flows may indicate greater upstream migration of rainbowfish past Mudginberri Billabong, thereby reducing the concentration of fish in Mudginberri Billabong during the recessional flow period.

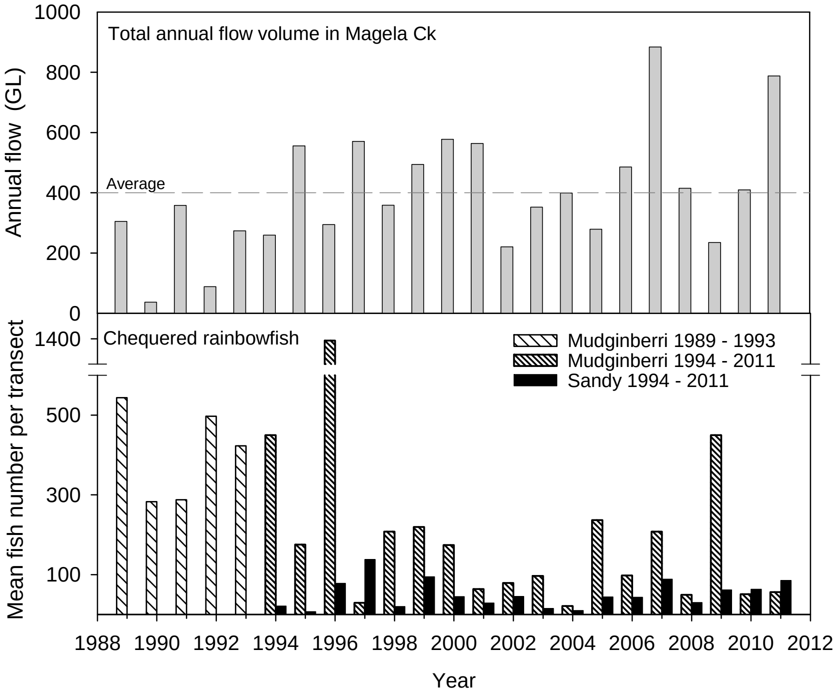


Figure 2.24 Relative abundance of chequered rainbowfish in Mudginberri and Sandy billabongs from 1989 to 2011 with associated total discharge in Magela Creek (gauging station G8210009)

The paired-billabong dissimilarity value for 2011 is consistent with the range of values reported since 2001, a period over which there has been no evidence of mine-associated changes to fish communities in Mudginberri Billabong downstream of Ranger (Supervising Scientist annual report 2008–09).

Shallow lowland billabongs

Monitoring of fish communities in shallow billabongs has usually been conducted every other year (see Supervising Scientist annual report for 2006–07). The last assessment of fish communities in shallow lowland billabongs was conducted in May 2009 with results reported in the Supervising Scientist annual report for 2008–09. The scheduled sampling of fish communities in 2011 was postponed to enable staff resources to be dedicated towards an intensive sampling of other biota (phytoplankton, zooplankton and macroinvertebrate communities) in these shallow billabong habitats.

2.3 Jabiluka

2.3.1 Developments

The site continues to be maintained under the long-term care and maintenance regime of management. 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 at Ngarradj.

2.3.2 On-site environmental management

2.3.2.1 Water Management

The site continues to be maintained as a passive discharge site.

2.3.2.2 Audit and Routine Periodic Inspections (RPIs)

Three inspections were undertaken at Jabiluka during 2010–11 (Table 2.7). An environmental audit was held in May 2011 and RPIs were held in August, November and February.

TABLE 2.7 RPI FOCUS DURING THE REPORTING PERIOD

Date	Inspection type	Foci
17 August 2010	RPI	Hardstand area, interim water management pond (IWMP) and drop structure, vent raise, access road, Djarr Djarr
17 November 2010	RPI	IWMP, hardstand area, access road, Djarr Djarr, silt traps
15 February 2011	RPI	IWMP and drop structure, hardstand revegetation, helipad area

2010 Audit review outcomes

The conditional finding from the May 2010 Environmental Audit relating to rehabilitation of redundant boreholes in Mine Valley was followed up through the RPI process. The redundant boreholes in Mine Valley are required to be capped as part of the site’s long-term care and maintenance. Stakeholders were updated on the progress of rehabilitation work in Mine Valley through the Jabiluka MTCs. The work was not completed prior to the commencement of the 2011 audit of the Jabiluka authorisation and the original finding from the 2010 audit was not escalated. Negotiations between traditional owners and ERA regarding final rehabilitation of remaining bores are ongoing.

2011 Audit outcomes

The annual environmental audit of Jabiluka was held in May 2011 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 2.4. The audit process found evidence to grade one criterion as conditional and one as not verified while all other criteria were found to be acceptable. The conditional finding relates to the ongoing works to finalise rehabilitation of redundant bore holes in Mine Valley.

2.3.2.3 Minesite Technical Committee

The Jabiluka MTC met six times during 2010–11. Dates of meetings and significant issues discussed are shown in Table 2.8.

TABLE 2.8 JABILUKA MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items
8 July 2010	Monitoring of Mine Valley bores, annual environment report, Annual Plan of Rehabilitation no.13, wet season report and monthly water quality reports
9 September 2010	As above, and rehabilitation at Djarr Djarr, SSD monitoring at JSC
11 November 2010	As July, Restoration criteria for Djarr Djarr, Jabiluka lease boundary, rehabilitation of exploration bore holes in Mine Valley
13 January 2011	As July, Djarr Djarr rehabilitation, 2009/10 annual environmental report
11 March 2011	Annual Plan of Rehabilitation no.13, Djarr Djarr rehabilitation, Mine Valley bores
12 May 2011	Annual Plan of Rehabilitation no.14 and submission date, Djarr Djarr rehabilitation, Jabiluka lease boundary, 2009/10 annual environment report

2.3.2.4 Authorisations and approvals

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

2.3.2.5 Incidents

There were no incidents reported for the 2010–11 reporting period.

2.3.3 Off-site environmental protection

2.3.3.1 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 achieved. Each month during the wet season, ERA reports the water quality in Ngarradj (Swift Creek) to the major stakeholders (SSD, DoR 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.

In addition to the ERA program, the Supervising Scientist conducts monitoring in Ngarradj Creek. 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, the Supervising Scientist Division 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 Ngarradj Creek

The electrical conductivity (EC) and water level data measured early in November 2010 recorded only the water quality of the standing water around the monitoring station before flow commenced. Flow was first recorded at the Ngarradj monitoring station on 13 November 2010 and is reflected by the change in EC, associated with a rainfall event on 11–12 November 2010. Water levels within Ngarradj had decreased to such an extent that between 7 and 11 November, 24 and 27 November and 6 and 12 December 2010 the EC sensor was out of the water. Hence no data were recorded for these periods (Figure 2.25). Water levels increased considerably in late December 2010 and mid-January 2011, with corresponding reduced EC levels. Water levels were relatively low in late January with EC stable at around 10 μS/cm. Periods of high water levels from February to early April resulted in low, stable EC levels of 4–8 μS/cm.

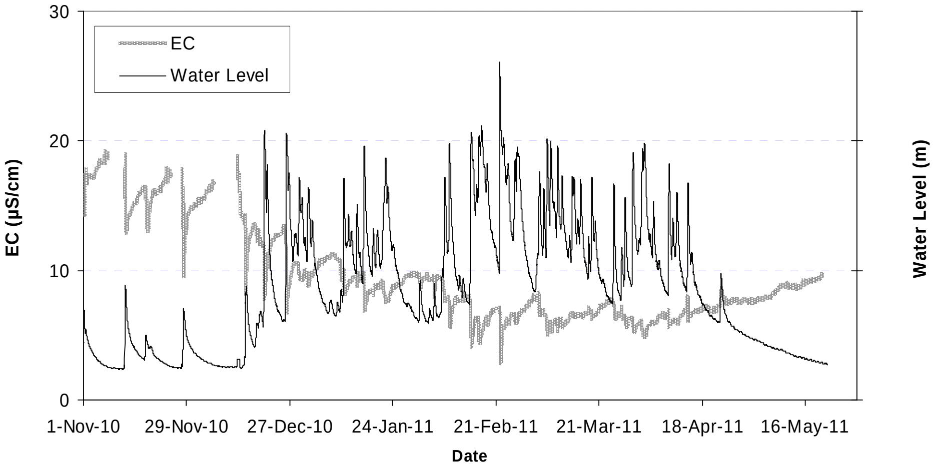


Figure 2.25 Electrical conductivity measurements in Ngarradj between November 2010 and June 2011

Rainfall largely ceased since in mid-April and consequently EC levels slowly rose, typical of low flow conditions at the beginning of the dry season. On 20 May 2011 continuous monitoring of Ngarradj ceased as the probes were out of the water.

2.4 Nabarlek

2.4.1 Developments

In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd, thereby acquiring the Nabarlek lease, and 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 the 28 May 2008 allowing exploration and rehabilitation works at Nabarlek to proceed. A revised Mining Management Plan (MMP), including revised rehabilitation bond calculations, was submitted to the Supervising Authority for approval in July 2009. The revised MMP was approved by DoR in September 2009 with $1.8 million currently held as security bond for the site. A MMP for the 2011–12 operating year was submitted to DoR in June 2011 and is awaiting approval.

2.4.1.1 Minesite Technical Committee

The Nabarlek MTC met once during the reporting period. The following items were discussed at a meeting held on 8 July 2010:

- closure criteria
- recalculation of the security bond
- solute concentrations in groundwater
- asbestos removal
- proposed drilling program

2.4.1.2 Authorisations and approvals

There was no change to the Authorisation during 2010–11.

2.4.1.3 Incidents

There were no environmental incidents reported at Nabarlek during 2010–11.

2.4.2 On-site conditions

The site is subject to at least two formal 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.

2.4.2.1 Audit outcomes

The 2010 audit was held on 6 October 2010 and tested compliance with commitments taken from the 2010 Nabarlek Mining Management Plan as submitted by UEL. Of these commitments, 15 were found to be acceptable, 2 were graded a category 2 non-conformance, 14 conditional, with 12 observations being made, as per the grading system detailed in Table 2.4. Whilst the audit team noted several opportunities for improvement, it was observed that environmental management continues to improve at Nabarlek uranium mine. Uranium Equities Ltd was commended on its efforts in weed management and rehabilitation, particularly the management of asbestos and rehabilitation of the old camp area. In addition, six issues raised by previous audits had been closed out.

2.4.2.2 Post-wet season inspection

SSD inspected Nabarlek on 28 June 2011 with site operators UEL and representatives from DoR and NLC. UEL has completed the clean up and disposal of the asbestos throughout the former mine and camp areas. A pit was dug at the former camp site for disposal of the camp infrastructure and any asbestos material. The concrete pads and roadway have been left in place at this time. UEL obtained the appropriate approvals for on-site asbestos disposal from the Northern Territory Government. A large concrete plinth has been placed above the asbestos disposal pit to mark its location.

5000 seedlings were planted across the recontoured waste rock dump run-off pond area over the 2010–11 wet season following a series of burns and weed treatments of the area to reduce para grass density. Across site revegetation is maturing well with natural recruitment beginning to occur in some areas. Minor erosion was noted in the area of the former waste rock dump run-off pond which UEL has committed to addressing prior to the coming wet season.

2.4.2.3 Radiologically anomalous area (RAA)

The area of the RAA is 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. UEL has conducted a detailed gamma survey of the area and is currently evaluating remediation strategies for the RAA. UEL has informed the MTC that it intends to excavate the site and bury any contaminated material below 2m of clean compacted fill. An engineering plan is currently being developed and will be submitted to the MTC with a detailed application once complete.

2.4.3 Off-site environmental protection

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

2.5 Other activities in the Alligator Rivers Region

2.5.1 Rehabilitation of the South Alligator Valley uranium mines

Background on the remediation of historic uranium mining sites in the South Alligator Valley has been provided in the 2008–09 Supervising Scientist's 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. Material was recovered from the following sites for co-disposal in the new facility:

- South Alligator Village containment
- El Sherana Camp containment
- El Sherana Weighbridge containment
- Battery Bund containment
- Contaminated soil stored in containers at South Alligator Village

In addition to this, all material with readings in excess of 1.25 μSv/h (±20%) from the following locations was placed in the new containment facility:

- Rockhole uranium processing plant tailings residues
- El Sherana mine
- Palette stockpile area

eriss conducted a close out radiological survey of the old containment areas during July 2010 to ensure that all radiologically contaminated material has been removed. ***oss*** staff inspected both the new containment and historic containment sites on 15 December 2010. Revegetation is progressing well over the old containment areas.

Erosion previously noted at the new containment site has been repaired. A large drain has been installed up-gradient of the containment to reduce the volume of water flowing across the containment cap. Some minor erosion was noted from early wet season rains and it would be expected that some further erosion repair work will be required following the 2010–11 wet season.

2.5.2 Exploration

oss undertakes a program of site inspections and audits at exploration sites in western Arnhem Land. In addition to the Nabarlek audit previously mentioned, SSD conducted an audit of the Cameco King River Camp and exploration activities in conjunction with representatives of DoR and NLC. The audit was held on 22–23 September 2010 whilst the camps were operating and exploration was being actively undertaken. There were no significant issues identified with the King River operation.

The Myra Camp and surrounding exploration licences have been acquired by Alligator Energy. Alligator Energy was not conducting any surface disturbing works during 2010 and an audit was not conducted.

2.6 Radiological issues

2.6.1 Background

2.6.1.1 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 the 'Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing' (2005), 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'.

The 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.
>
> Source: 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.

2.6.1.2 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 with results reported to MTC members on a quarterly basis.

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

An application to optimise the Radiation and Atmospheric Monitoring Plan was submitted to the MTC in November 2008. Second and third versions of the application were received in July and December of 2009. The revised application to optimise the radiation and atmospheric monitoring plan remains under consideration by the Supervising Authority at the point of reporting.

All ERA quarterly reports due during the reporting period were received and reviewed by the Supervising Scientist Division.

2.6.2 Radiation at and from Ranger

2.6.2.1 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 2.9 shows the annual doses received by designated and non-designated workers in 2010, 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 2010 calendar year were approximately 3.4% and 19% 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 2.9 ANNUAL RADIATION DOSES RECEIVED BY WORKERS AT RANGER MINE

	Annual dose in 2009		Annual dose in 2010	
	Average mSv	**Maximum mSv**	**Average mSv**	**Maximum mSv**
Non-designated worker	Not calculated[1]	0.9	Not calculated	0.57
Designated worker	1.1	4.5	0.67	3.93

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.

Exploration, mine production and processing production workers received the majority of their radiation dose from external gamma, with average doses for mine and processing production workers less than the previous year at 0.35 mSv and 0.58 mSv respectively (average dose to exploration workers was not reported in 2009). The dose to processing production workers from the inhalation of radioactivity trapped in or on dust fell from an average of 0.6 mSv last year to an average of 0.47 mSv this year. The majority of the radiation doses received by workers in the processing and mine maintenance areas were from radon decay products. Electricians received similar average doses from all three pathways. Radon decay product concentrations continue to be the highest for workers in mine production, forming an average contribution of 0.17 mSv in 2010 (down from 0.3 mSv in 2009).

2.6.2.2 Radiological exposure of the public

National radiation protection standards require that the annual dose received by a member of the public from practices such as uranium mining and milling must not exceed 1 millisievert (mSv). This dose is on top of the radiation dose received naturally, which averages approximately 2 mSv per year in Australia, but which ranges from 1–10 mSv per year, depending on location.

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

Inhalation pathway

Both ERA and SSD monitor the atmospheric environment for two forms of airborne radioactivity:

- radionuclides trapped in or on dust (or long lived alpha activity, LLAA)
- radon decay products (RDP).

The main areas of habitation in the vicinity of Ranger and Jabiluka are Jabiru, Mudginberri and Jabiru East. Consequently, SSD monitoring focuses on these three population centres in the region (Map 3). Airborne RDP and LLAA concentrations are measured monthly and the results compared with ERA’s atmospheric monitoring results from Jabiru and Jabiru East. Of the two forms of airborne radioactivity, RDP accounts for most of the dose received by the public. In the 2010 annual radiation monitoring report, Ranger reported the average mine derived airborne RDP concentration at Jabiru as 0.009 $\mu J/m^3$, in addition to background, for the 1983 hours in which the wind was blowing from the mine towards Jabiru. This equates to a mine derived dose from RDP of 0.019 mSv in addition to the natural background dose of 0.36 mSv per year, or an above background increase of 5%.

Figures 2.26 and 2.27 present RDP and LLAA data measured at Jabiru and Jabiru East by SSD, and a comparison with ERA data from January 2005 to March 2011. Both RDP and LLAA concentrations measured by SSD and ERA show the expected seasonal trend with higher values during the dry and lower values during the wet season. Higher RDP concentrations are expected in the dry season due to dry soil allowing greater permeation of radon into the atmosphere, and LLAA concentrations are higher due to the dustier conditions during the dry season. The generally higher LLAA concentrations measured by ERA in Jabiru East are due to the different sampling locations (SSD Field Station and Airport car park, respectively).

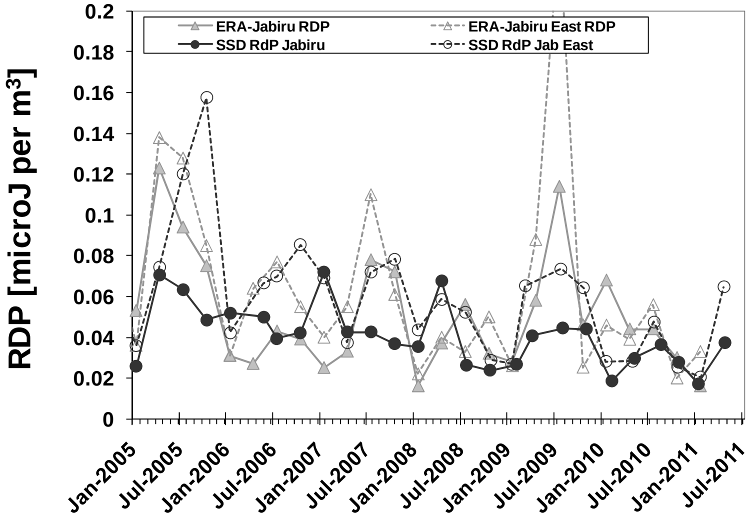


Figure 2.26 Radon decay product concentration measured by SSD and ERA in Jabiru and Jabiru East from January 2004 to March 2010

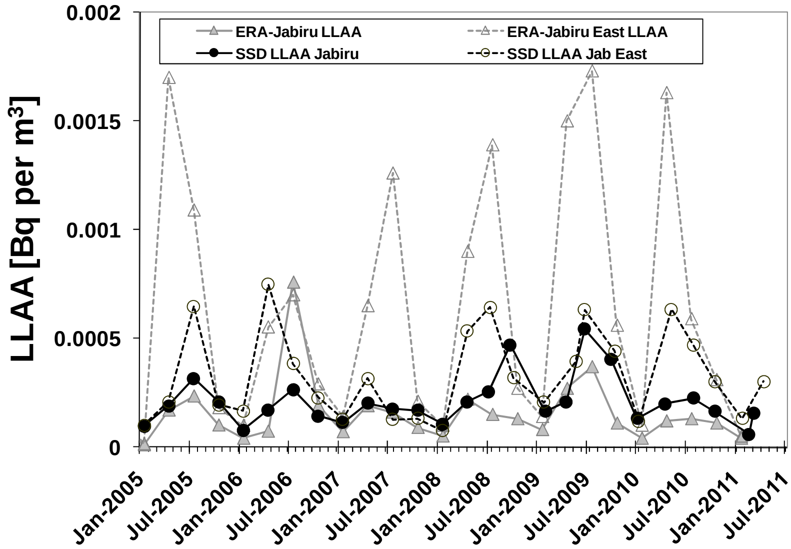


Figure 2.27 Long lived alpha activity concentration measured by SSD and ERA in Jabiru and Jabiru East from January 2004 to March 2010

In 2010, the dry season average RDP concentrations measured by ERA were only slightly higher than those measured by SSD during the same time period (July–September), with both data sets showing the (suppressing) effect of an unusually wet year. During the reporting year of July 2010 – June 2011 northern Australia experienced one of the wettest years on record. Heavy and consistent rainfall kept the soil waterlogged for extended periods which inhibited radon emanation from the soil, even during the dry season in 2010. The damp soil also suppressed dust generation which is reflected in the below average LLAA concentrations. Figure 2.28 shows the inverse relationship between rainfall and concentrations of RDP at Mudginberri for the first quarter of 2011.

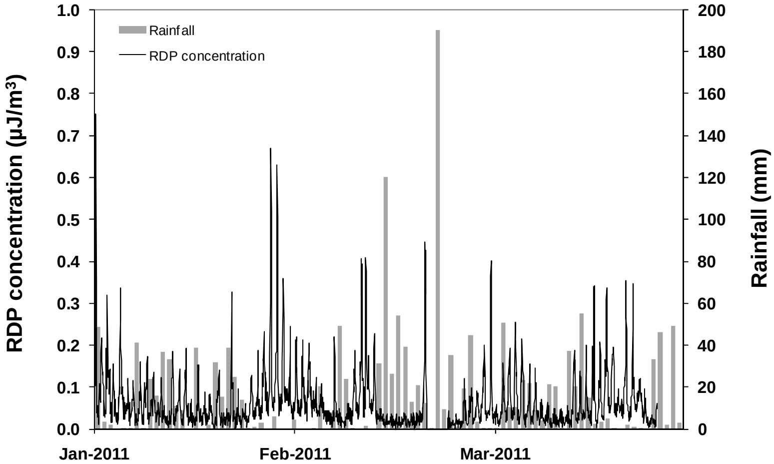


Figure 2.28 RDP concentration and rainfall measured at Mudginberri in the first quarter of 2011

Table 2.10 gives the average annual RDP concentration in air at Jabiru and Jabiru East and the total annual dose at Jabiru as calculated from ERA and SSD (in brackets) monitoring data.

TABLE 2.10 RADON DECAY PRODUCT CONCENTRATIONS AT JABIRU AND JABIRU EAST AND TOTAL AND MINE-DERIVED ANNUAL DOSES RECEIVED AT JABIRU 2007–10*

		2007	2008	2009	2010
RDP concentration [µJ/m³]	Jabiru East	0.059 (0.064)	0.033 (0.046)	0.100 (0.055)	0.040 (0.032)
	Jabiru	0.038 (0.049)	0.037 (0.038)	0.066 (0.039)	0.047 (0.028)
Total annual dose [mSv] Jabiru		0.37 (0.47)	0.36 (0.37)	0.64 (0.38)	0.45 (0.28)
Mine derived dose [mSv] at Jabiru		≈ 0	0.001	0.03**	0.019***

* Numbers in brackets refer to SSD data

** Mine-derived dose calculated from the RDP concentration difference of 0.029 µJ/m³ that persisted for 941 hrs during 2009. Data provided in the ERA Radiation Protection and Atmospheric Monitoring Program annual report 31 December 2009

*** Mine-derived dose data provided in the ERA Radiation Protection and Atmospheric Monitoring Program annual report 31 December 2010.

The dose calculation assumes an occupancy of 8760 h (one year) and a dose conversion factor for the public of 0.0011 mSv per µJ·h/m^3. Mine derived annual doses from the inhalation of radon progeny, as reported by ERA, are also given in the table.

Ingestion pathway

Radium in Magela Creek waters is routinely monitored by both ERA and SSD and the limit for radium in Magela Creek is based on dietary uptake of the indigenous people downstream of the mine. Local indigenous people have expressed concern about the radionuclide concentration in mussels from Mudginberri Billabong. Consequently, SSD routinely monitors the aquatic aspects of the ingestion pathway and bioaccumulation monitoring samples have been collected each year and analysed for both radionuclides and heavy metals (see discussion above for details on the monitoring program for Ra in mussels). The collections include yearly collections of mussels at Mudginberri Billabong (the potentially contaminated site) and Sandy Billabong (control site in the Nourlangie catchment).

Routine monitoring results from 2000–2010 show that on average the ^{226}Ra activity concentration in mussel flesh from Mudginberri Billabong is higher than at Sandy Billabong and the committed effective dose from the ingestion of ^{226}Ra and ^{210}Pb in mussels from Mudginberri Billabong is about twice the committed effective dose from the ingestion of Sandy Billabong mussels (results for the 2010 collection are discussed in chapter 2, section 2.2.3). Historical data, however, show that there is no indication of an increase of ^{226}Ra (or uranium) activity concentrations in mussel flesh in Mudginberri Billabong over time and thus the difference is unlikely to be mine-related. Reasons for the higher ^{226}Ra activity concentrations measured include the mineralised nature of the Magela Creek catchment area and the associated naturally higher ^{226}Ra content in Mudginberri Billabong sediments and water, and the lower Ca and Mg concentration in water compared with Sandy Billabong. In addition, differences in mussel growth and health may affect radium uptake (see chapter 3, Supervising Scientist annual report 2007–08, for more detail).

With the rehabilitation of Ranger there will be radiological protection issues associated with the land use by local indigenous people and a shift towards terrestrial food sources. These foodstuffs include both terrestrial animals and plants. Over the last 25 years, SSD has gathered radiological concentration data on bush foods throughout the Alligator Rivers Region in the Northern Territory. New data, in particular for terrestrial food items, are acquired on an ongoing basis and are used to replace IAEA default radionuclide concentration factors with locally derived values. This provides a more reliable estimate of ingestion doses. In addition, local radionuclide concentration factors will be used to derive soil closure criteria for the rehabilitation of Ranger.

2.6.3 Jabiluka

2.6.3.1 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.

2.6.3.2 Radiological exposure of the public

Although there were no activities reported at the Jabiluka minesite, the population group that may, in theory, receive a radiation dose due to future activities at Jabiluka is a small community of around 60 individuals about 10 km south of Jabiluka at Mudginberri.

The Supervising Scientist has a permanent atmospheric research and monitoring station at Four Gates Rd radon station a few kilometres west of Mudginberri (see Map 3). RDP and LLAA concentrations are measured there on a monthly basis.

Figure 2.29 shows the quarterly averages of RDP and LLAA concentrations measured at Four Gates Rd radon station by SSD up to March 2011.

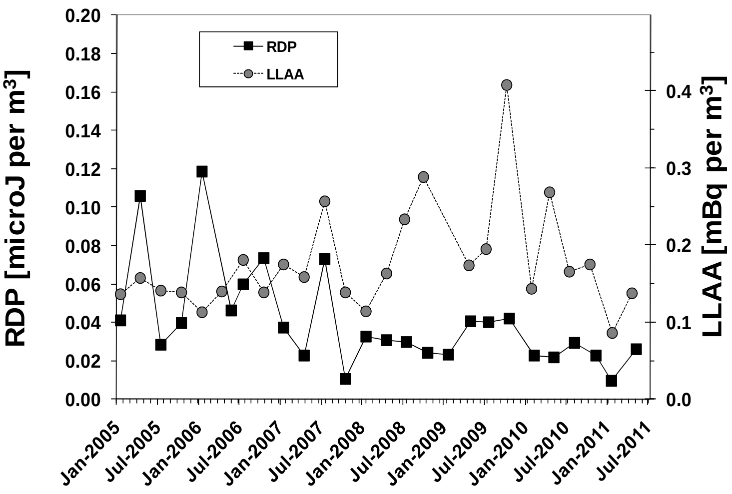


Figure 2.29 Radon decay product (RDP) and long lived alpha activity (LLAA) concentrations measured at SSD's Mudginberri Four Gates Rd radon station from July 2004 to March 2011

The average airborne radionuclide concentrations measured in 2010 would translate into an annual total effective dose, including natural background, of 0.23 mSv from RDP and ~0.011 mSv from LLAA. Only a very small fraction of these doses would be due to mine-derived radionuclides.

2.7 EPBC assessment advice

oss continues to provide advice to the Environment Assessment and Compliance Division (EACD) of SEWPaC on referrals submitted in accordance with the EPBC Act for new and expanding uranium mines. During the reporting period ***oss*** provided coordinated responses from SSD on the Olympic Dam, Kintyre and Wiluna uranium projects.

3 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 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 the Alligator Rivers Region Technical Committee (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 4 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 Key Knowledge Needs 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 2010–11 research program are presented in this report, with a summary introduction to these topics provided below.

During 2009–10 a project was commissioned to integrate the large volumes of knowledge acquired by ***eriss*** across its research program areas into a series of conceptual models describing potential contaminant transport pathways associated with uranium mining in the Alligator Rivers Region. This is being done as part of the evolving ecological risk assessment framework being developed by the Supervising Scientist for the operating phase of the mine. One of the key objectives of the project is to determine if there are any significant gaps in our scientific knowledge about the pathways that could potentially adversely impact on the health of the environment outside of the mine lease or project area. Efforts in 2010–11 focused on finalising an assessment of the relative importance of each pathway in terms of its potential to cause adverse biological effects to the off-site environment. The contaminant pathways conceptual models developed by this project, and the associated screening level risk analysis, will assist in communicating the actual level of significance of these pathways to key stakeholders.

As stated in the last annual report, 2009–10 was a period of intensive consolidation for all aspects of the research program contributing towards the acquisition and interpretation of continuously monitored water quality data in Magela and Gulungul Creeks adjacent to the Ranger mine. It was noted at that time that the intention was for the continuous monitoring system with associated event-based automatic sampling to become SSD's primary water quality monitoring platform, starting with the 2010–11 wet season. This milestone was achieved and marked the final transition from method development to routine deployment of the continuous monitoring system. Accordingly, from this annual report forward the results from the continuous monitoring program will be reported in chapter 2.

Continuous monitoring data provide the important ability to be able derive annual solute load budgets upstream and downstream of the Ranger mine. The difference between the upstream and downstream loads is a measure of the amount of solutes exported from the minesite in each wet season. Analysis of these data enables an assessment to be made of how these load inputs are trending through time. The continuous monitoring data that have been obtained over the past five wet seasons have been used for this purpose and the findings are reported here.

Substantial progress has been made on a program of ecotoxicological test work (introduced in the 2008–09 annual report) to derive Mg water quality trigger values (TVs) for pulse exposures to magnesium over periods of 4, 8, and 24 h. The aim is to establish a quantitative relationship between the TVs and exposure durations such that TVs can be derived for any given pulse duration and magnitude detected by the continuous water quality monitoring system. Testing was completed during 2010–11 for five of the six species being assessed.

In situ toxicity testing, using aquatic snails, was extended from Magela to Gulungul Creek starting with the 2009–10 wet season, reflecting the possibly increased potential for impacts on Gulungul Creek from the extensive works undertaken to increase the height of the walls of the tailings dam. The deployment of snails in both creeks was continued through the 2010–11 wet season and the findings from the now two years of deployment in Gulungul Creek are presented and discussed in this report.

Given the high affinity of uranium (U) for organic matter in sediment, the consequences of U accumulating in sediment needs to be addressed as a component of a sediment quality assessment for waterbodies impacted by U mining activities, both for the operating and closure phases of mines. Accordingly a multi-year project has been underway to develop a sediment quality criterion for uranium. The start of this work was described in the last annual report. A combination of conventional taxonomic identification (for macroinvertebrates) and leading edge ecogenomic techniques (for bacteria and microinvertebrates) is being used to derive a concentration response relationship for billabong sediments spiked with a gradient of uranium concentrations. An update on the progress of this project is provided in this report.

The major program of works being done by ***eriss*** to instrument four erosion plots on an eight hectare trial landform constructed during late 2008 and early 2009 by Energy Resources of Australia Ltd (ERA) was described in the last annual report. An assessment is presented here of the amounts of bedload washed off these plots for the 2009–10 and 2010–11 wet seasons. Complementing these field measurements is the use of geomorphic computer modelling to forward predict the rates of erosion from rehabilitated mine landforms through periods of decades and centuries. The CAESAR (Cellular Automaton Evolutionary Slope and River) landform evolution model is being used to do this. A summary of the progress of the modelling to date is presented in this report with a comparison between predicted and actually measured erosion rates for two of the erosion plots.

A number of projects are currently underway to address aspects of rehabilitation associated with future closure of the Ranger Project Area, including ecosystem reconstruction and final landform design and revegetation. The Georgetown analogue area, a ~400 hectare area of natural vegetation located on the south-eastern edge of the Ranger mine, is providing much of the required reference data about local vegetation communities. The substantive progress that has been made in relating the occurrence of particular plant community groups within the analogue area to physical terrain and other environmental determinants is described.

A good estimate of the pre-mining radiological baseline is an essential precursor to being able to quantify rehabilitation success for a uranium minesite and to provide assurance that the requisite international standards for protection of members of the general public post rehabilitation are being met. Previous annual reports have documented that progress being made to infer this baseline for the Ranger site using a combination of aerial radiometrics acquired for the lease area before mining started and contemporary intensive ground surveys of undisturbed radiological anomalies (radiological analogues). This work has been largely completed and the first robust estimates that have been able to be made for the site as a whole are reported. These data will enable the success of the ultimate rehabilitation of the site to be assessed against international radiological standards.

The ARR is an area where there is customary harvesting of both aquatic and terrestrial bushfoods by local indigenous people. The consumption of these bushfoods, especially in the vicinity of operating or decommissioned uranium mines, needs to be addressed as a potential radiation exposure pathway for members of the public, both now and in the future. ***eriss*** has been measuring activity concentrations of radionuclides in ARR bushfoods and associated environmental media for 30 years. The data allow concentration ratios for the transfer of radionuclides from soil and water to bushfoods to be calculated and thereby facilitate the estimation of ingestion doses for those circumstances where only the soil or water activity concentrations are known. The creation of a bushfoods and environmental media database that compiles the 30 years of data into a consistent and quality controlled information repository is described.

Developing a remote sensing monitoring framework for the ARR will provide the basis for efficiently and cost-effectively acquiring the spatial data needed to be able to place the land surface status of operating and rehabilitated minesites into a regional context. A systematic remote sensing capture by the World-View 2 satellite, incorporating full ground control and coincident collection of ground spectral data, was undertaken for the Magela floodplain and the area around the Ranger mine in May 2010. High resolution images covering 730 km^2 of the Magela Creek catchment were acquired. Work through 2010–11 focused on orthorectification and correction of the imagery for atmospheric interference effects to provide the basis for producing high resolution maps of vegetation and habitat types.

The catchment of Ngarradj Creek (which flows through the Jabiluka mineral lease) is an excellent location to determine the importance of large wood (riparian trees and in-channel debris) for creating aquatic habitat and stable river channels in the natural environment, because there are long reaches that have experienced little human modification. The conclusions from this work, which was done as part of a suite of projects to characterise the baseline condition of the creek prior to the start of any mining at Jabiluka, are reported here.

eriss was a key collaborator in the catchment water budgets and water resource assessment project that was part of the Tropical Rivers and Coastal Knowledge (TRaCK) CERF-funded research hub headquartered at Charles Darwin University. The work involved mapping the maximum and minimum extents of flood inundation for the Mitchell and Daly River catchments using a combination of radar and optical satellite imagery analysis. The outputs fed into the seasonal catchment water balance models that were developed for these catchments.

More comprehensive descriptions of ***eriss*** research are published in journal and conference papers and in the Supervising Scientist (SSR) and Internal Report (IR) series. Publications by Supervising Scientist Division staff in 2010–11 are listed in Appendix 2. 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 2011, is available on the SSD web site at www.environment.gov.au/ssd/publications.

3.1 Conceptual models of contaminant transport pathways for the operational phase of the Ranger mine

3.1.1 Background

Conceptual models of potential contaminant pathways associated with uranium mining in the ARR have been developed as part of the evolving ecological risk assessment framework that was started by the Supervising Scientist in the early 1980s. In response to recommendations by the World Heritage Commission Independent Scientific Panel and ARRTC, a specific project was initiated to produce a comprehensive conceptual model of contaminant pathways associated with the operational phase of the Ranger mine.

Development of a new conceptual model of contaminant pathways associated with the operational mining phase was commenced in 2004. The primary purpose of the conceptual model was to place off-site environmental impact issues associated with the operational phase of mining at Ranger into a risk management context. Although an overall tabular and diagrammatic form of the main elements of the conceptual model was produced, sub-models for the multiple contaminant pathways identified in the conceptual model were not finalised at that time. Much of this work was completed in 2009–10 (see 2009–10 Supervising Scientist annual report), resulting in a total of 32 stressor/contaminant pathway sub-models identified and reviewed. Efforts in 2010–11 focused on finalising an assessment of the relative importance of each pathway in terms of its potential to cause adverse biological effects to the off-site environment.

3.1.2 Methods

An internal expert panel approach was used to produce a total importance score for each contaminant pathway. A standard 3 × 3 scoring matrix (Table 3.1.1) was developed with the magnitude of the assigned score being based on (a) the size/potential maximum generating capacity of the relevant contaminant source (*high*, *medium* or *low*); and (b) the potential maximum capacity (load and rate) of the relevant pathway to transport contaminants from the mine site to the surrounding environment (*high*, *medium* or *low*). The current level of scientific certainty based on existing research and monitoring (*high*, *medium* or *low*) information and the current level of adverse biological impact on receptors based on results from monitoring (*yes*, *no* or *unknown*) associated with each contaminant pathway was also determined and reported.

TABLE 3.1.1 SCORING MATRIX FOR ASSESSMENT OF RELATIVE IMPORTANCE OF CONTAMINANT PATHWAYS

		Maximum size/generating capacity of source		
		Low	**Medium**	**High**
Maximum capacity of pathway	**Low**	Low	Low	Medium
	Medium	Low	Medium	Medium
	High	Medium	Medium	High

3.1.3 Results

Six of the 32 stressor/contaminant pathway sub-models were assessed as being of high importance during the operational phase of mining (Table 3.1.2). For five of these six pathways the available comprehensive monitoring data indicates no detectable impact on the environment outside of the mining lease. For the case of the remaining pathway (inorganic stressors- airborne emissions) it was judged that there was insufficient evidence to say that there was no measurable environmental impact.

The main mine-derived inorganic contaminants involved in the inorganic stressors- airborne emissions pathway are sulfur (as sulfur dioxide) and nitrogen (as nitrogen oxides) released from the power station stack, nitrogen oxides from the product calciner stack, ammonia released as fugitive emissions from storage tanks and pipes or the water treatment plant, and other inorganic emissions from vehicles and mining plant or equipment. Whilst point source monitoring of stacks on the mine site is conducted by the mine operator, not all of these data have been assessed in an environmental impact context. In the case of sulfur, emissions of sulfur dioxide from the power station are unlikely to be an issue since measurements that were made when the acid plant was also operating, indicated that the mine site made an insignificant contribution to the total load of S being deposited from the atmosphere in the local region.

Of the remaining sub-models, 21 were assigned medium importance and 6 low importance (details not presented here).

Three of the six pathways assessed as being of high importance relate to the transport of contaminants via the surface water to surface water pathway. This is not unexpected given that the surrounding surface water systems are the primary potential receptors of contaminants released in runoff from the mine site.

TABLE 3.1.2 CONTAMINANT PATHWAYS FOR RANGER URANIUM MINE ASSESSED AS BEING OF HIGH IMPORTANCE BASED ON SIZE/MAXIMUM CAPACITY OF SOURCES AND MAXIMUM CAPACITY OF PATHWAY

Pathway	Size/max generating capacity of source (H,M,L)	Max capacity of pathway (H,M,L)	Scientific certainty (H,M,L)	Impact No = N Unknown = U	Importance in operational phase
Inorganic stressors – surface water to surface water pathway	H	H	H	N	High
Inorganic stressors – airborne emissions pathway (released from stacks and pipes)	H	H	H	U	High
Radionuclides – surface water to surface water pathway	H	H	H	N	High
Radon-222 attached/unattached radon progeny pathway	H	H	M	N – Human U – Biota	High
Radon-222 exhalation pathway	H	H	H	N	High
Suspended sediments – surface water to surface water pathway	H	H	H	N	High

The relative importance of each pathway was assigned based on the unmitigated potential of the pathway to transport contaminants from the mine site into the surrounding environment. However, this does not mean that high importance pathways are resulting in, or are likely to result in, impact on receptors within the ARR environment. The actual volume (load) and concentration of contaminants transported by these pathways at any time (and therefore the level of potential risk to receptors) depends on a range of chemical, biological, physical, and radiological factors and the effectiveness of existing management controls. These latter control measures are designed to reduce risks to the environment to acceptable levels either by containing contaminants on the mine site or minimising the volume, concentration and availability of contaminants that may be transported via the various pathways. Given the importance of these controls, details about the risk mitigation measures applicable for each contaminant pathway have been included in the model narratives produced for each of these pathways.

The assessment identified some knowledge gaps which may be fed into the ARRTC Key Knowledge Needs (KKN) framework following further consideration. Key amongst these was a lack of knowledge about the fate of organic contaminants, for example, hydrocarbons and pesticides used on site; and inorganic contaminants from the mine site stacks, storage tanks and pipes. The specific issue for the organics is that these species have not been analysed, even at a screening level, in the water that exits the site. Hence no specific assessment can be made about potential for impact, despite this likely being a no or low impact issue. In the case of the inorganic contaminants, emissions from the stacks are monitored by ERA. One additional factor that could also warrant closer attention is the potential for transport of weeds off site, despite the existence of an active weed identification and control program.

3.1.4 Conclusions and future work

While knowledge gaps exist for some pathways and contaminants, there is no evidence to suggest that any of these pathways are currently resulting in adverse biological impacts on the environment within the ARR. Results of ongoing chemical, radiological and biological monitoring undertaken by the Supervising Scientist continue to show that the environment of the ARR remains protected from uranium mining related impacts via the aquatic pathway (the dominant potential vector) and from airborne radionuclides in the case of human health protection.

The contaminant pathways conceptual models developed by this project, and the associated screening level risk analysis, will assist in communicating the actual level of significance of these pathways to key stakeholders.

A related but separate task will be to develop models of the contaminant pathways uniquely associated with the mine closure and rehabilitation phases of mine life. This closure pathways conceptual model will inform and assist the development of closure criteria and the specifying of the monitoring framework needed to address them.

3.2 Magela Creek solute load update

3.2.1 Background

The Supervising Scientist Division (SSD) undertakes comprehensive water quality monitoring to ensure the protection of the Ramsar-listed Magela Creek wetlands and the people living semi-traditional livelihoods, downstream of the Ranger uranium mine. This leading practice program has been developed over a number of years, progressively incorporating improved methods and state-of-the-art technology. The most recent improvement has involved the implementation of routine continuous water quality monitoring. During the five year period of development of this method (described in previous annual reports) there was regular engagement with stakeholders to communicate the results, and to develop a shared understanding of the power of continuous monitoring compared with discrete, weekly grab sampling. Starting with the 2010–11 wet season, continuous monitoring, incorporating event-based collection of water samples (fully automated using automatic sampling units), has replaced grab sampling as the primary method for measuring water quality in Magela and Gulungul Creeks. The validated monitoring data are posted weekly in arrears on the SSD website for viewing by both stakeholders and the general community.

As well as providing primary water quality data (electrical conductivity, turbidity and pH) in Magela and Gulungul Creeks for impact assessment and community assurance purposes, the continuous monitoring data have been used to develop an annual mine ‘solute budget’. In principle, this enables tracking and comparison from one year to the next of annual solute loads transported by Magela Creek upstream and downstream of the mine, allowing an assessment to be made of the annual performance of the site’s mine water management system. The calculation of a robust and internally consistent solute budget depends on detailed analysis of the data from SSD’s upstream and downstream monitoring stations, used in conjunction with data from sites that are monitored by ERA.

The main Magela Creek channel splits into three channels a short distance upstream of the location of SSD’s downstream site, with SSD’s monitoring station being located in the West Channel (see Fig 3.1b in 2008–09 annual report). This west channel receives flow at all times with the central and east channels holding water only during medium to high flow conditions. Over the last three wet seasons the issue of flow splitting was systematically addressed by carrying out a number of stream gauging measurements to determine the relationship between total stream discharge and that which reports to the west channel in which SSD’s monitoring pontoon is located.

Unfortunately at the time of writing of this report, SSD had not received the required on-site tributary data from ERA. As a result, reporting of the most recent solute loads from the mine site itself, and comparison with previous years, will not be able to be done until next year’s annual report. This report will therefore focus on the overall solute loads transported by Magela Creek, with comparison between the totals loads upstream and downstream of the mine.

3.2.2 Electrical conductivity – magnesium relationships

Relationships between electrical conductivity (EC) and magnesium (Mg) in Magela Creek have been derived by correlating Mg concentrations in grab water samples with concurrent measurements of in situ EC. Such relationships (and the technical rationale for them) have been reported previously for the upstream (MCUGT) and downstream (MCDW) sites in Magela Creek (Supervising Scientist annual report 2008–09). See Map 2 for the locations of these sites.

The previously reported relationships between EC and Mg have been updated by adding the most recently obtained data from the 2009–10 and the 2010–11 wet seasons. A quadratic relationship was reported previously for MCDW. However, with the addition of the data from the more recent wet seasons the relationship is now better defined by a linear regression (Figure 3.2.1). This change in the relationship is due to the increased number of samples collected during high EC (and hence high Mg) events since the introduction of event-based sampling, increasing the number of points in the upper end of the relationship (where EC > 50 µS/cm). The relationship shown here (Figure 3.2.1) for MCUGT is similar to that reported previously.

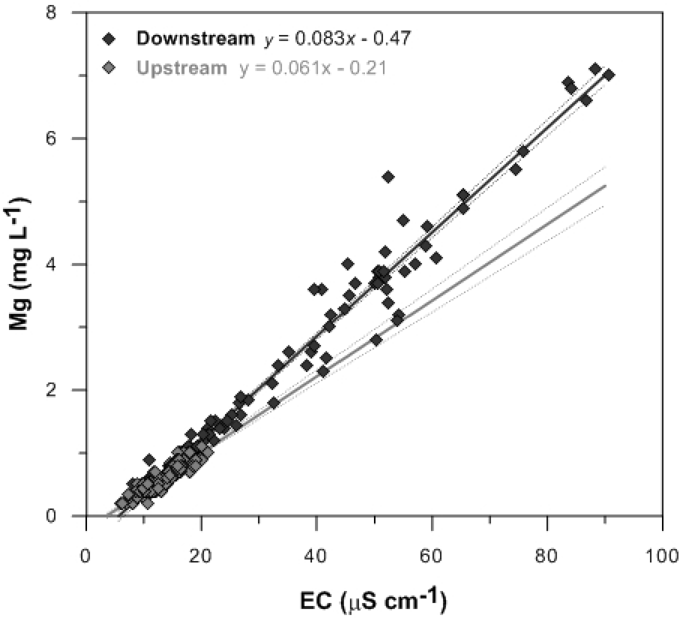


Figure 3.2.1 Best fit relationships between electrical conductivity (EC) and magnesium (Mg) concentrations for the upstream (R^2 = 0.84, P<0.0001) and downsteam (R^2 = 0.96, P<0.0001) monitoring stations in Magela Creek, with the upper and lower 95% confidence limits shown

The even distribution of the residuals about the horizontal axis in the residual plot for the downstream regression equation supports the use of the linear relationship for estimating Mg concentrations at the downstream site (Figure 3.2.2).

The updated relationships shown in Figure 3.2.1 have been used to re-derive Mg concentration data from the continuous EC data measured at MCUGT (upstream) and MCDW (downstream) for all wet seasons between 2005–06 and 2010–11.

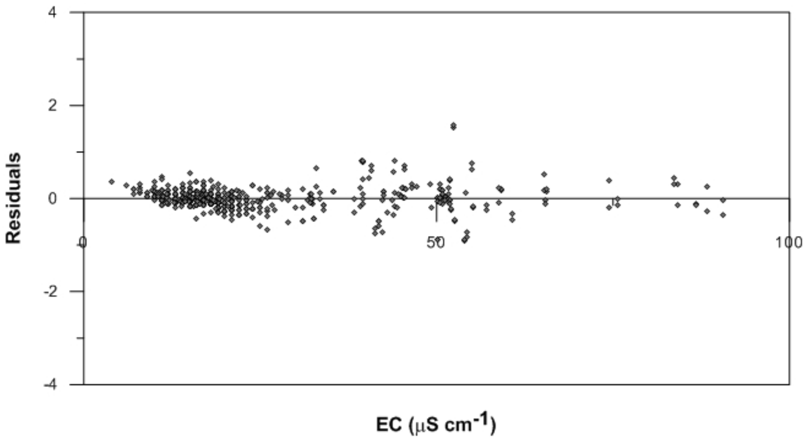


Figure 3.2.2 Residuals plot for the relationship between electrical conductivity (EC) and magnesium (Mg) for the downstream site on Magela Creek, $y = 0.083x – 0.47$

3.2.3 Magnesium loads

Previously, Mg loads downstream of the mine have been calculated using the continuous Mg concentration data estimated at MCDW and the total flow discharge (Q) for Magela Creek measured at the G8210009 gauging station (located ~400 m upstream of MCDW) The approach is described in detail in the Supervising Scientist annual report for 2008–09. However, this method has been found to overestimate the actual Mg load at the downstream site since it assumes that the EC measured in the western channel at the MCDW site is the same across the three creek channels, independent of flow conditions. This is not actually the case, as the EC in the western channel is higher compared with the other two channels as a result of solutes from the minesite (located on the western side of Magela Creek) being preferentially conveyed down the west channel, especially during low flow periods. To more accurately calculate Mg load downstream of the minesite, the relative proportions of solutes and total stream discharge travelling through each channel at the MCDW site at any given stream height must be determined.

The EC in each channel (eastern, central and western) at the cross section at G8210009 was measured during the 2010–11 wet season by ERA, using continuous monitoring stations deployed in each channel. The hourly mean EC values for each of the downstream channels and for the Magela Creek upstream site (MCUGT) for reference, are plotted against hourly mean discharge values measured at G8210009 (Figure 3.2.3).

The data in Figure 3.2.3 show that the EC in the eastern channel is equivalent to the upstream EC under all flow conditions, with the high EC events (> 20µS/cm) being confined to the central and western channels of the creek. These higher EC events only occur when the total stream discharge measured at G8210009 is < 200 m^3/s. At higher discharge rates, the EC in all channels moves towards values that are measured at the upstream site. This is largely due to the fact that mine inputs to Magela Creek occur via Coonjimba and Georgetown Billabongs which become 'backed-up' during high flow events in the creek, effectively restricting outflow of higher EC mine-derived water from the billabongs (see Supervising Scientist annual report 2008–09).

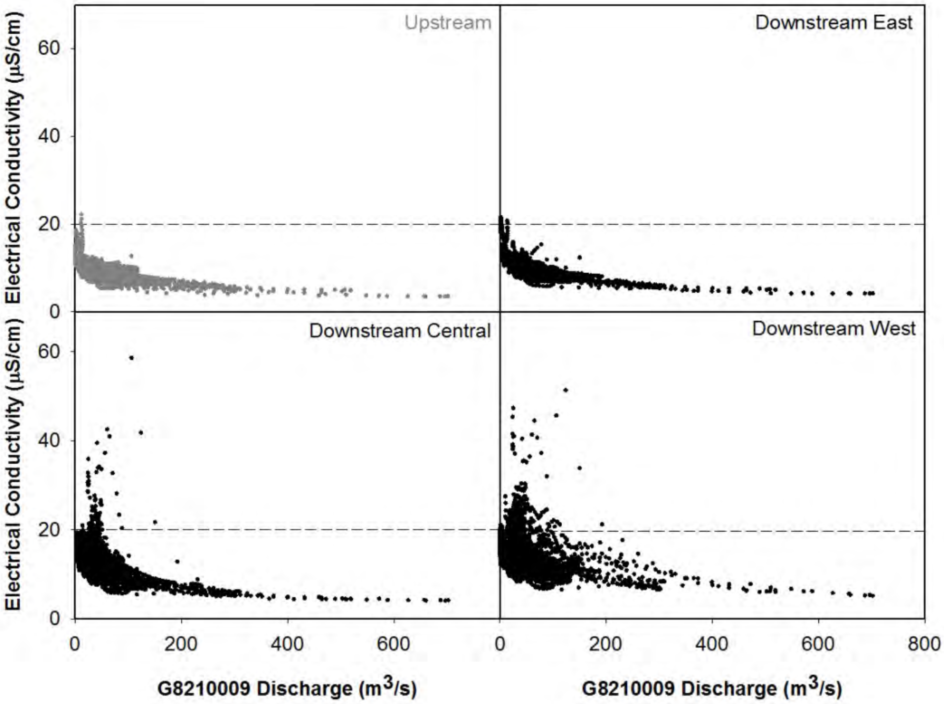


Figure 3.2.3 Plots showing mean hourly electrical conductivity for Magela Creek upstream (grey) and downstream sites (east, central and western sections of the channel at G821009, black) versus mean hourly discharge measured at G8210009. The dotted line indicates an EC value of 20µS/cm.

The proportion of the total stream discharge travelling down the western channel at MCDW can be determined using the relationship between the discharge measured in the west channel alone and the total discharge measured concurrently at G8210009. These relationships for the 2008–09, 2009–10 and 2010–11 wet seasons shown in Figures 3.2.4 a, b and c, respectively. The data from the three wet seasons were combined to derive an average relationship (Figure 3.2.4 d) which can be used to estimate the west channel discharge as a function of total flow for seasons prior to 2008–09.

The data show that as the total Magela creek discharge increases, the proportion of the discharge travelling down the western channel at MCDW decreases exponentially (reported previously in Supervising Scientist annual report 2008–09). This occurs due to the steep sloping west bank of Magela Creek compared with the very low slope gradient towards the east bank allowing the majority of over-bank flow to spread to the east for up to 1 km under high flow conditions.

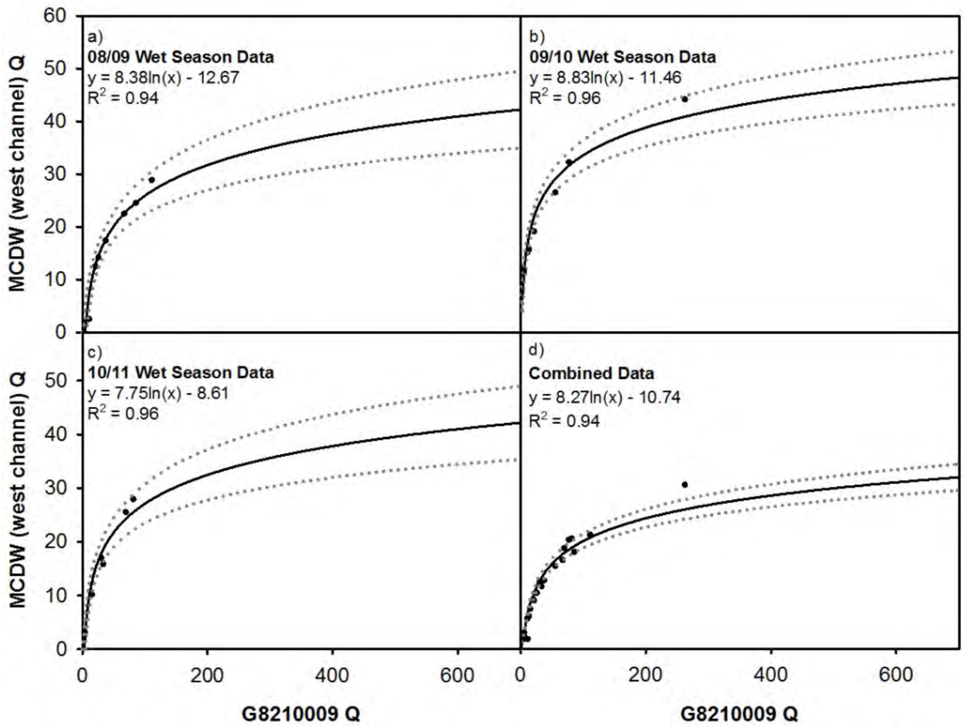


Figure 3.2.4 Discharge (Q) in m³/s measured in the western channel at MCDW versus total Magela Creek discharge measured at G8210009 for the 2008–09 (a), 2009–10 (b), and 2010–11 (c) wet seasons with the averages for the three seasons plotted in (d). The dashed lines are confidence limits for the fitted relationship.

The Mg loads since the 2005–06 wet season have been recalculated using a new method that takes into consideration the cross channel gradient in EC. The total Mg load at the downstream site is estimated by combining the Mg load transported in the western channel and the Mg load transported in the central and eastern channels. The western channel Mg load was calculated using the Mg concentrations derived from the MCDW continuous EC trace and the west channel discharge estimated using the equations in Figure 3.2.3. The Mg loads in the central and eastern channels were calculated by using the Mg concentrations derived from the upstream MCUGT EC data together with the residual discharge (ie total Magela Creek discharge measured at G8210009 minus the western channel discharge). It should be noted that this method will result in a slight underestimation of the total load travelling in the central channel for discharges < 200 m^3/s (see Figure 3.2.3). The newly derived loads are compared to loads calculated using the original method in Table 3.2.1 below.

These data suggest that over the past six wet seasons, between 30–40% of the total Mg load transported by Magela Creek has been contributed by the mine site and that this seasonal contribution has (in proportional terms) been consistent over the years. There is certainly no evidence of an increase through time in loads of Mg being exported from the minesite. The low difference value in 2008–09 was simply the result of this being a relatively low rainfall year, with reduced loads coming from both upstream, and from the minesite.

TABLE 3.2.1 MG LOADS (T) MEASURED IN MAGELA CREEK UPSTREAM AND DOWNSTREAM OF THE MINE

		Loads calculated using the old method (*overestimated*)		Loads calculated using the new method (*slightly underestimated)*	
Season	***US***	**DS**	**Minesite contribution (%)**	**DS**	**Minesite contribution (%)**
2005–06	*184*	404	+55%	274	+33%
2006–07	*152*	531	+71%	236	+36%
2007–08	*150*	364	+59%	244	+39%
2008–09	*78*	175	+55%	111	+30%
2009-10	*131*	276	+53%	194	+33%
2010–11	*188*	398	+53%	267	+30%

The improved method for determining the downstream Mg loads in Magela Creek produced lower annual load estimates compared with the method used previously. Whilst the actual seasonal Mg load at the downstream site will fall somewhere between the loads calculated using these two methods, this will not change the conclusion that there is no evidence for an increase in annual loads coming from the minesite over the past five years of the continuous monitoring record. Additional flow gauging methods are needed at flow rates greater than 250 cumecs to reduce the uncertainty in the upper regions of the regressions used to estimate the contribution of the discharge in the west channel at MCDW to the total discharge.

3.2.4 Summary and future work

During the 2011 dry season, detailed cross channel section surveys will be carried out at the Magela Creek cross sections at both G8210009 and MCDW. These measurements will enable better characterisation of the likely cross channel distribution of flows in Magela Creek under high flow conditions. The ERA discharge and EC data for the Georgetown and Coonjimba flow lines have been sought. Once received they will be used to independently derive the mine solute contribution to Magela creek for each wet season over the past six years. These data will then be compared with the overall upstream/downstream differences reported in Table 3.2.1

3.3 Effects of magnesium pulse exposures on aquatic organisms

3.3.1 Background

Continuous monitoring of electrical conductivity (EC) in Magela Creek enables equivalent magnesium (Mg) concentrations to be derived, since there is a very strong relationship between EC and Mg (see section 3.2.2, above). These monitoring data have shown that peak Mg concentrations associated with pulse events arising from mine site discharges at times exceed a provisional site-specific Limit for Mg (3 mg/L) in Magela Creek, and have, on one occasion, reached a maximum value of approximately 16 mg/L. In this context it should be noted that the ecotoxicity data upon which the Mg provisional Limit was derived are based on continuous exposures over three to six days (depending on the test species). Given that the majority of the Mg concentration pulses occur over timescales of only minutes to hours, it was unknown if these shorter duration exceedances could have the potential for adverse effects on aquatic biota. To address this important issue, an assessment of the toxicity of Mg under a pulse exposure regime was initiated in late 2008. The latest findings are reported here.

The project has involved assessing the toxic effects to six tropical freshwater species of Mg pulses of 4, 8 and 24 hours duration, to derive Mg water quality trigger values (TVs) for these pulse durations. The aim is to establish a quantitative relationship between the TVs and exposure durations such that TVs can be derived for any given pulse duration. In 2010–11, testing was completed for five of the six species being assessed, and the results are summarised below.

3.3.2 Results

The results show that Mg toxicity typically decreased with a reduction in exposure duration (Table 3.3.1). Table 3.3.1 presents the Mg concentrations that caused a 10% (IC10) and 50% (IC50) inhibition in the organism response relative to a control (unexposed) response. As an example, the 4-h, 8-h, 24-h and continuous exposure concentration-response relationships for *Hydra viridissima* (green hydra) are provided in Figure 3.3.1. This graph clearly shows the reduction in toxicity as the pulse duration decreases. Based on the IC50 values where available, the reduction in Mg toxicity of a 4-h exposure duration compared with a continuous (96-h or 120-h) exposure duration ranged from two-fold (*H. viridissima*) to almost 50-fold (*Amerianna cumingi*).

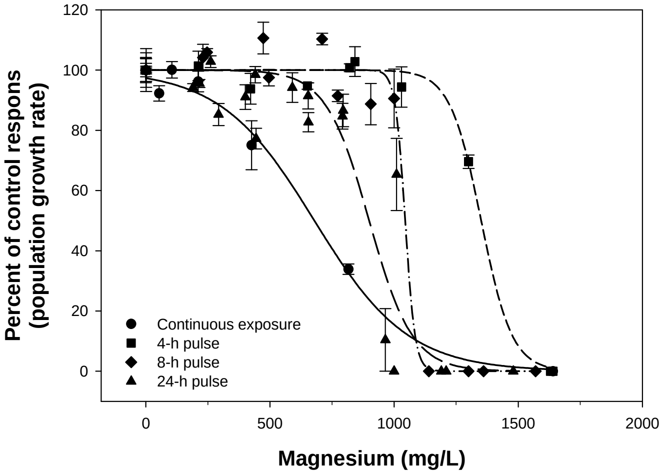


Figure 3.3.1 Effect of exposure duration on the toxicity of magnesium to *Hydra viridissima*. Data points represent means (n = 3) with associated ± standard error bars shown. Concentration-response curve fits (3-parameter sigmoid model) for the data can be identified as follows: solid line – continuous exposure; short dashed line – 4 h pulse exposure; dashed-dotted line – 8 h pulse exposure; and long dashed line – 24 h pulse exposure. See Table 3.3.1 for corresponding toxicity estimates.

TABLE 3.3.1 TOXICITY OF PULSE EXPOSED MAGNESIUM (MG/L) COMPARED WITH CONTINUOUS EXPOSURE

Species	**4-h pulse**		**8-h pulse**		**24-h pulse**		**Continuous exposure (96 – 120-h)[a]**	
	IC10[b]	**IC50[c]**	**IC10**	**IC50**	**IC10**	**IC50**	**IC10**	**IC50**
Lemna aequinoctialis (duckweed)	4212	>4220[d]	1495	3781	80	2851	36	629
Moinodaphnia macleayi (cladoceran)								
Exposed at test commencement	1017	1461	612	1043	216	502	39	122
Exposed around onset of reproductive maturity	212	358	62	296	128	247	na	na
Amerianna cumingi (snail)	3031	>4170	387	2743	301	1936	5.6	96
Hydra viridissima (green hydra)	1213	1351	1001	1045	709	900	246	713
Mogurnda mogurnda (fish)	>4100	>4100	>4100	>4100	>4100	>4100	4008	4054

a Continuous exposure data reported from a previous study (van Dam et al 2010, *Environmental Toxicology and Chemistry* 29(2), 410–421).

b IC10: Concentration causing a 10% inhibition of the test endpoint relative to the control (unexposed) response.

c IC50: Concentration causing a 50% inhibition of the test endpoint relative to the control (unexposed) response.

d Values were reported as 'greater than' values where the model could not predict the relevant IC value within the Mg concentration range tested, the maximum of which approximately corresponded to the maximum Mg concentration that could be tested at the specified Mg:Ca ratio of 9:1 without exceeding the solubility limit of $CaSO_4$ (ie ~4200 mg Mg/L).

As noted previously (see Supervising Scientist annual report 2008–2009), the cladoceran, *Moinodaphnia macleayi*, was also exposed to pulses of Mg around the onset of reproductive maturity (at around 27-h old; compared with the pulse being administered at the commencement of the test). The hypothesis being tested here was that exposure to Mg at a key period of organism development, when energy demands for reproduction must be met in addition to those required for growth and maintenance, would result in a more sensitive response.

The toxicity values for *Moinodaphnia macleayi* (Table 3.3.1) and the effects graphs shown in Figure 3.3.2, clearly support the hypothesis of life stage effect for this species. Regardless of pulse duration, pulses administered around the onset of reproductive maturity always resulted in more severe effects than the same pulse applied at the start of the test. This finding is at variance with a common assumption in ecotoxicology that early life stages of species (ie neonates) are more sensitive than later life stages. The exact mechanism by which exposures around the onset of reproductive maturity result in more toxic effects is not known, but could be related to (i) a lack of energy resources available for reproduction, due to the increased energy requirements for maintenance (associated with the added stress of coping with Mg exposure), and/or (ii) increased permeability to ions of the exoskeleton immediately after moulting.

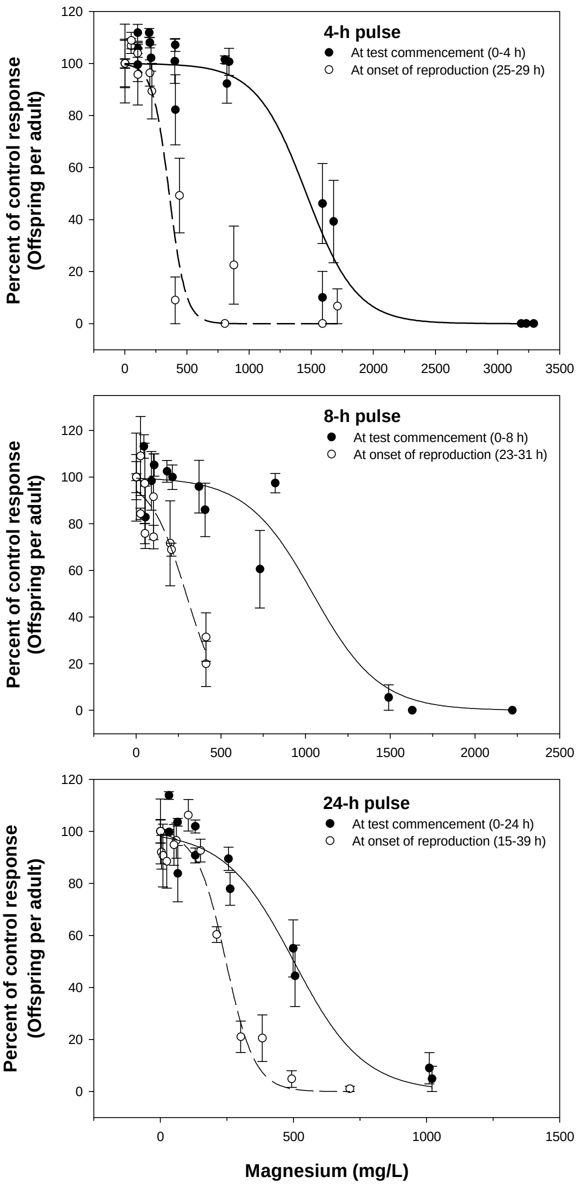


Figure 3.3.2 Effect of the timing of exposure on the toxicity of magnesium to *Moinodaphnia macleayi* (Top: 4-h pulse; middle: 8-h pulse; bottom: 24-h pulse). Data points represent means (n = 10) with associated ± standard error bars shown. Concentration-response curve fits (3-parameter sigmoid model) for the data can be identified as follows: solid line – Mg exposure at test commencement; dashed line – exposure bracketing the onset of reproductive maturity. See Table 3.3.1 for corresponding toxicity estimates.

3.3.3 Furtherwork

Assessment of the effect of Mg pulse exposures to the sixth and final test species, the green alga, *Chlorella* sp, was still in progress at the time of compiling this report. To date, this species has presented specific challenges related to the difficulties in recovering a sufficient proportion of the micro-algal cells from the Mg exposure solutions and returning them to control water without compromising the subsequent comparison of growth rates between control and Mg treatments. Additionally, further investigations will seek to better understand the response of *M. macleayi* to Mg pulses around the onset of reproductive maturity.

Once the results for the green alga are finalised, a quantitative relationship will be derived between Mg water quality trigger values and exposure duration, to be applied to the monitoring and assessment framework for the Ranger mine. This will enable the environmental significance of any periodic excursions of Mg in Magela Creek to be quickly determined.

3.4 Toxicity monitoring in Magela and Gulungul Creeks

3.4.1 Background

Toxicity monitoring evaluates the responses of aquatic animals exposed in situ in Magela and Gulungul Creeks to diluted runoff water entering the creeks from the Ranger minesite. Egg production over a four day deployment period by the freshwater snail, *Amerianna cumingi*, has been the method used in Magela Creek since 1990–91 and in Gulungul Creek since 2009–10. Results of the tests have been reported regularly in each of the Supervising Scientist's annual reports (see section 2.2.3.2 of this report for 2010–11 wet season results).

After each wet season, the 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. Unlike previous wet seasons, snail egg production during the 2009–10 season in Magela Creek was found to be consistently (8 out of 9 tests; Figure 3.4.1) and significantly higher at the downstream site compared with the upstream site. The positive difference was particularly marked in the 3rd test and to a lesser extent in the 4th and 5th tests. An assessment of the 2010 data (see 2009–10 annual report) in the context of the physical and chemical variables being measured concurrently in Magela Creek was not able to attribute any specific cause for this variance in test behaviour.

This report examines progress made in applying the toxicity monitoring test to Gulungul Creek. In this context it should be noted that the different environmental conditions to which snails are exposed in this relatively small catchment (compared with Magela Creek) enhances the information base of environment-response data available to identify likely correlates, and possibly causes, of differences in egg numbers at a given time and location in both creek systems.

It was suggested in the 2009–10 annual report that the increased downstream egg numbers could have been due to additional organic matter being deposited in the snail test containers at the downstream location (see section 2.2.3.2 of the 2009–10 Supervising Scientist annual report). Such material could provide an additional source of food for the snails. This organic matter could have come from inflows from Georgetown and Coonjimba Billabongs and/or from material eroded from recently-disturbed land adjacent to Magela Creek downstream of the mine and associated with exploration activities. To assess if organic matter could be a contributing factor, the detrital material accumulating in the snail containers in both Magela and Gulungul Creeks during the 2010–11 wet season was collected and analysed for its content of inorganic and organic matter.

3.4.2 Comparison of toxicity monitoring results in Magela and Gulungul Creeks

Results from the first season of the trial deployment of toxicity monitoring in Gulungul Creek were reported in the Supervising Scientist's annual report for 2009–10 (section 3.2). Results for the snail reproduction tests conducted in both Magela and Gulungul Creeks for the 2009–10 and 2010–11 wet seasons are plotted in Figure 3.4.1 by way of mean egg count per snail pair at upstream and downstream sites, and upstream-downstream difference values.

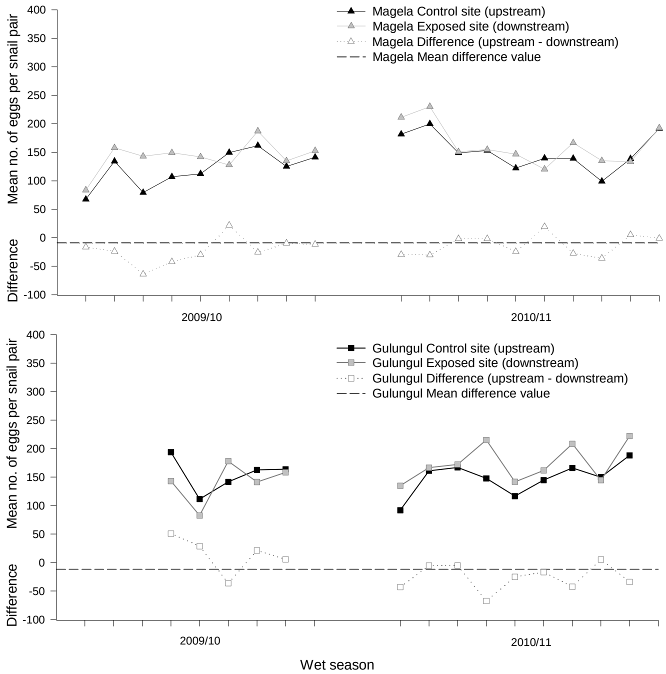


Figure 3.4.1 In situ toxicity monitoring results for freshwater snail egg production for Magela and Gulungul creeks for 2009–10 and 2010–11 wet seasons

Analysis of variance (ANOVA) testing of the egg count and upstream minus downstream difference data from both creeks for the two years of testing showed: (i) for egg count data, no significant differences in egg counts between years, streams or amongst sites; and (ii) for difference data, no significant differences between streams or years, but a significant Year ×

Stream interaction (P<0.001) due to the higher difference values (or greater upstream egg production) observed in Gulungul Creek in 2009–10 compared with difference data from Gulungul Creek in 2010–11 and from Magela Creek for both seasons. This significant interaction is discussed further in section 2.2.3.2 and in relation to the higher variability in snail egg laying response in Gulungul Creek compared with Magela Creek, below.

The toxicity monitoring results from Figure 3.4.1 indicate greater variability between upstream and downstream sites in the egg counts from Gulungul Creek compared with the same response measured in Magela Creek. Water quality difference values were calculated from the median upstream and downstream values of 10 minute readings measured during each of the four-day tests conducted over the two wet seasons. The standard deviation of the four-day upstream-downstream difference values for the continuously monitored water quality variables and snail egg numbers in both Gulungul and Magela Creek were then derived. The results are shown in Table 3.4.1. The more variable (compared with Magela Creek) water quality in Gulungul Creek, caused by the greater proportional influence of runoff to the stream from catchment sources between the upstream and downstream sites in this relatively small drainage basin, may be responsible for the more variable biological response observed.

TABLE 3.4.1 STANDARD DEVIATIONS (SD) OF UPSTREAM-DOWNSTREAM DIFFERENCE VALUES FOR WATER QUALITY VARIABLES AND SNAIL EGGS NUMBERS IN BOTH MAGELA AND GULUNGUL CREEK FOR 2009–10 AND 2010–11 WET SEASONS

Wet season	Difference variable	Magela SD	Gulungul SD
2009–10	Snail egg numbers	23.6	32.5
	Temperature (°C)	0.14	0.34
	Conductivity (µS/cm)	3.14	2.81
	Turbidity (NTU)	1.07	12.29
2010–11	Snail egg	18.9	23.1
	Temperature (°C)	0.09	0.48
	Conductivity (µS/cm)	1.33	2.42
	Turbidity (NTU)	1.21	3.36

Statistical power in this toxicity monitoring technique (ie the probability that a statistical test will correctly reject a false null hypothesis) is increased when, in the absence of human-related disturbance downstream of potential sources of impact, the upstream-downstream difference (response) values display low variability over time. This is achieved when the absolute responses measured at upstream and downstream sites are very similar to one another over time. This concordance (or 'tracking') in egg number between upstream and downstream sites is the typical pattern in Magela Creek (Figs 3.4.2 & 2.18), but appears to be less the case for the pattern in Gulungul Creek. Identifying the factors responsible for differences in egg production between sites is important so that such variation may be accounted for and inferences about possible mining impact correctly attributed. This aspect is considered below, in section 3.4.3.

3.4.3 Relationships with suspended inorganic and organic matter

The measurement of suspended inorganic and organic matter (SIM and SOM respectively) settling in the snail containers commenced in both creeks in the 2010–11 wet season.

Relative measures of SIM and SOM were obtained for each of the nine tests conducted in Magela Creek and for the final five (out of nine) tests conducted in Gulungul Creek. The test procedure involved placing replicate plastic jars, upright and without lids, at the base of each duplicate floating snail container (upstream and downstream) for the four day duration of the test. Material that had been deposited in a container was collected by filtering the dilute slurry through a glass fibre filter in the laboratory. The filter was then sequentially dried and ashed to estimate the inorganic and organic contributions to the total. The summary statistics for the measured data are shown in Figure 3.4.2.

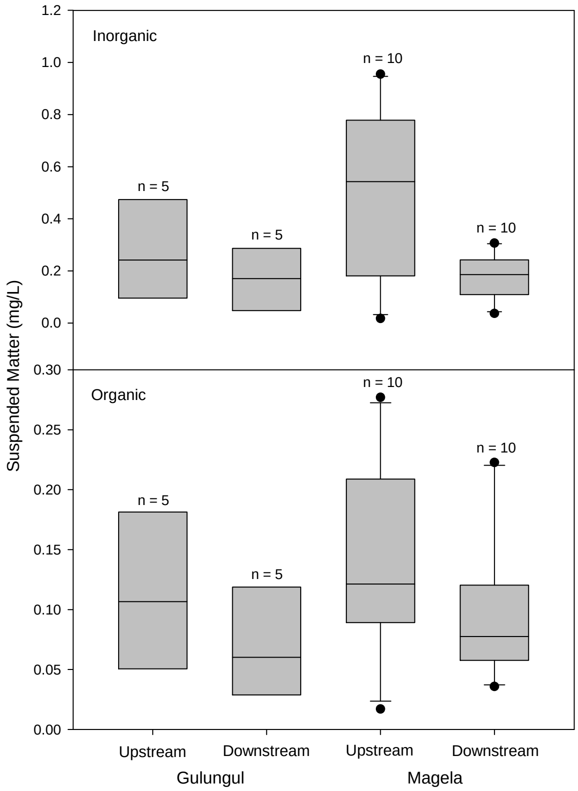


Figure 3.4.2 Boxplots of maximum and minimum values, lower and upper *quartiles*, and the median for suspended matter settling in floating snail containers located in Magela and Gulungul creeks for 2010–11 wet season. For sample size (n) greater than 10, statistical outliers are indicated by closed circles.

Statistical analysis of the data summarised in Figure 3.4.2 indicates:

1. Across both creeks and all sites, SIM and SOM were highly (positively) correlated with one another ($P<0.01$). (Evident also by the summary statistics shown in Figure 3.4.2.)
2. While the amount of SIM did not differ significantly between creeks or sites (upstream vs downstream) ($P>0.05$), there was a tendency for SIM to be higher at the upstream sites compared with the downstream sites (Figure 3.4.2).
3. SOM differed significantly ($P<0.05$) between creeks (higher in Magela) and was significantly higher at upstream sites compared to the downstream sites (Figure 3.4.2).

The best (positive) correlates of SOM and SIM with stream discharge variables (not shown) were with the maximum fall in water level in one continuous time period and the standard deviation (SD) of water level measured at 15 minute intervals. High variability in water level would reflect conditions that maximise turbulence and, hence, act to keep particulate matter in suspension in the creek and be available for deposition in the snail test containers.

No strong relationships were found between SOM and SIM and mean snail egg number measured amongst sites in Magela and Gulungul creeks. All correlations between SIM and mean snail egg number were negative while most between SOM and mean snail egg number were positive. However, it is unlikely that this result indicates possible inhibition and enhancement by SIM and SOM, respectively, upon snail reproduction given that SOM values were actually higher at the upstream sites, whereas snail egg numbers were generally higher at the downstream sites. Thus, the hypothesis that SOM contributes to higher downstream egg production is not supported by the data obtained to date.

Apart from water level, SOM and SIM were also found to be correlated with other water quality variables including EC and water temperature. A careful examination of all water quality variables and other environmental factors associated with the snail tests will be required to better understand the likely causes of observed variations in snail egg numbers. To this end, collection of data for settled suspended matter will continue in ensuing wet seasons, while an analysis of snail egg number in the context of the water quality and stream flow data for the full six-year period over which continuous data have been gathered will also continue.

3.5 Developing sediment quality criteria for uranium

Given the high affinity of uranium (U) for organic matter in sediment, the consequences of U accumulating in sediment needs to be addressed as a component of a sediment quality assessment for waterbodies impacted by U mining activities. In particular, U trigger values that are sufficiently protective for sediment associated biota are required. Historically, there has been little systematic work conducted on the toxicity of U in sediments to aquatic biota, and the toxicity estimates produced by the few international studies that have been published have varied by at least three orders of magnitude (from 5.3 to >5000 mg U/kg dry weight). The lack of a robust toxicity guideline for U in sediment is of concern – not only for the local situation but also nationally given the projected expansion of the uranium mining industry.

Consequently, a project was initiated in 2009 that aims to develop U sediment trigger values that will have applications both for operational water management and for the development of sediment quality closure criteria for the Ranger site. The study site is in Gulungul Billabong, a natural backflow billabong at the confluence of Gulungul and Magela Creeks (see Map 2 for location). Gulungul Billabong is downstream of the Ranger mine and its ecology is considered to be unimpacted by mining activities. Initial progress on this project, which is a collaboration between ***eriss***, Charles Darwin University (CDU) and CSIRO Centre for Environmental Contaminants Research (CECR), was presented in the 2008–09 Supervising Scientist annual report.

To date, two pilot field experiments have been undertaken (Pilot 1: 2009–10 wet season, Pilot 2: 2010–11 wet season), to assess and prove up the most robust method and experimental design in advance of conducting the full scale work. The testing regime involved the spiking of natural billabong sediments with uranium in the laboratory. The treated sediments were transplanted back into the billabong and the extent of re-colonisation was observed after the sediments were retrieved at the end of the wet-season.

The full scale deployment scheduled for the 2011–12 wet season will require the assessment of five to seven U concentrations in order to produce well defined concentration-response curves and toxicity estimates.

3.5.1 Pilot 1: method and results

Pilot 1 was described in detail in the 2008–09 Supervising Scientist annual report. Briefly, four treatments (ie zero added U control; 5400 mg/kg (sodium) sulfate control; 400 mg/kg U; and 4000 mg/kg U (added as uranyl sulfate)) were prepared in the ***eriss*** Darwin laboratory using a ~3 month mixing and equilibrating period. The sediments (nine replicates for each treatment) were deployed in 2 L plastic containers with mesh sides and base at the study site on 9 December 2009. Concurrent with deployment of the laboratory-processed sediments in the field, a zero U site control was added. This site control used sediment that had not been pre-treated in the laboratory. The sediment containers were retrieved on 30 March 2010, after having being submerged for 3 months. Prior to processing, cores of sediment (30–50 mm depth × 15 mm diameter) were obtained from each container for detailed chemical (CSIRO CECR) and microbial (CDU) analysis. The contents of each replicate container were then passed through stacked sieves of 8 mm, and 500, 125 and 63 μm mesh, with the > 500 μm fractions retained for macroinvertebrate characterisation and each of the smaller mesh fractions preserved separately in 90% ethanol for microinvertebrate (125 and 63 μm) characterisation.

Chemical analysis of the spiked sediment prepared in the laboratory showed that the spiking method resulted in rapid and complete adsorption of U onto the sediment and that the concentrations were close to the nominal targets (Table 3.5.1). There was very little U present in the porewater of the sediment (Table 3.5.1) and the U was evenly distributed through the depth of the test containers (data not shown).

Chemical analysis of the sediment in the containers after the three-month deployment showed that the majority of the U was still present. Furthermore, chemical analyses of natural billabong sediment samples taken only 10 cm away from a container containing the highest concentration of 4000 mg/kg U showed very little elevation in U concentrations. The majority of the U bound to the sediment, both before and after deployment, was present in the dilute-acid extractable fraction (AEM), which provides a measure of the bioavailable fraction of U present in the sediment (Table 3.5.1). Taken together, the above findings showed that not only did the form of U in the sediment not functionally change, but that essentially none escaped into the natural sediment outside the containers.

TABLE 3.5.1 SEDIMENT CHEMISTRY FROM THE PILOT 1 STUDY

Analysis	Site control	Pre-deployment				Post-retrieval				10 cm adjacent to High U treatments
		Control	Sulfate	Low U	High U	Control	Sulfate	Low U	High U	
TRM U (mg/kg)	6	6	6	490	4360	6	7	455	4090	7–26
AEM U (mg/kg)	4	4	4	400	3740	3	3	460	4230	
Porewater U (µg/L)	<1	1	<1	180	360	–	–	–	–	n/a
U AEM / TRM Ratio	–	0.66	0.69	0.81	0.85	0.52	0.50	1.04	1.03	n/a

TRM= Total recoverable metals (aqua regia), AEM = dilute acid-extractable metals (1-M hydrogen chloride), TOC = total organic carbon, AVS = acid-volatile sulfide, U = uranium, S = Sulfur.

The results from the first pilot test were potentially confounded by the inadvertent creation of highly compacted, fine grain sized sediment (ie ‘mud bricks’) that was not representative of the natural sediment, and appeared to be non-conducive to macroinvertebrate (and possibly other faunal) colonisation. The ‘mud bricks’ were created as a result of the large amount of sediment manipulation, specifically, the removal of coarser organic matter and an extended period of homogenisation of the U-spiked sediments, followed by ‘sun-baking’ of the fine-grained material in the field prior to the start of the first rains and inundation.

Preliminary macroinvertebrate assessment found that abundances and species richness were so low across treatments that no discrimination across the exposure gradient was possible. In contrast, preliminary (multivariate analysis) data for the microbial communities showed an apparent effect (as shown by the separation of the high U replicates in the ordination plot) at 4000 mg U/kg, but not at 400 mg U/kg, compared with the control (Figure 3.5.1). The microbial results also showed a difference between the spiking control and site control sediments, which suggests that the laboratory treatment of the sediments significantly altered the native bacterial communities present in the sediment. The sulfate control also appeared to be different to the site control, although there was variability amongst replicates (Figure 3.5.1). The microzoobenthos samples were not assessed as originally planned, due to the difficulties in sorting very small and often cryptic organisms from the fine sediment. Instead, microzoobenthos samples have been analysed (by CSIRO CECR) using a similar ecogenomic approach as was used at CDU to characterise the microbial community.

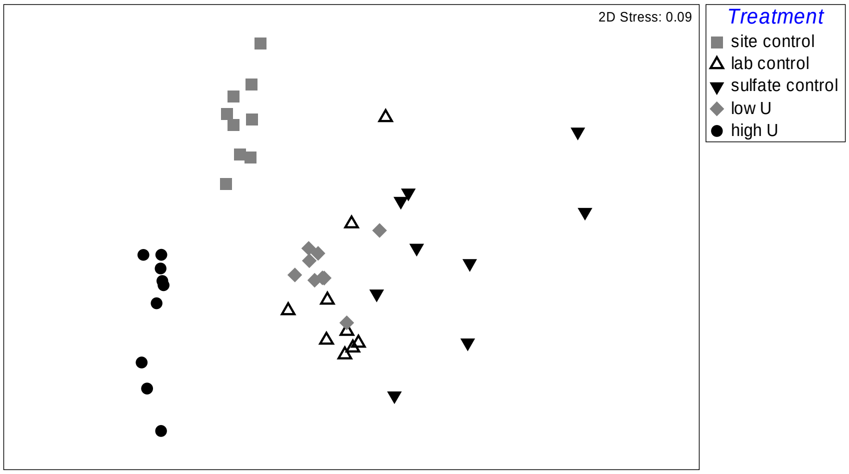


Figure 3.5.1 Multi Dimensional Scaling (MDS) ordination of microbial communities measured in treatment replicates through ecogenomics for the site (Gulungul) control and sediments treated with uranium (U) and pure water (lab control). Low U = 400 mg/kg and High U = 4000 mg/kg

The Pilot 1 study results indicated that biological effects of U in sediments could be apparent at the highest U concentration that was used. However, the results may have been confounded by the method of sediment preparation. The only way to overcome this latter problem was to minimise (i) the amount of sediment manipulation, in particular, the sieving and the extent of mixing, and (ii) the duration of aerial exposure prior to wet season inundation.

3.5.2 Pilot 2: progress

The Pilot 2 study was undertaken during the 2010–11 wet-season, and focused on evaluating an alternative method for sediment spiking, which minimised disturbance of the physical characteristics of the sediment and the duration of the storage period prior to deployment. The method involved gentle pouring of a solution of uranyl sulfate over the sediment, allowing the solution to infiltrate through the sediment and drain through the mesh base of the container into a collecting vessel. The solution, along with any sediment incidentally drained, was then re-poured over the sediment after the sediment had been gently mixed to facilitate the even distribution of U through the sample. Chemical analyses confirmed that the majority of the U (90%) was removed from the U solution after two pourings of the solution through the sediment. An additional benefit of the method was that the sulfate introduced with the U (as uranyl sulfate) could be flushed out of the sediment by washing with deionised water, which removed the sulfate but not the U bound to the sediment. This method was used to produce a control and three U treatments (ie 0, 500, 1000 and 2000 mg kg^{-1}). A site-control was also included as per Pilot 1.

The sediments (five replicates for each treatment) were deployed on 25 November 2010 and retrieved on 11 April 2011 after being submerged for 5 months. Conditions at the study site were significantly different to the preceding year due to early rain and very high rainfall for the season. The sediments were deployed when the site was wet (Figure 3.5.1), and the water overlying the site was ~1 m deeper when the sediments were retrieved compared with Pilot 1. Cores of sediment (30–50 mm depth × 15 mm diameter) were obtained from each container for detailed chemical, microbial and microinvertebrate analysis. The remaining sediment in each container was then elutriated through a 500 μm mesh sieve and retained for macroinvertebrate characterisation. The samples were being processed and analysed at the time of publication of this report and, hence, will be reported in the 2011–12 Supervising Scientist annual report.

a) **b)**

Figure 3.5.1 Sediment treatments deployed at the beginning of a) the 2010–2011 wet-season and b) the 2009–2010 wet-season

3.6 Assessing soil erosion on the trial landform

3.6.1 Introduction

In the 2009–10 annual report, the initial results from a long-term SSD program of research to assess sediment and solute losses from a trial rehabilitation landform constructed at the end of 2008 by ERA were described. The purpose of the trial landform is to test over the long term proposed landform design and revegetation strategies for the site, such that the most appropriate one can be implemented at the completion of mineral processing on the site. While SSD is leading the erosion assessment project, and providing most of the staff resources, there is also a substantial level of assistance and collaboration being provided by technical staff from ERA. SSD is also contributing to the revegetation component of the trial landform with progress on the work that is being done to assess vegetation analogue communities being presented later in this report (see section 3.7 'Use of natural analogues to guide planning for rehabilitation of the Ranger minesite').

The trial landform was designed to test two types of potential final cover layers for the rehabilitated mine landform: waste rock alone; and waste rock blended with approximately 30% v/v of fine-grained weathered horizon material (laterite). In addition to two different types of cover materials, two different planting methods were initially being assessed: direct seeding and tube stock.

The locations of SSD's four erosion plots (30 m × 30 m) constructed during the 2009 dry season (see 2009–10 annual report) are shown on Figure 3.6.1. The first two plots contain waste rock, and the second two, mixed waste rock and laterite. The plots were physically isolated from runoff from the rest of the landform area by constructed borders.

Due to the failure of the direct seeding treatment in the first year, all areas on the landform, including the erosion plots, have now been in-fill planted with tube stock. The failure of the direct seeding has meant that the development of vegetation coverage in the initially direct-seeded areas has substantively lagged behind the tube stock areas. In this context it should also be noted that an approximately 75 m wide irrigation 'buffer' strip was established along the eastern edge of the trial. This strip was created to protect SSD's erosion plots from supplemental irrigation during the 2009–10 dry season. This irrigation was used to assist the establishment of vegetation across the bulk of the surface of the landform. The erosion plots were specifically excluded to prevent the application of salts contained in irrigation water and the complications this would have caused with trying to measure the intrinsic solute loads produced from the cover materials during the subsequent wet season. A consequence of this exclusion of irrigation is that the growth rate of the planted tubestock in the erosion plots lagged behind that of the tubestock-planted area on the bulk of the landform. In practice this has meant that the effect of vegetation coverage on erosion rates would likely have been minimal for all four plots over the first two wet seasons.

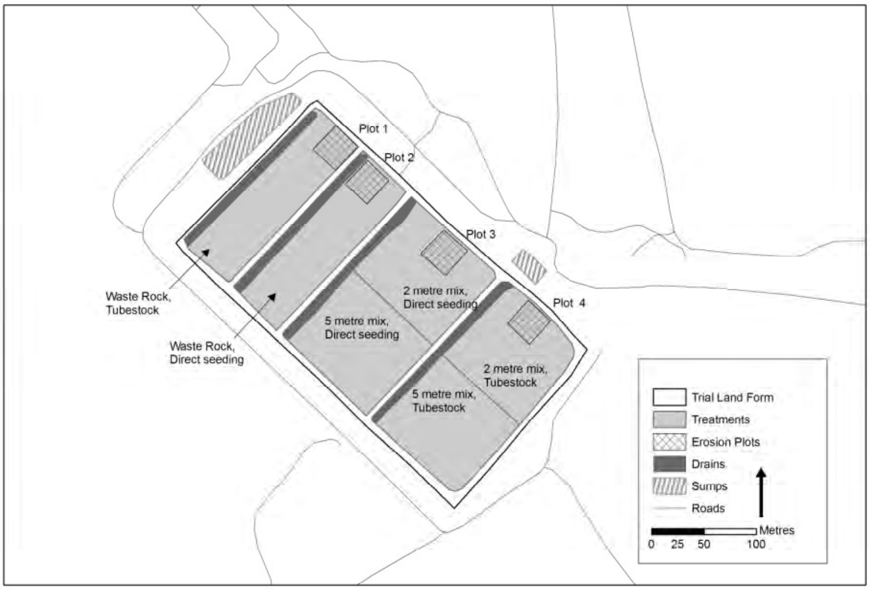


Figure 3.6.1 Layout of the plots on the trial landform

Each erosion plot is instrumented with a range of sensors that were described in detail in the 2009-10 annual report. In summary, these include: a pressure transducer and shaft encoder to measure stage height; a turbidity probe to measure the suspended sediment concentration; electrical conductivity probes located at the inlet to the stilling well and in the entry to the flume to provide a measure of the concentrations of dissolved salts in the runoff; an automatic water sampler to collect event based samples; and a data logger with mobile phone telemetry connection.

The latest results from two projects being conducted as part of the portfolio of SSD projects for the trial landform are described below. Firstly, the measurements of erosion bedload yields from each plot over the past two water years. Secondly, the findings from computer modelling that is being used to predict changes in the rates of erosion and shape of the trial landform through time.

3.6.2 Measurements of bedload

Preliminary sediment and solute losses from the four erosion plots were presented for the first year of monitoring (2009–10 water year) in last year's annual report. A water year that extends from the driest month for 12 consecutive months, instead of being represented by a calendar year, is used to report the results since the use of a calendar year would inappropriately combine data from two different wet seasons. This is because the wet season in the ARR typically extends over a six to seven month period from late October in one year to the end of April in the next (for example, October 2010 to April 2011). To include, within the correct water year, significant rainfall events that can also occur several weeks at either end of the wet season, a 'water year' has been defined as the period from September in the first year to August in the next.

Sediment is transported by flowing water as either suspended load or bedload. Suspended load refers to relatively fine-grained sediment transported in continuous or intermittent suspension, depending on grain size, flow velocity and fluid turbulence. Given that it can be transported in suspension over long distances it is most likely to have a downstream impact on water quality. Bedload is coarse sediment that is best defined as that part of the sediment load that moves on or near the ground surface rather than in the main bulk of overland flow. It stops moving once flow velocity reduces below a critical value. Both suspended and bedload sediment components are being measured as part of this project. The results of the bedload measurements will be reported this year, with the suspended sediment data to be reported next year.

As described in last year's annual report, bedload is trapped in either a drain at the down slope end of the plot, or in a deep collection basin at the discharge end of the drain. The material from both the drain and basin is combined to form the bedload sample. Bedload samples were collected usually at weekly to monthly intervals during the wet season, or on an as needs basis in response to isolated large rainfall events. The collected samples were transported to the ***eriss*** laboratory in Darwin, oven dried and weighed.

The grainsize distribution for each bedload sample from each plot was determined using a combination of sieve and hydrometer (gravity settling) methods to determine the percentage of gravel (> 2 mm), sand (< 2 mm and > 63 µm), and silt and clay (< 63 µm). The bedload yields for each plot for each water year are contained in Table 3.6.1. The annual rainfall recorded for each plot for each water year is also shown in Table 3.6.1.

TABLE 3.6.1 YIELDS AND PARTICLE SIZE DISTRIBUTION OF BEDLOAD FROM THE FOUR EROSION PLOTS FOR 2009-10 AND 2010-11 (SEPTEMBER TO AUGUST, INCLUSIVE)

Water year	Erosion plot	Annual rainfall (mm)	Annual bedload yield ($t/km^2.yr$)	% Gravel (> 2 mm)	% Sand (< 2 mm & > 63 µm)	% Silt and clay (< 63 µm)
2009–10	Plot 1	1507	108	34	60	6
2010–11	Plot 1	2246	62	34	63	3
2009–10	Plot 2	1516	143	34	55	11
2010–11	Plot 2	2313	112	41	55	4
2009–10	Plot 3	1480	115	37	59	4
2010–11	Plot 3	2208	57	46	53	1
2009–10	Plot 4	1518	137	35	61	4
2010–11	Plot 4	2319	55	50	49	1

Annual bedload yields

The 2010–11 water year was much wetter than 2009–10, with annual rainfall being between 727 and 801 mm higher on each plot (Table 3.6.1). For a given year, bedload yields are similar between both surface cover types and both vegetation planting treatments (Table 3.6.1). However, the highest bedload yields were always generated from Plot 2 (Table 3.6.1). While it is still not clear why Plot 2 generates the highest yields, shallow rip lines dominate the lower section of the plot resulting in diffuse overland flow connecting with the down slope plot border. Unusually, bedload yields were higher in 2009–10 than in 2010–11 (Table 3.6.1). This is consistent with previous research in the Alligator Rivers Region that has shown that sediment yields decline progressively over at least the first three years following a major surface disturbance, such as the construction of an artificial landform, as a result of initial washout of fine particles and the formation of an armoured surface. However, it differs from other types of environments where sediment yields are usually observed to be linearly related to annual runoff or rainfall.

There was a substantial flush of fine sediment (silt and clay) in the 2009–10 water year which had the effect of reducing the supply of this size fraction for the second year (Table 3.6.1). Such early preferential removal of fine sediment usually results in an increase in the surface cover of residual gravel via a process called armouring. Concurrently with the development of armouring there is an increase in the percentage gravel in the bedload (Table 3.6.1). The data indicate the high rainfall of the 2010–11 wet season transported a greater percentage of gravel in comparison to the sand, and silt and clay fractions. Sand was the dominant (by mass) sediment size fraction transported off the erosion plots, consistent with results for other plots constructed from waste rock at the Ranger mine (Table 3.6.1).

The bedload yields for both the first and second year after construction of the trial landform exceeded 55 $t.km^{-2}.yr^{-1}$ (Table 3.6.1), were high by Australian standards for natural land surfaces where sediment yields usually range from 4-46 $t.km^{-2}.yr^{-1}$, but were much less than the 188-5100 $t.km^{-2}.yr^{-1}$ recorded for unrehabilitated waste rock stockpiles in the Alligator Rivers Region. This finding highlights the high erodibility of freshly placed waste rock and laterite, and indicates the need for appropriate engineering design of drainage structures and sedimentation basins.

3.6.3 Computer modelling of erosion using the CAESAR model

The geomorphic stability of the trial landform through time is being assessed using the CAESAR (Cellular Automaton Evolutionary Slope and River) landform evolution model (LEM). The predictions of the model are being compared with what is actually being measured through successive wet seasons, to provide a validation check on the ability of this model to predict changes in erosion rates through time.

CAESAR was originally developed to explain changes in river channel morphology through time in response to changing climate and rainfall. It has also been applied to investigate the movement of contaminated sediment in rivers. Recently, through international collaboration with the University of Hull (UK) initiated by SSD, the model has been modified and applied to study the evolution of proposed rehabilitated mine landforms in northern Australia. Most recently it is being used to model the erosion from SSDs purpose-built erosion plots located on the trial landform. A comparison of the model results with field data collected over the 2009-10 wet season is reported here.

Methodology

The model requires three types of input data: (1) a digital elevation model (DEM) that represents the surface geometry; (2) rainfall data; and (3) the particle size distribution of the material on the surface.

A DEM of the trial landform was produced from data collected by a Terrestrial Laser Scanner in June 2010. Each of the four erosion plots were scanned at a resolution of 2 cm at a distance of 100 metres. For the purposes of this study, the data for the erosion plots were interpolated to produce a surface grid with a horizontal resolution of 20 cm. The modelled results from only Plots 1 and 2, representing a waste rock surface treatment, are reported here since the measured flow and suspended sediment data, to be used for comparison, from plots 3 and 4 had not been processed at the time this work was done.

Rainfall data were measured for each erosion plot using a rain gauge installed at the downstream end of each plot.

The particle size distribution data required for the model were obtained from bulk samples of surface material from eight locations within each of the two plots. Nine grain size classes (Figure 3.6.2) were produced by averaging the data from the eight locations. The less than 63 µm size class is treated as suspended sediment within CAESAR.

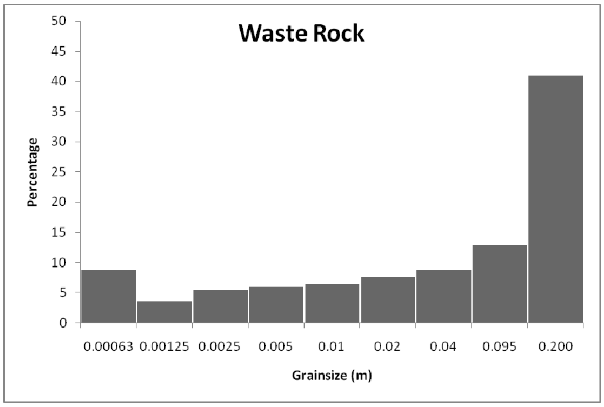


Figure 3.6.2 Grainsize (particle size) distribution data for Plot 2

The model outputs were compared with field data collected from the outlet of each erosion plot, which was instrumented with the range of sensors described above.

Three sets of simulations were carried out. The first simulation involved the application of the 2009–10 wet season rainfall data to Plot 2, whilst the second simulation involved the application of the 2009–10 wet season data to Plot 1. Finally, the 2009–2010 wet season was repeated 20 times to simulate how the erosion might trend through time on Plot 2. The calculated runoff volume of water and the mass of material reporting to each of the nine grain size classes was output from the model every 10 minutes of simulated time. Surface elevations and the distribution of grain sizes for material remaining on the landform surface were calculated for every month of the simulation.

Figure 3.6.3 shows the comparison between measured and predicted bedload and suspended sediment data for Plot 2, with the field-measured hydrograph shown for reference. In general the modelled and measured bedload and suspended sediment data show a close correspondence over time. However, the increases in bedload field data are asynchronous with the modelled data, as bedload samples were taken sporadically with a typical 2 week frequency compared to the 10 minute output resolution of the model data. Unlike the bedload, the measured suspended sediment data is at the same 10 minute resolution as the modelled data and there is an excellent correspondence between the measured and predicted loads in terms of both timing and magnitude. Figure 3.6.3 indicates that the field-measured and simulated periods of increased suspended sediment and bedload occurred in the same time period as the larger runoff events in the plot.

Unfortunately due to initial instrumentation problems there were less processed data available for runoff or suspended sediment from Plot 1. However, as plots 1 and 2 are only 60 metres apart, it was assumed there would be little difference in the rainfall occurring on

Plot 1. Consequently, the rainfall data for Plot 2 were used in the simulation for Plot 1. While less processed field data were available for comparison, the simulations for Plot 1 showed a very good correspondence between the modelled and observed bedload yields. In addition, like Plot 2, the increases in field-measured and modelled bedload yields corresponded to the larger runoff events.

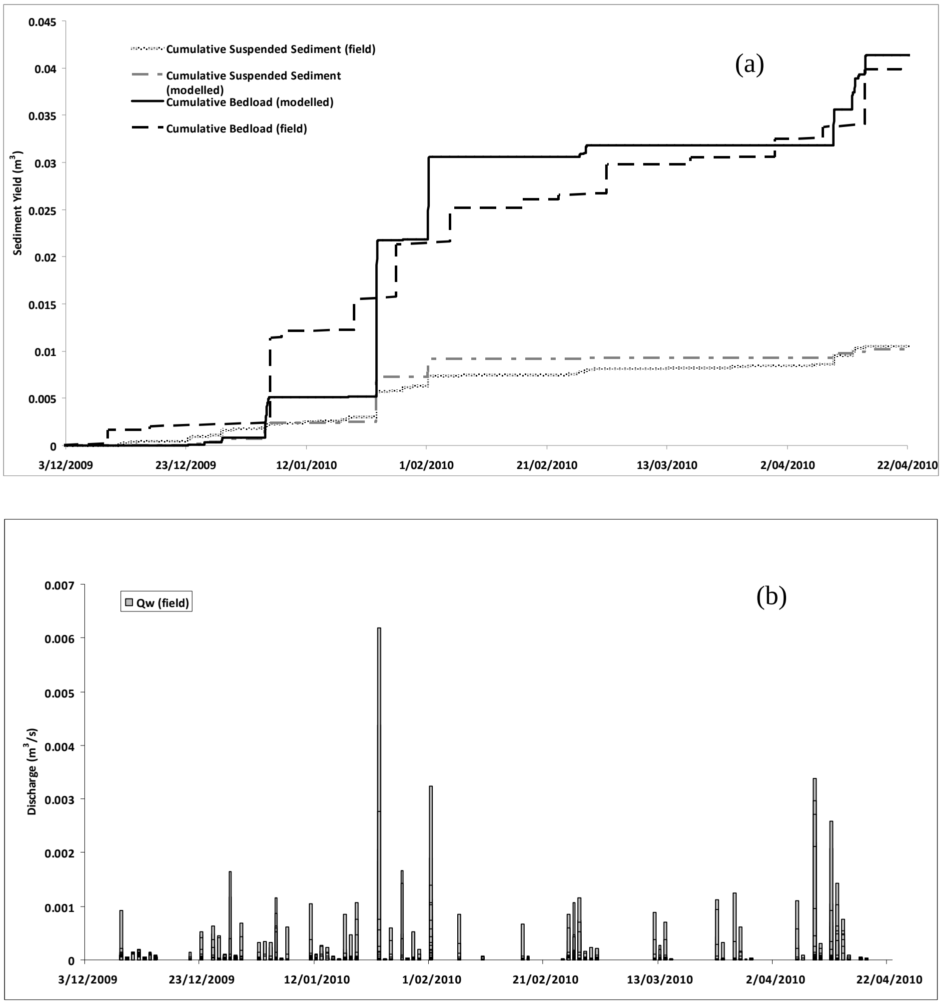


Figure 3.6.3 Plot 2 (a) modelled and field measured bed and suspended sediment yields; and (b) measured surface runoff

The rainfall sequence from the 2009–2010 wet season was repeated twenty times to produce a hypothetical 20 years simulation of the evolution of Plot 2 (Figure 3.6.4). This enabled a preliminary assessment to be made of how the rate of erosion and the plot morphology may change over this period of time. Figure 3.6.4 shows that a rapid tail off and decrease in erosion rates is predicted to occur after the first five years.

Discussion

The results to date provide confidence that CAESAR is capable of providing realistic predictions of initial erosion rates. There is an excellent correspondence between modelled and measured data – both in the volumes of bedload, suspended load and water fluxes as well as in the timing of their delivery. The good results obtained to date provide greater confidence in being able to extend the application of the model to steeper slope scenarios, for example batter slopes, that are not addressed by the design of the current trial landform.

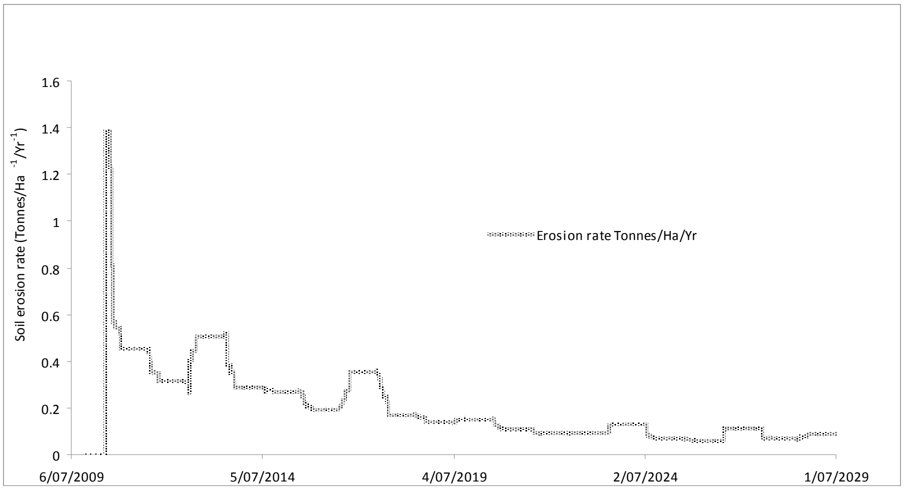


Figure 3.6.4 Simulated erosion rates for Plot 2 over 20 years

This is the first time that a LEM has been evaluated against field data at such high resolution spatial and temporal scales. Implications for the use of LEMs in soil erosion prediction, as well as model strengths and limitations, are discussed below.

The erosion rate of approximately 0.1–0.2 t ha^{-1} yr^{-1} (equivalent to a denudation rate of approximately 0.01 mm yr^{-1}) (Figure 4) predicted for a preliminary 20 year simulation of plot 2 approximates the long term erosion and denudation rates established for the region using a variety of different methods. An assessment using the fallout environmental radioisotope caesium-137 (^{137}Cs) as an indicator of soil erosion status for two transects in the much steeper Tin Camp Creek catchment produced net soil redistribution rates between 0.013 and 0.86 mm y^{-1}. Overall denudation rates for the region range from 0.01 to 0.04 mm y^{-1} determined using stream sediment data from a range of catchments of different sizes. The decadal scale predictions produced by the CAESAR model, once the initial period of acclimation for the surface has passed, are well within the values measured for natural regional terrain.

It is important to recognise that several critical caveats need to be placed on the results produced to date. These include recognizing that these simulations have been run for an 'idealised' environment. The erosion plots have relatively uniform characteristics, and have a gently sloping surface that represents a single component of the overall mine landform, albeit potentially a major component by surface area, that is likely to be least susceptible to erosion. The role of developing vegetation was also not addressed by the 20-year simulation. The sensitivity of erosion rate to slope angle and to extent and nature of vegetation cover needs to be implicitly considered as part of future modelling runs. In addition, a sensitivity analysis will need to be done to assess the effects of potential extreme rainfall events.

Continued monitoring of the trial landform over successive wet seasons will enable the effects of surface weathering, self armouring and the development of vegetation coverage to be quantified. These field data will be used to further refine the relevant algorithms in the CAESAR model and thereby increase its capacity for more robustly predicting long-term rates of erosion from rehabilitated mine landforms.

3.7 Use of natural analogues to guide planning for rehabilitation of the Ranger minesite

3.7.1 Background

A number of projects are currently underway to address aspects of rehabilitation associated with future closure of the Ranger Project Area, including ecosystem reconstruction and final landform design and revegetation. The Georgetown analogue area, a ~400 hectare area of natural vegetation located on the south-eastern edge of the Ranger mine (Figure 3.7.1 inset), is providing much of the reference data about local vegetation communities. These vegetation data have been gathered by ERA and ***eriss***. Unlike the flat lowland Koolpinyah surface found over most of the Ranger lease this area has particular terrain characteristics that better match those of the proposed final landform, particularly its low relief with associated vegetation communities that are representative of the variety of plant forms found in lowland and low hill terrain environments of the ARR.

The primary objectives of the work being conducted in the analogue area are:

1 Identify and derive quantitative terrain parameters which provide a landscape-based reference for specifying design criteria for the final rehabilitated landform.

2 Characterise the plant communities and identify the key environmental determinants of those communities from the terrain descriptors derived in 1.

3 Use the findings from (1) and (2) to assist with:

   a. selection of the most appropriate species for revegetation of the Ranger mine landform post decommissioning, and

   b. the development of revegetation closure criteria and a suitable post-closure, performance monitoring regime.

In relation to item 1 above, analysis of the analogue terrain has previously been undertaken by ERA using a Digital Elevation Model (DEM) of the analogue area. Little information was available on the accuracy of the DEM used, beyond the statement that it had a resolution of 20 metres. If applied as a measure of either horizontal or vertical accuracy, such a DEM would be considered relatively coarse. Given the shallow slopes that characterise the analogue area, it was considered that use of such a coarse resolution DEM might not provide the level of accuracy needed to derive the required terrain parameters. Accordingly, a recent focus of SSD’s work has been to use a much higher-resolution DEM for this purpose. Re-derivation from the DEM of the descriptive physical features required for terrain analysis is currently in progress and some preliminary findings are reported below. The full details will be reported in the next annual report.

For the range of key vegetation community types that represent the array of environments likely to be found across the rehabilitated footprint, relationships between the occurrence of such communities and key geomorphic features of the landscape (eg soil type, slope, effective soil depth, etc.) need to be identified. By identifying the key environmental features that are associated with particular vegetation community types, either (i) the conditions required to support these communities or, alternatively, (ii) the community types that best suit particular environmental conditions, may be specified for the different domains of the rehabilitated landform at Ranger. (A key caveat to apply here is that the range of likely conditions to be found across the rehabilitated landform is met, similarly, in the natural analogue area; otherwise the natural analogue is not able to inform on all aspects of decision-making for site rehabilitation.)

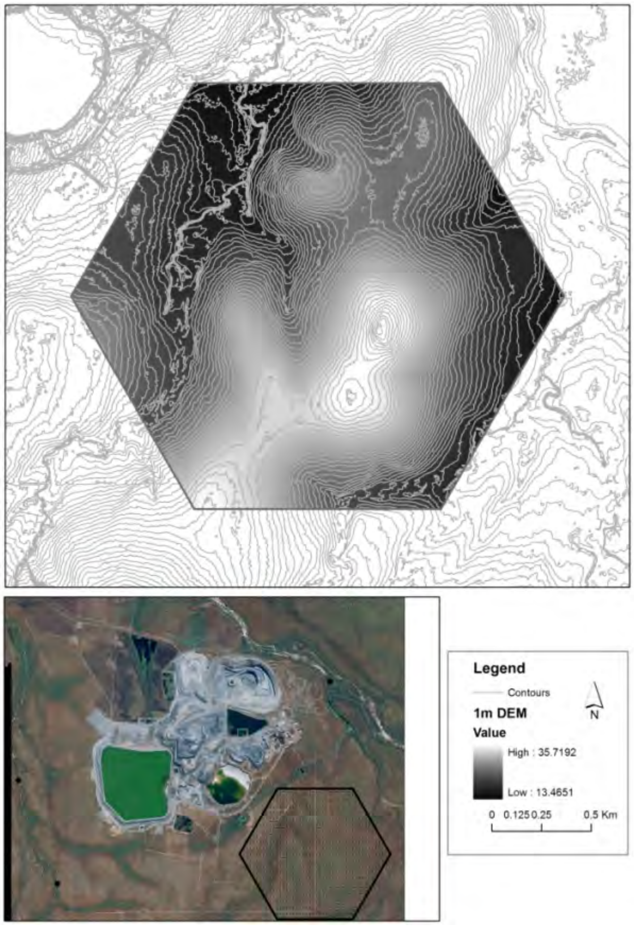


Figure 3.7.1 Top: Digital Elevation Model (DEM) of the Georgetown analogue area. Inset shows location of the analogue area relative to the mine.

3.7.2 Derivation of landform parameters for Georgetown analogue area

An airborne LiDAR (Light Detection and Ranging) survey of the Ranger project area commissioned by ERA and captured on the 1st of October 2010, provided a very-high resolution (± 0.25 m horizontal; ± 0.15 m vertical) DEM of the Ranger Project Area. Using data received as 0.5m interval contours, a 1 metre resolution DEM of the Georgetown analogue was generated (Figure 3.7.1).This DEM represents a much higher resolution dataset than had previously been used for terrain analysis of the area, and is more appropriate for use with its gently graded aspect. A range of descriptor variables (Table 3.7.1) capturing the geomorphic, drainage and hydrological characteristics of the analogue landform were extracted using GIS software, for each of the 72 plant survey locations. These parameters are being used to assess their ability to account for the composition and distribution of different plant species and communities.

TABLE 3.7.1 MEAN VALUES FOR LANDFORM AND GROUNDWATER LEVEL VARIABLES DERIVED FOR CORRESPONDING VEGETATION COMMUNITY SITES ON THE GEORGETOWN ANALOGUE AREA

	Vegetation classification group			
Landform variables	**1 Melaleuca woodland**	**2 Mixed eucalypt woodland (MEW)**	**3 Dry MEW, Type 1**	**4 Dry MEW, Type 2**
Slope (%)	2.18	2.24	2.16	2.15
Profile curvature	-0.003	0.012	0.397	0.007
Plan curvature	0.062	0.028	-0.351	0.012
Slope length (m)	113.1	47.0	68.8	42.1
Elevation (m)	19.7	25.0	22.5	25.4
Length-slope factor	0.499	0.363	0.669	0.266
Erosion-deposition index	1.306	0.729	1.085	0.571
Aspect (degrees)	180.3	139.3	243.1	267.7
Wetness index	9.43	9.18	9.06	8.85
Relief (600 m radius)	11.548	12.66	10.287	11.509
Depth to groundwater	4.65	4.64	4.37	4.15

Depth-to-groundwater data collected by ERA from 28 bores drilled across the analogue area in late 2010 were also assessed to provide a measure of water availability for plants. These groundwater level data were interpolated to produce a surface grid so that readings could be extracted for each of the 72 plant survey locations.

Detailed analysis of these landscape terrain descriptors is currently underway and the findings will be presented in the next annual report.

3.7.3 Vegetation classification

Since 2003, ***eriss*** and/or ERA have derived a number of vegetation classifications for lowland and hillslope locations in the ARR, including undisturbed (from mining) sites on the Ranger lease. The classifications that are most consistent with those derived and published for the broader ARR include three dominant elements: (i) *Melaleuca* woodlands associated with riparian and floodplain zones subject to seasonal inundation, (ii) a common mixed eucalypt woodland community and (iii) dry mixed eucalypt woodland types with dominant species that are deciduous in nature.

A notable feature of the ***eriss***-ERA vegetation classifications that include sites from across the ARR is the representation within each of the three broad vegetation categories from above, of sites from the Georgetown analogue area. Because this geomorphologically discrete but diverse Georgetown location is representative of regional plant communities and contains some terrain characteristics that match those of the proposed final landform, effort in recent years has been directed at additional vegetation sampling in this area to provide sufficient data needed for reliable plant-environment modelling for this location alone.

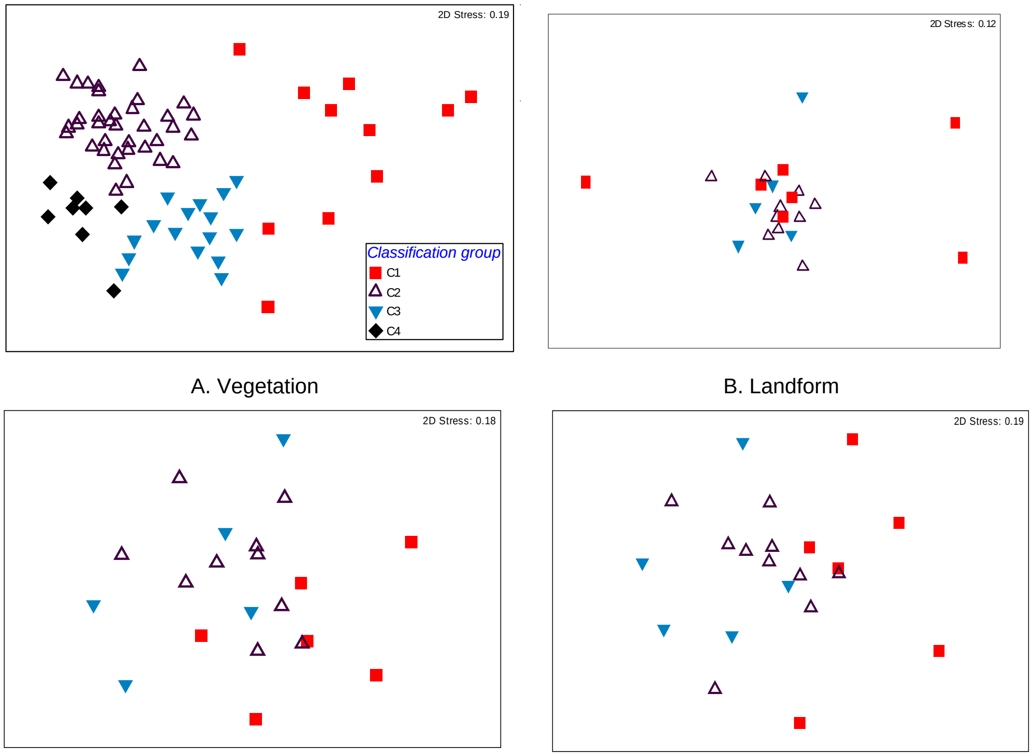
Data for trees and shrubs are now available for 72 sites on the Georgetown analogue area as a result of quantitative plant density surveys conducted in 2010. From these data, four broad (and statistically distinct) classification groups were derived from multivariate analysis, and these are depicted in a multivariate ordination in Figure 3.7.2A and in tabular form, showing the dominant and characteristic plant species for each vegetation community type, in Table 3.7.2. The classification contains an additional dry mixed eucalypt woodland type to that contained in the earlier three-group classification derived from data obtained over the broader ARR.

3.7.4 Plant-environment relationships

A number of statistical approaches were previously used by ERA to model plant-environment relationships for about 150 natural vegetated sites across the Ranger lease. Particular species were found to occur in areas of higher erosion risk (steeper slopes) in the natural landscape, suggesting that they could be good candidates for revegetation on steeper areas of the mine landform. Other species dominated wetter, seasonally-inundated areas and hence could be considered for planting in areas with poor drainage and/or ponding.

However, there were a number of potential limitations associated with the analysis of the vegetation and environmental data sets by ERA. These included analysis of presence-absence data only, derivation of landform (terrain) parameters from a low-resolution DEM, lack of documentation of the procedures for generating the DEM, lack of soil chemistry and groundwater data, no attempt to model community assemblages and use of some multivariate analysis methods not particularly suited to the analysis of biological assemblage data.

The most recent, albeit preliminary, analysis of the plant and environmental data sets addresses many of the issues identified above. Apart from newly-acquired landform and groundwater data, the current analyses also include soil physico-chemistry data that were gathered earlier by ERA for 22 of the Georgetown area analogue sites.



A. Vegetation

B. Landform

C. Soil

D. Landform and soil

Figure 3.7.2 Multi-dimensional Scaling ordination plots associated with vegetation and environmental data from sites surveyed on the Georgetown analogue site adjacent to the Ranger mine: A. Vegetation community structure data from 72 sites, according to classification group (defined in Table 3.7.1). (Surveys of vegetation > 2 m in height were conducted on 1 hectare plots.); B. Landform (terrain) data from 22 sites; C. Soil data (22 sites); and D. Landform and soil data (22 sites).

TABLE 3.7.2 DESCRIPTIONS OF THE RANGER ANALOGUE COMMUNITIES IDENTIFIED IN THIS STUDY

Broad vegetation community	Dominant and/or distinguishing tree or shrub species	Classification unit from this study (Fig 3.7.2)
Melaleuca woodland	*Melaleuca viridiflora, Pandanus spiralis, Planchonia careya*	C1
Mixed Eucalypt woodland	*Acacia mimula, Eucalyptus tetrodonta, Corymbia porrecta, E. miniata, Xanthostemon paradoxus, Terminalia ferdinandiana*	C2
Dry mixed Eucalypt woodland: Type 1	*C. foelscheana/latifolia, X. paradoxus, T. ferdinandiana, P. careya, Cochlospermum fraseri*	C3
Dry mixed Eucalypt woodland: Type 2	*T. pterocarya, A. mimula, X. paradoxus, C. disjuncta, E. tectifica*	C4

Community-level analyses

Summary data for the ten recently-derived landform parameters, as well as depth-to-groundwater, are provided in Table 3.7.1. Multivariate analyses examined the association between the nine landform parameters and depth-to-groundwater and plant community patterns. Aspect, elevation, profile and plan curvature and slope length were correlated with the multivariate community space but the level of correlation of various combinations of the variables was low ($r < 0.24$). Multivariate hypothesis testing of the geomorphometric data associated with each of the four vegetation classification categories showed significant differences in landform features of sites representing the vegetation categories. These differences were associated with the distinct character of the main mixed eucalypt woodland classification class (category 2, Table 3.7.2). The key landform attributes contributing to this separation have yet to be determined from the analysis.

More detailed analyses were conducted on the 22 sites for which soil physico-chemistry data were available. These analyses examined the relationship between soil physico-chemistry and/or landform/groundwater data (ie separately and in combination), with corresponding vegetation community data from the same sites. Maximum correlation values of 0.3, 0.47 and 0.51 were found for correlations between landform only, soil physico-chemistry only, and landform and soil physico-chemistry in combination, within the multivariate community space. Correlates occurring consistently amongst the results were:

- For landform only: wetness index, elevation and length-slope factor;
- For soils only: zinc, cation exchange capacity, A horizon texture and sulfur;
- For landform and soils combined: cation exchange capacity, A horizon texture, iron and less commonly, bore infiltration (rate at which soils absorb rainfall) and length-slope factor.

Figures 3.7.2B, C and D plot multidimensional scaling ordinations of landform, soil and combined landform and soil data corresponding to vegetation community type respectively. The relative separation of the classification groups within each ordination is generally consistent with the vegetation-environment correlations just described, with the landform ordination showing the most interspersion (ie least separation) of sites by classification type, and the soils and landform ordination showing the least interspersion with a pattern that more closely resembles the ordination based upon plant community data.

This result, indicating the greater strength of association between soil physico-chemistry and vegetation patterns than between landform and vegetation patterns, suggests that an earlier analysis (results reported in an ***eriss*** Annual Research Summary) which concluded there was little influence of soil physico-chemistry upon vegetation communities needs to be reviewed and re-assessed. Regardless, most of the significant soil and landform variables described above only appear to distinguish sites of seasonal inundation, where *Melaleuca* woodland occurs, from the other woodland community sites. The occurrence of *Melaleuca* woodlands on low-lying, seasonally-inundated locations is well understood. In this sense, the reported findings may not appear to be particularly useful for understanding conditions that distinguish the different eucalypt communities found on the analogue site. However, the geomorphometric distinction of the mixed Eucalypt woodland community found from multivariate hypothesis testing (above) appears to contradict this aspect of the analysis. Work will continue to resolve this issue and fully explore relationships between environmental variables and vegetation communities on the analogue area.

Population-level analyses

Environmental relations for individual plant species are typically modelled using regression techniques. This modelling has not yet been undertaken but as a precursor to this, a correlation matrix for the density data of the dominant plant species on the analogue area (from Table 3.7.1) and soil and landform variables was prepared. Indicator species for the Melaleuca woodland community from Table 3.7.1 (eg *Pandanus spiralis*, *Melaleuca viridiflora*) were strongly correlated with soil and landform variables indicative of depositional (seasonally-inundated) and low-lying terrain areas, which is an unsurprising finding (see above). Conversely, *Acacia mimula*, *Eucalyptus miniata* and *E. tetrodonta* correlated with higher altitude locations of low slope length. Low erosion-deposition index values were associated with occurrences of *Xanthostemon paradoxus*, *E. tetrodonta* and *A. mimula*, indicating their dominance in areas more susceptible to erosion in the landscape. *Corymbia disjuncta*, *E. tetrodonta* and *Terminalia pterocarya* were associated with areas of low relief, while *C. foelscheana* was associated with areas of high relief. These descriptions are generally consistent with the earlier findings from ERA that *A. mimula*, *X. paradoxus*, *E. tetrodonta* and *C. foelscheana*, at least, occur in areas of higher erosion risk in the natural landscape and so may play an important role for early revegetation of the mine landform.

Because the most recent available data sets include quantitative vegetation data and more accurate and complete sets of environmental variables (compared with the earlier ERA work) to characterise the analogue sites, future analyses have greater potential to reveal the environmental conditions over which different plant species occur in the landscape. Being able to be more precisely define the range of these conditions will assist with assessing which plant species are best suited to different parts of the rehabilitated mine landform.

3.8 Using historic airborne gamma surveys to determine the pre-mining radiological baseline for Ranger mine

3.8.1 Background

Before mining started at Ranger in 1981, orebodies 1 and 3 were outcropping in places and several other radiation anomalies were also known to exist in the area. Compared to typical environmental background radiological conditions, these areas exhibited naturally higher soil uranium concentrations and consequently elevated gamma ray fields detected by airborne radiometric surveys. From a radiological perspective, assessing the success of mine site remediation at a uranium mine is based upon comparison with the pre-mining radiation levels. To establish reference radiological conditions for the Ranger mine it is therefore important to have a robust knowledge of the magnitude and spatial extent of the areas that exhibited naturally elevated radiation levels pre-mining.

Airborne gamma surveys (AGS), coupled with groundtruthing measurements, have been used previously for area wide assessments of radiological conditions at remediated and historic mine sites in the ARR and the results have been reported in previous annual reports. Using historic AGS data can provide a means to infer pre-mining conditions, if the airborne data can be calibrated using an existing undisturbed/unmined radiological anomaly that was also covered by the original AGS. Whilst a pre-mining AGS was flown over the Alligator Rivers Region including the Ranger site in 1976, no ground radiological data of the resolution and spatial coverage needed to calibrate the AGS data are available from that time. In this project data from a high resolution ground survey collected between 2007 and 2009 at an undisturbed radiologically anomalous area have been used to calibrate the AGS data for that anomaly. The calibrated 1976 AGS data set was then used to infer pre-mining radiological conditions for various altered landform features on site.

3.8.2 Methods

Data from the 1976 Alligator Rivers Geophysical Survey, acquired from Rio Tinto by the NT Government, were re-processed in 2000 by the Northern Territory Geological Survey (NTGS) and then re-sampled at a pixel size of 70 × 70 m^2 in 2003. This data set is available in the public domain and was used to identify Anomaly 2, about 1 km south of the Ranger lease, as the most suitable undisturbed area to be used for groundtruthing (see 2009-10 annual report). It exhibits a strong airborne gamma signal, has not been mined, nor is it influenced by operations associated with the mine. Energy Resources of Australia (ERA) has also provided to SSD higher resolution data from an AGS that was flown in 1997. The Anomaly 2 component of this dataset was used to further refine the extensive groundtruthing fieldwork, conducted in the dry seasons 2007 to 2009, and to establish the exact location and radiological intensity distribution of the Anomaly.

More than 1800 external gamma dose rate measurements were made at 1m height above the ground, to characterise the footprint of Anomaly 2. These measurements were complemented by the determination of soil uranium, thorium and potassium activity concentrations via in situ gamma spectrometry at 150 sites. Dry season radon exhalation rates were measured at 25 sites over a period of three days, and soil scrape samples were taken at these sites for high resolution gamma spectrometry analysis in the ***eriss*** radioanalytical laboratory. Track etch detectors were also deployed at these sites for three months to measure dry season airborne radon concentration and to establish whether there is a correlation between airborne radon concentration, radon exhalation flux and soil ^{226}Ra activity concentrations.

Differences in survey parameters of the AGS and on ground datasets, such as field of view of the detectors, detector calibration, spatial referencing and data processing means that the data sets are not directly comparable. In order to be able to compare results with the AGS data, upscaling is required of the data measured on ground. Due to the much better resolution and lower flying height of the 1997 AGS the groundtruthed data was firstly upscaled and correlated with the 1997 AGS subset above Anomaly 2. The 1997 and 1976 AGS datasets were then correlated, using the data acquired over the whole extent of the 1997 AGS (which is smaller than the extent of the 1976 Alligator Rivers Geophysical Survey) but excluding the footprint of the mine site. This was done in a GIS environment and results are presented below.

3.8.3 Results

Correlating the 1997 AGS and ground data

The AGS data originally received as projected coordinates of the Australian geodetic datum 1984 were reprojected into the WGS84 map datum, UTM Zone 53S. A shapefile was then created, defined by the boundary of the 2007–09 field data obtained for the Anomaly 2 area. Airborne gamma survey points acquired within this boundary were extracted and line segments created between points, representing the plane's flight path. These line segments were assigned the total counts (TC) and counts in the uranium channel (eU) of the corresponding AGS records.

To upscale the field data, a series of buffers with varying radii were created around the line segments of the 1997 AGS data, to find the radius that provided the best correlation between the AGS data along that line segment (TC and eU, respectively), and the external gamma dose rates measured in the field ($\mu Gy \cdot hr^{-1}$) and averaged across the buffer. To ensure that results were not affected by variations in field sample spacing, 29 buffers in which ground points were evenly distributed were chosen for further analysis. It was found that a 90 m buffer radius provided the best correlation and thus represented the optimal field of view for the 1997 dataset, and results of the correlation are shown in Figure 3.8.1.

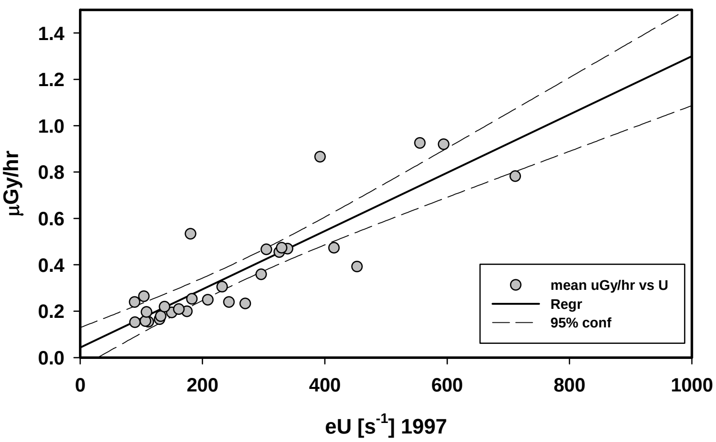


Figure 3.8.1 Averaged ground gamma dose rates within a 90 m buffer radius along the 1997 AGS line segments plotted versus counts per second in the uranium channel (eU) of the respective AGS record

Correlating the 1976 and 1997 AGS data

The two AGS raster datasets were displayed in projected coordinates of the WGS84 map datum, UTM Zone 53S, and a subset of the raster data was created. This subset incorporated the full extent of the 1997 AGS raster dataset excluding the footprint of the mine site. The 1997 raster data supplied by ERA (25 × 25 m^2 resolution) was then correlated with the 1976 raster data (70 × 70 m^2 resolution) of this subset, by averaging the 1997 data contained within a 1976 grid cell, and then comparing the average with the eU and TC of the 1976 grid cell. A total of 6916 records were obtained by this method, results of the correlation and R^2 are shown in Figure 3.8.2.

Pre mining external gamma dose rates and radon flux densities

Basic statistics of the 1976 AGS eU data for various areas, or shapefiles, were calculated in the GIS. The model enables conversion of the averaged AGS data into external gamma dose rates on the ground using the correlations derived above. The model also allows calculation of average pre-mining radon flux densities for selected areas of the minesite using previously established correlations between radon flux density, ^{226}Ra and external gamma dose rates measured on ground (see 2009–10 annual report). The minimum footprint area that can be assessed is set by the optimum buffer radius determined when up-scaling the external gamma dose rates measured on the ground to the AGS data. For the current case this is approximately 4 ha.

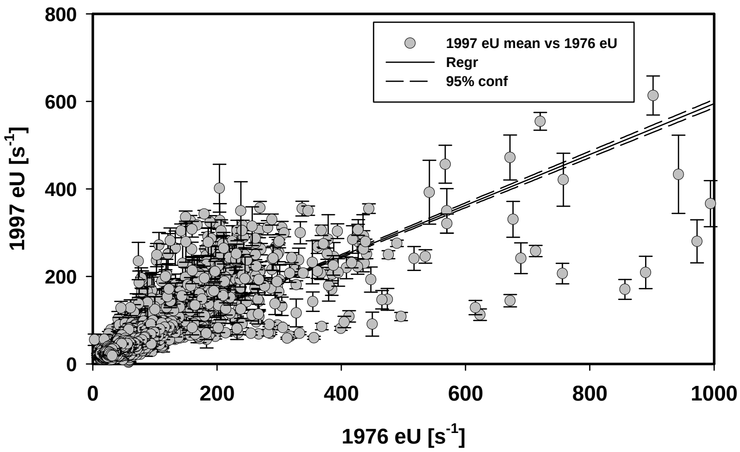


Figure 3.8.2 Average counts per second in the uranium channel (eU) of the 1997 AGS raster data plotted versus eU counts per second of the respective 1976 grid cell. Data extracted for the whole area of the 1997 AGS data subset, excluding the Ranger mine site.

Figure 3.8.3 shows a 1964 aerial photo that incorporates the greater Ranger mine area. The footprints of some of the currently existing mine site features have been overlaid for reference. The right hand side of the figure displays the 1976 eU data over the same area, with bright colours indicating areas of elevated radiation levels, and darker colours indicating environmental background values.

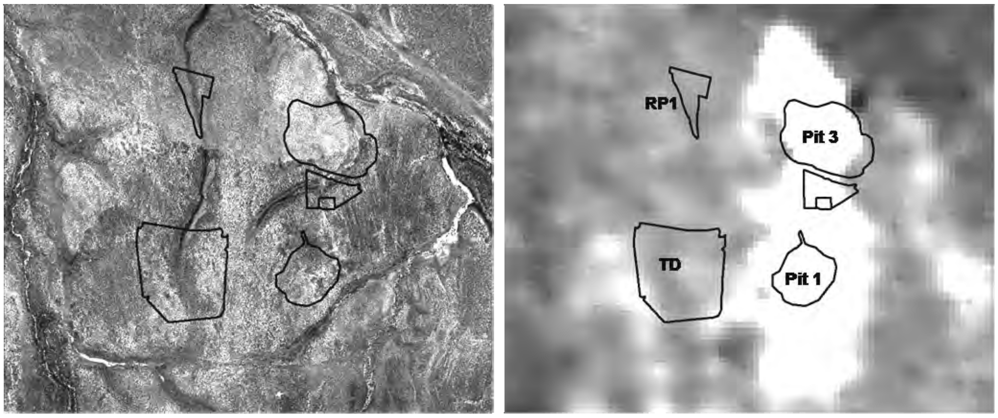


Figure 3.8.3 Footprints of major infrastructure features on site overlaid on an aerial photo of the greater Ranger mine area from 1964 and overlaid on 1976 AGS eU data. RP1 Retention Pond 1; TD Tailings Dam.

The average counts for each of those outlined areas have been determined in the GIS and converted to average external gamma dose rates and radon flux densities using correlations described above. Table 3.8.1 shows the estimated pre-mining external gamma dose rates and radon flux densities for each of these marked areas.

TABLE 3.8.1 ESTIMATED PRE-MINING EXTERNAL GAMMA DOSE RATES AND RADON FLUX DENSITIES FOR AREAS MARKED ON FIGURE 3.8.3

Infrastructure	Area [ha]	γ-dose rate [$\mu Gy \cdot hr^{-1}$]	Radon flux density [$mBq \cdot m^{-2} \cdot s^{-1}$]
Tailings Dam	110	0.11	0.19
RP1	17	0.10	0.16
Pit 1	40	0.87	4.1
Pit 3	77	0.44	1.9

The typical environmental background gamma dose rate determined for the whole extent of the 1976 AGS data set and using the derived correlation is approximately 0.1 $\mu Gy \cdot hr^{-1}$. This compares well with typical background gamma dose rates published for the ARR, ranging from 0.08 to 0.15 $\mu Gy \cdot hr^{-1}$. The modelled pre mining gamma dose rates and radon flux densities for orebodies 1 and 3 are also in very good agreement with published values measured on top of orebody 3 and determined using drill core from orebody 1, respectively. Gamma dose rates and radon flux densities reported were 0.95 $\mu Gy \cdot hr^{-1}$ and 4.1 $mBq \cdot m^{-2} \cdot s^{-1}$ for orebody 1 (44 ha) and 0.58 $\mu Gy \cdot hr^{-1}$ and 2.5 $mBq \cdot m^{-2} \cdot s^{-1}$ for orebody 3 (66 ha). Background values reported for the Ranger region were 0.13 $\mu Gy \cdot hr^{-1}$ and 0.13 $mBq \cdot m^{-2} \cdot s^{-1}$, respectively.

3.8.4 Conclusions

The correlation models developed by this project allow estimates to be made of the pre-mining baseline gamma dose rates and radon fluxes for any selected area (4 ha minimum) covered by the pre mining AGS data available over the greater Ranger area. The models will also allow prediction of pre-mining uptake of uranium series radionuclides into biota over the footprint of the Ranger mine, assuming secular equilibrium of the radionuclides in soils and using uptake factors determined for bushtucker in the region. This will facilitate the calculation of pre mining ingestion doses from bushtucker harvested from the site, in addition to the internal and external radiation doses to the environment as described below in section 3.9. The inhalation pathway needs to be quantified, using existing measurements of airborne radon concentrations on top of Anomaly 2 and dust re-suspension factors, which will then enable derivation of the total pre-mining radiological exposure to humans from all pathways.

3.9 Estimating radionuclide transfer to Northern Australian bushfoods and ingestion doses to members of the public

3.9.1 Introduction

The ARR is an area of past and present uranium mining activity. It is also an area where there is customary harvesting of both aquatic and terrestrial bushfoods by local Aboriginal people. The consumption of these bushfoods needs to be addressed as a potential radiation exposure pathway for members of the public, both now and in the future. In particular, the uptake of radionuclides via the bushfood pathway needs to be assessed for areas that have been impacted by the mining of uranium in order to provide the evidence base needed to assess the effectiveness of proposed rehabilitation strategies. The activity concentration of radionuclides in bushfoods may be obtained through direct measurement or estimated using transfer factors applied to measurements of radionuclide activity concentrations in environmental media such as soil and water.

The transfer of radionuclides from the environment to food items is commonly parameterised using a concentration ratio. Concentration ratio in this context is the ratio of the activity concentration of a radionuclide in the edible portion of the bushfood to that in the surrounding environmental media. By combining measurements of radionuclide activity concentrations in environmental media with concentration ratios and the masses of different types of bushfoods consumed by people in any one year, the annual ingestion dose can be estimated.

eriss has been measuring activity concentrations of natural-series radionuclides (ie those belonging to the uranium-238 and thorium-232 decay chains) in ARR bushfoods and associated environmental media for 30 years. The data allow concentration ratios for the transfer of radionuclides from soil and water to bushfoods to be calculated and thereby facilitate the estimation of ingestion doses for those circumstances where only the soil or water activity concentrations are known. This paper describes the creation of a bushfoods and environmental media database that compiles these 30 years of data into a consistent and quality controlled information repository. This database has been assigned the acronym ‘BRUCE’ – **B**ioaccumulation of **R**adioactive **U**ranium-series **C**ontaminants from the **E**nvironment.

3.9.2 About BRUCE

BRUCE is a Microsoft™ Access® database designed for the storage and handling of information on natural-series radionuclide activity concentrations in Northern Australian bushfoods and environmental media samples. Historical data accrued by the SSD have been reviewed, quality assessed and input to the database. The data include radionuclide activity concentrations in ARR bushfood, soil, sediment and water samples. Associated metadata such as spatial coordinates, wet to dry sample ratios and common and Aboriginal names of food species are also included. The database currently contains more than 2000 individual records and is continually growing as new data are acquired.

The transfer query function within BRUCE enables the calculation of concentration ratio for radionuclide transfer to ARR bushfoods. An additional query function that is currently under development will allow the calculation of ingestion doses to members of the public using composition of local diet and radionuclide dose conversion factors recommended by the International Commission on Radiological Protection.

Figure 3.9.1 shows a screenshot and results obtained using the transfer query function in BRUCE applied to radium-226 (^{226}Ra) in the fruit tissue of passionfruit (*passiflora foetida*). Included are results from all sites where both the activity concentrations in passionfruit and in the soil in which the plant was growing have been measured. The mean, minimum and maximum concentration ratio is calculated relative to the total soil ^{226}Ra activity concentration.

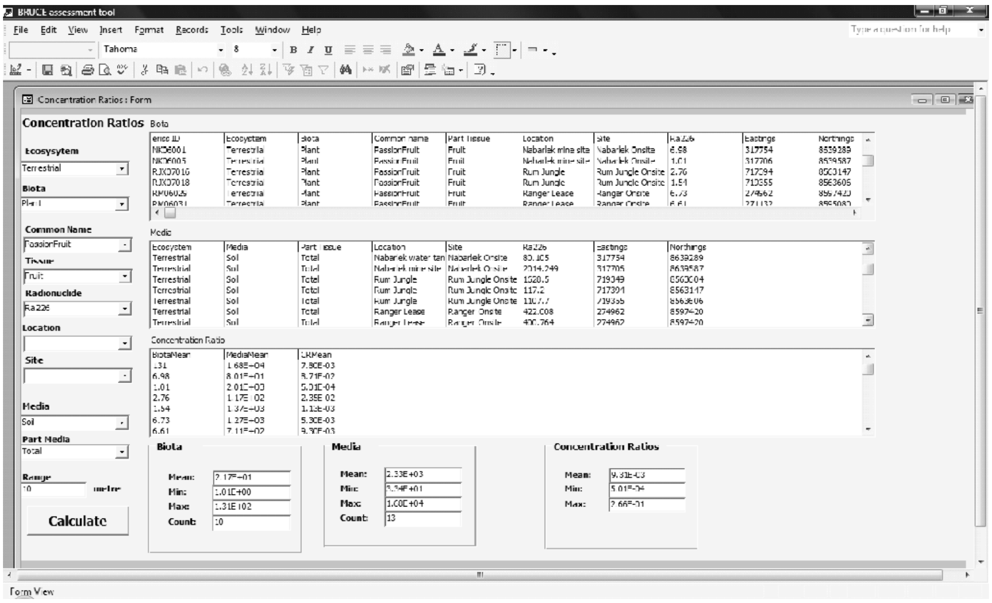


Figure 3.9.1 Example transfer query output from the BRUCE database showing ^{226}Ra activity concentration data for passionfruit (terrestrial plant) and associated soil, followed by the derived concentration ratios for each of these data pairs. The bottom three panels show the summary statistics for the primary data and the derived concentration ratios.

The above example illustrates a large variability in the ^{226}Ra-passionfruit concentration ratio. A similar variability in concentration ratio occurs for other radionuclide-bushfood combinations. Such variability has also been found for radionuclide uptake in foodstuff studies conducted elsewhere. In large part this variability occurs as a result of variations in the bio-availability of radionuclides present in different soil types (see Supervising Scientist annual report 2008–2009, chapter 3, section 3.7).

As illustrated above, the source data present in the database can be used to estimate concentration ratios applicable to the ARR, together with associated ranges for existing radionuclide-bushfood combinations. The concentration ratios can be utilised to predict ingestion doses to members of the public for various remediation scenarios at the Ranger minesite and elsewhere in the ARR. If the pre-mining soil activity concentration data are known, then the baseline activity concentrations for bushfood prior to the start of mining can be inferred (see previous paper 'Using historic airborne gamma surveys to determine the pre-mining radiological baseline for Ranger mine', section 3.8).

3.9.3 Relevance to radiation protection of non-human species – Australian and international context

International trends in radiation protection indicate the need in some circumstances to be able to demonstrate that non-human species in natural habitats are protected against deleterious radiation effects from practices releasing radionuclides to the environment. This has emerged in recent years as a best practice approach for assessing possibility of radiation impact on the non-human environment from components of the nuclear fuel cycle, including uranium mining.

The 2007 Recommendations of the International Commission on Radiological Protection distinguishes environmental protection objectives from human protection objectives and establishes a framework within which radiation exposure to non-human species from radionuclides released to the environment can be assessed and interpreted. The framework uses reference organisms as conceptual and numerical surrogates for the estimation of radiation dose rate to living organisms which are representative of a contaminated environment.

The common method for estimating radionuclide transfer to non-human species – necessary for internal dosimetry calculations – is to use the concentration ratio. Concentration ratio in this context is the ratio of the average activity concentration of a radionuclide in the whole organism to that in the surrounding environmental media. This can differ from the concentration ratio derived for bushfood, which is generally defined for a specific edible tissue component of the animal or plant.

The need to determine transfer factors relevant to a range of environment and species types has led to an increased focus, nationally via ARPANSA and internationally via the EMRAS (**E**nvironmental **M**odelling for **RA**diation **S**afety) program of the IAEA. In particular, ARPANSA has identified that there is a need to collect and assemble concentration ratio data on biota typical of Australian environments in order to facilitate more robust application of existing assessments tools.

Although the activity concentration data in BRUCE has not been specifically collected for application to the non-human environment in the context of whole-of-organism values, the data may be able to be used to produce concentration ratios that can be converted from tissue specific to whole organism for some organism types. Generic conversion factors are available to facilitate this. If this conversion is done then the radiation dose rates to ARR biota in mine-impacted areas could be estimated using existing assessment tools such as ERICA (**E**nvironmental **R**isk from **I**onising **C**ontaminants: **A**ssessment and Management) or ResRad Biota (**Res**idual **Rad**ioactivity Biota).

Whole organism concentration ratios for freshwater mussels and fish in the ARR were collated and quality controlled over the past year. These data have been supplied to Working Group 5 ('Wildlife Transfer Coefficient' Handbook) of the IAEA EMRAS II programme, and have been included in a draft IAEA Technical Report, *Handbook of parameter values for the prediction of radionuclide transfer to wildlife,* which will be published later in 2011. This report provides a summary of worldwide radionuclide transfer data for non-human species, with associated ranges, standard deviations and means (geometric and arithmetic). The new parameter values presented in this latest IAEA report will replace the default values currently used in ERICA to assess radiation dose rates to non-human species from radionuclides released to the environment.

3.10 Remote sensing framework for environmental monitoring within the Alligator Rivers Region

A systematic remote sensing capture, incorporating full ground control and coincident collection of ground spectral data was undertaken for the Magela floodplain and Ranger uranium mine in May 2010. Three World-View 2 images covering 730 km^2 of the Magela Creek catchment were acquired. Project work in 2010-11 focused on orthorectification of the imagery and atmospheric correction to provide the basis for producing high resolution maps of vegetation and habitat types.

3.10.1 Introduction

Before multispectral satellite imagery can be utilised for quantitative applications, a number of pre-processing steps, including geometric and radiometric correction, need to be undertaken. A high degree of radiometric accuracy is required so that time series acquisitions can be used to reliably quantify extents of change, and so that remote sensing data can be accurately matched to field-based measurements (such as plant biophysical parameters).

To obtain quantitative information from multispectral satellite sensors such as WorldView-2, factors affecting the raw digital numbers (DN) such as sensor characteristics, illumination geometry and atmospheric effects need to be removed. Effects of the atmosphere, such as scattering and absorption, vary across the optical spectrum by either adding to, or diminishing the surface radiance values recorded by the satellite sensor. A number of different methods have been developed to correct for the effects of the atmosphere on satellite imagery including: image based methods; radiative transfer models; and the empirical line method.

The empirical line method has been used to convert at-sensor radiance values to surface reflectance for numerous multispectral satellites and airborne hyperspectral sensors. The technique is based on establishing a relationship between atmosphere sensor radiance (L_{TOA}) values and surface reflectance (P_S) values measured from calibration targets located within the image area. The P_S values of the calibration targets are measured using a field spectrometer and ideally should cover the range of albedo (the fraction of solar energy reflected from the Earth’s surface) values found within the imagery. The L_{TOA} values are then extracted from the imagery and compared with the field measured P_S values to define prediction equations that can be used to convert image-derived L_{TOA} to P_S values for each waveband.

The aim of this work was to assess the ability of the empirical line method to convert very high spatial resolution multispectral WorldView-2 imagery from L_{TOA} to P_S values using quadratic prediction equations. The results for two of the three images are reported here.

3.10.2 Methods

Image pre-processing

Orthorectification of the imagery was undertaken using the sensor's Rational Polynomial Coefficients (RPC) combined with an array of accurately geo-referenced ground control points (GCPs). The one second Shuttle RADAR Topography Mission (SRTM) Digital Elevation Model (DEM) was used as part of the orthorectification process. Coordinates for 24 GCPs distributed evenly across the imagery were acquired using a DGPS (Differential Global Positioning System) with an overall average positional accuracy of 10.6 mm for the X and Y coordinates. Nine GCPs were used in the orthorectification of Image 2 while ten GCPs were used for Image 1. The overall accuracy assessment of the orthorectification based on six independent GCPs resulted in an average Root Mean Square Error (RMSE) of 1.82 m. To account for sensor characteristics, the images were converted from DN to L_{TOA} spectral radiance.

Field spectra

A combination of both calibration panels and field targets were utilised to convert L_{TOA} values to P_S. A total of 24 targets were measured in the field along with two calibration panels. The two calibration panels and five selected field targets (Table 3.10.1) were used to derive the prediction equation between L_{TOA} and P_S for each waveband, while the remaining 19 targets (Table 3.10.2) were used to assess the accuracy of the prediction equations. Spectra were collected according to SSD's field sampling methods.

TABLE 3.10.1 DESCRIPTION AND MEAN COEFFICIENT OF VARIATION (CoV) FOR TARGETS USED TO DERIVE PREDICTION EQUATION TO CONVERT BETWEEN L_{TOA} AND P_S

ID	Target description	CoV*
C1[c]	(~95%) Tyvec® calibration panel	0.97
C2[c]	(~67%) White calibration panel	2.77
C3[c]	Sports field grass	6.96
C4[d]	Synthetic bowling green	15.58
C5[d]	Asphalt road	17.13
C6[e]	Open Water – Jabiluka billabong	9.29
C7[e]	Open Water – Jabiluka billabong	9.31

* Mean CoV for each target based on field spectra. Wavelength 400–1040 nm

Spectra collection date: ([c] = 11/5/10), ([d] = 13/5/10), ([e] = 27/5/10)

Empirical line calibration and accuracy assessment

The very high resolution averaged field spectra (P_S) were re-sampled to provide spectral bandwidth data corresponding to each WorldView-2 waveband. The average L_{TOA} values corresponding with each calibration panel and field target were then extracted from the imagery. A non-linear quadratic relationship was fitted between L_{TOA} and P_S.

The overall accuracy of the empirical line calibration was assessed by comparing image derived P_S values with field measured P_S for the 19 validation targets. Summary statistics were obtained to assess the performance of each spectral band, and each individual validation target, using the RMSE and the Mean Absolute Percent Error (MAPE), which enable the assessment of the relative error for each target.

TABLE 3.10.2 DESCRIPTION AND MEAN COEFFICIENT OF VARIATION (CoV) FOR TARGETS USED TO DERIVE PREDICTION EQUATION BETWEEN L_{TOA} AND P_S

ID	Target description	CoV*
V1[a]	Sports field grass	13.23
V2[a]	Open Water – Jabiru Town Lake	14.10
V3[a]	Open Water – Jabiru Town Lake	55.82
V4[b]	Asphalt road	5.52
V5[b]	Sports field grass	9.42
V6[c]	Sports field grass	4.31
V7[c]	Sports field grass	5.91
V8[c]	Sports field grass	7.88
V9[c]	Sports field grass	12.25
V10[c]	Golf green	8.86
V11[d]	Builders Sand	6.89
V12[d]	Sand / blue stone	31.86
V13[d]	Sand / concrete slab	9.83
V14[d]	Native grass	17.43
V15[d]	Rock outcrop	39.28
V16[d]	Bare earth (scrape)	13.59
V17[e]	Open Water – Jabiluka billabong	10.18
V18[e]	Bare earth	13.76
V19[e]	White road base	14.64

* Mean CoV for each target based on field spectra. Wavelength 400–1040 nm

Spectra collection date; ([a] = 6/5/10), ([b] = 7/5/10), ([c] = 11/5/10), ([d] = 13/5/10) ([e] = 27/5/10)

3.10.3 Results

The combination of calibration panels and field targets enabled the development of a non-linear relationship between L_{TOA} and P_S. A total of seven targets were used to derive the prediction equation, resulting in statistically significant relationships for each waveband ($R^2 = 0.99$, $P < 0.0001$, 99% confidence level).

Summary statistics for each band are presented in Table 3.10.3. The overall RMSE values for each band show that there was a high degree of agreement between the satellite-derived P_S values and field-measured P_S values for the 19 validation targets. Five of the eight bands recorded RMSE values below 1.5% with the coastal band recording the lowest value of 0.94%. The red-edge and two NIR bands recorded the highest RMSE values. However, the MAPE values (which assess relative error) show that the red-edge band recorded similar errors to the bands in the visible portion of the electromagnetic spectrum.

TABLE 3.10.3 SUMMARY STATISTICS DERIVED FROM THE VALIDATION TARGETS FOR EACH WAVEBAND

Band	RMSE%	MAPE%
Coastal (1)	0.94	18.39
Blue (2)	1.05	14.01
Green (3)	1.20	11.48
Yellow (4)	1.29	13.75
Red (5)	1.36	16.78
Red Edge (6)	1.86	16.02
NIR 1 (7)	2.13	25.97
NIR 2 (8)	2.14	44.83

3.10.4 Conclusions and future work

The combination of both calibration panels and image targets enabled the development of prediction equations covering the full range of albedo values within the image. The high accuracy achieved in the geometric correction of the imagery and the spatial and radiometric resolution of the WorldView-2 sensor enabled calibration targets to be easily identified in the imagery. Importantly the calibration targets used ensured that the predicted P_S values were interpolated within the bounds of the prediction equations. Assessment of the prediction equations based on 19 independent validation targets show that overall accuracy was high, with RMSE values between 0.94% and 2.14% across the eight multispectral bands. The results show that the empirical line method using quadratic prediction equations can be used to successfully calibrate the eight multispectral bands of the WorldView-2 satellite image to surface reflectance. This method will enable us to routinely process very high resolution imagery for time series and quantitative analyses.

Further work will be undertaken to calibrate the third World-View 2 image where Bidirectional Reflectance Distribution Function (BRDF) effects are evident due to the differing illumination and viewing geometry. A vegetation map of the Magela floodplain is under development using the 2010 imagery. Another World-View 2 image was acquired in May 2011, and is currently being processed.

3.11 Importance of large wood for creating aquatic habitat and stable channels in the Ngarradj Creek catchment

3.11.1 Background

Recent Australian research has quantified the role of large wood (wood of any origin and length with a diameter greater than 0.1 m) in dissipating stream energy, forming pool habitats by local bed scour, protecting river banks from erosion and damming rivers with long rafts causing avulsions or abrupt, wholesale changes of river courses. Large wood in Australian streams is sourced by a range of processes from the nearby riparian zone, which has often been degraded by post-European settlement vegetation clearing. However, the extent of large wood loadings within the bankfull channel for different riparian plant community types is essentially unknown for most Australian rivers. The Ngarradj catchment (Figure 3.11.1) is an excellent location to determine the importance of large wood for creating aquatic habitat and stable river channels in the natural environment because there are long reaches which have experienced little human modifications.

The locations of the study sites are in proximity to the former ***eriss*** East Tributary (ET) and upper Ngarradj (UN) river gauging stations (Figure 3.11.1) where there are riparian *Allosyncarpia ternata* ST Blake forests and meandering stream channels. *Allosyncarpia ternata* is an evergreen tree up to 18 m high with grey fissured, fibrous bark and ternate leaves that is endemic to western Arnhem Land, Northern Territory. The riparian forest is unusual because it comprises only a narrow strip bordering the immediate river channel (Figure 3.11.2). The surveyed reaches were 130 m (15 channel widths) long and 292 m (29 channel widths) long on the East Tributary and upper Ngarradj Creek, respectively. Such reaches are long enough for meandering rivers to include at least two standard pool-riffle sequences. Previous research on *A. ternata* forest has been largely confined to non-riparian locations associated with sandstone escarpments and valleys where different forest dynamics and disturbance processes occur than in riparian zones.

3.11.2 Large wood and aquatic habitat

The forested, laterally stable, unconfined, meandering rivers represented by these two sections of Ngarradj Creek are defined as sand-bed streams with a sinuous pattern (sinuosity > 1.5 which means that the channel is at least 1.5 times longer than the valley in which it is located), a continuous but narrow floodplain and a narrow, forested riparian corridor.

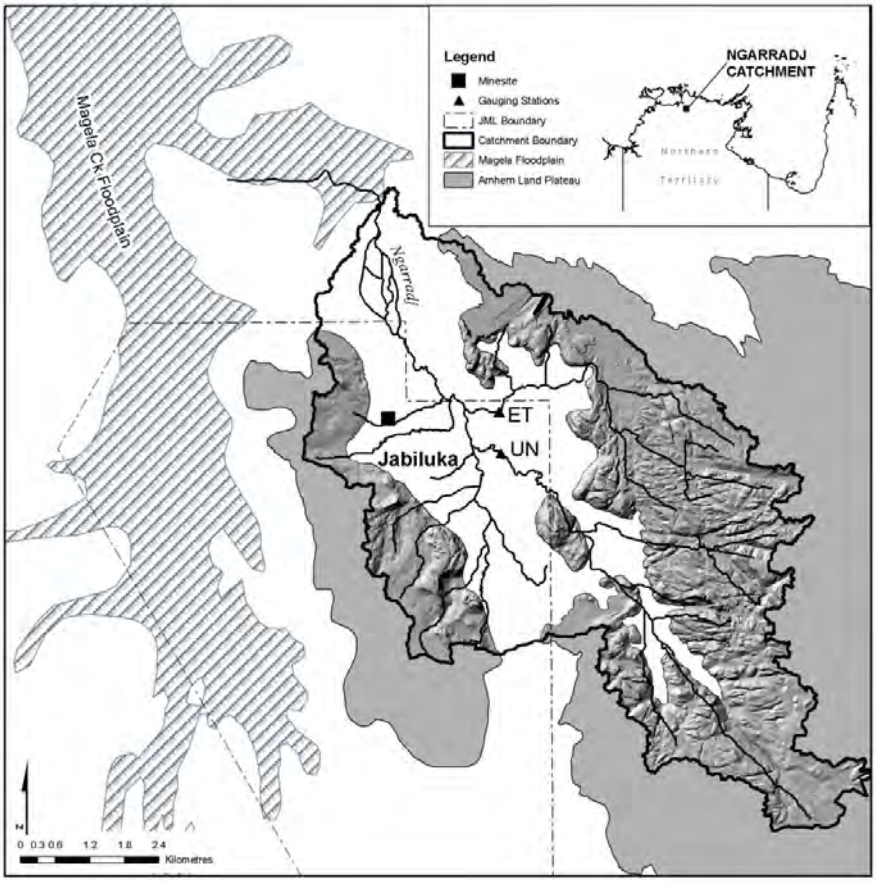


Figure 3.11.1 The Ngarradj catchment showing the study sites at East Tributary (ET) and upper Ngarradj Creek (UN)

Figure 3.11.2 The riparian *A. ternata* forest on upper Ngarradj Creek which is the sinuous green ribbon across the dry lowlands

The characteristics (loading, spatial distribution, orientation, composition, arrangement, blockage ratios, dynamics) and recruitment processes of large wood were measured along both study reaches, together with the length and depth of every aquatic habitat type (principally pools, runs and riffles) present. Every living tree within the bankfull channel and within contiguous quadrats aligned perpendicular to the channel through the riparian *Allosyncarpia* forest was identified to species level (study undertaken October 2010).

Quadrat surveys of trees in the riparian forest on contiguous transects perpendicular to the channel at both sites found that *A. ternata* was the dominant tree (42–85%), with *Lophopetalum arnhemicum*, *Syzygium forte* ssp *potamophilum*, *Calophyllum sil*, *Carellia brachiata*, *Erythrophlem chlorostachys* and *Xanthostemon eucalyptoides* also being present in reasonable numbers.

A total census of large wood in the bankfull channel for both reaches found that loads ranged between 184 m^3/ha (upper Ngarradj Creek) and 302 m^3/ha (East Tributary). At upper Ngarradj Creek, dead wood comprised 61.3% and living trees comprised 38.7% of the total large wood load, whereas at East Tributary, the percentages were 34.5 and 65.5%, respectively. Most living trees were located on the river banks within the bankfull channel. Between 94 and 97% of living trees were located on the banks, with only between 3 and 6% in the river bed. The roughness created by the dense stands of bank-side trees is responsible for low flow velocities along the channel margins and hence the zero bank erosion rates measured over four years. At upper Ngarradj Creek there were 272 pieces of large wood at an average spacing of 1.07 m. At East Tributary there were 230 pieces at an average spacing of 0.57 m. In addition, 12.6% of the large wood in the bankfull channel at East Tributary exhibited fire scars compared with 16.2%, at upper Ngarradj Creek. This provides evidence that fire and the resultant damage to the riparian trees cause some recruitment of large wood to the channel.

Small diameter wood (<0.3 m) dominates in terms of the number of pieces, but large diameter wood (>0.3 m) dominates in terms of volume in both reaches. Debris dams were uncommon but, when present, often caused significant localised expansions in channel width because of outflanking by erosion at the extremities of the dam. Blockage ratios refer to the percentage of the bankfull channel area occupied by large wood. They are usually less than 5% but the few debris dams that are present do block a significant proportion of the bankfull channel area (>16%). Blockage ratios less than 5% usually do not impact on flood routing, but ratios of 16% would increase flood heights for the same peak discharge.

Most of the large wood was orientated with the long axis downstream. Downstream orientations are only possible where rivers have the stream power to reorient and transport a significant proportion of the recruited large wood from the riparian zone.

Large wood loadings within both study reaches varied greatly longitudinally with up to three orders of magnitude variation at the spatial scale of one channel width lengths down the channel. At East Tributary, the mean loading per unit channel width of length was 1.90 ± 0.46 m^3 (range 0.65 to 6.8 m^3). At upper Ngarradj Creek the mean large wood load was 1.87 ± 0.28 m^3 (range 0.06 to 5.4 m^3).

In the seasonally wet tropics of northern Australia, strong winds and tropical cyclones are important recruitment processes along with bank erosion and fire. Strong winds followed by a lightning strike in February 2002 resulted in significant wind throw and branch breakage in the East Tributary study reach. Large wood recruitment equivalent to 912 m^3/ha occurred in the affected area. Subsequently, the core of Cyclone Monica passed over the Ngarradj catchment on 25 April 2006, resulting in an estimated 42% loss of woodland canopy cover.

The maximum 3 sec wind gusts were 36–64 m/s during Cyclone Monica. A survey of the large wood inventory in the upper Ngarradj study reach was made after Cyclone Monica. The number of individual pieces of large wood was found to have increased from 272 to 720, and the total load increased from 184 to 324 m^3/ha. The number of pieces of large wood per metre channel length increased from 1.07 to 2.48 pieces per metre. High winds and tropical cyclones can clearly be a significant large wood recruitment process but are rarely discussed in the large wood literature.

A longitudinal profile survey of the East Tributary study reach before Cyclone Monica showed that there were 13 pools in the surveyed reach with an average spacing of 1.75 channel widths (Figure 3.11.3). This is much less than the 4 to 8 channel widths commonly associated with pool-riffle sequences in meandering, gravel-bed streams. Of these 13 pools, only two were dominantly produced by bend processes (secondary currents), the remainder being caused by localised bed scour due to the presence of large wood. Scour mechanisms included under scour, over scour, lateral scour and constriction scour. Each scour mechanism produced a distinctive pool type, namely transverse scour pool, log step pool, longitudinal pool and convergence pool, respectively (Figure 3.11.3).

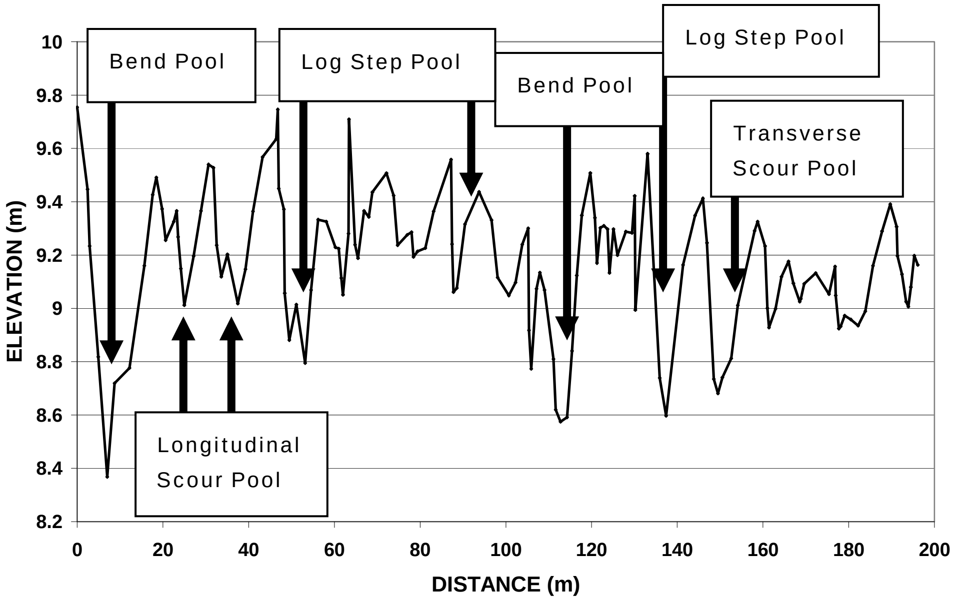


Figure 3.11.3 Longitudinal bed profile of the East Tributary of Ngarradj Creek showing locations of examples of various types of pools present

The close spacing of pools reflects the addition of pools between bends in sinuous streams due to localised scour induced by the high large wood load. Scour pools are important refuges in the seasonally flowing streams common to northern Australia. In some cases these pools can persist right through the dry season providing a source of recruitment when flow is re-established the following wet season. Loss of pools is known to reduce fish abundance.

Step structure formed by logs is important for energy dissipation, which reduces erositivity of a stream. On East Tributary, there were four log steps in the study reach which accounted for 14% of the total hydraulic head loss along that length of the stream. Two log steps have remained in the same location for the last 13 years.

3.11.3 Conclusions

The channels in the two study reaches have been stable over the last 13 years. Measured bank erosion rates over four years at both sites were not significantly different from zero and mean annual net bed scour was statistically identical to net bed fill. Changes in the channel cross section at 8 permanently marked locations in each study reach were minor over the 6 years between 1998 and 2003. The reason for the existence of the stable meandering channel is the presence of the riparian *A. ternata* forest and the supply of large amounts of large wood to the channel by a range of recruitment processes, including strong winds, bank erosion and fire. The diversity of pool types initiated and sustained by the presence of this large wood increases aquatic habitat diversity which should also lead to increased fish species diversity.

This work has provided an important baseline data set for Ngarradj Creek which can be used to assess future changes and to determine whether any changes which do occur are either natural or man-induced. In particular, any future mining-related activities within the Jabiluka Mineral lease should not disturb the river channels and the vegetation, especially riparian trees, growing on the bed and banks of the Ngarradj Creek catchment in order to maintain the stability of this fluvial system.

3.12 Tropical Rivers and Coastal Knowledge (TRaCK) Research Program

The TRaCK research hub headquartered at Charles Darwin University in Darwin is one of the major components of the CERF program that was managed by DSEWPaC (Department of Sustainability, Environment, Water, Population and Communities). ***eriss*** was a key collaborator in Project 4.1: Catchment water budgets and water resource assessment. This work involved flood inundation mapping for the Mitchell and Daly River catchments using a combination of radar and optical satellite imagery analysis.

3.12.1 Mapping the extent of wet season inundation on the Daly River floodplains

Identification of 'wettest' and 'driest' wet seasons

The wet seasons that received the highest and lowest rainfall were identified using Foley's precipitation deficit index. Foley's precipitation deficit index measures the standardised monthly mean annual precipitation over a specified lag period relative to the long-term mean annual precipitation. Other studies have shown that 3 years is a sufficient lag period for antecedent rainfall conditions to influence vegetation dynamics in Australia's tropical savannas. Hence, we calculated Foley's precipitation deficit index using a 3 year lag period. This analysis provided the basis for locating the years corresponding to the likely maximum and minimum interannual inundation extents of the selected catchments.

The year that best matched the availability of both optical and L-band Synthetic Aperture Radar (SAR) data for mapping maximum inundation extent was 2009. The year that best matched the satellite record for optical data for mapping minimum inundation extent was 2005 (there were no L-band SAR data available for years that fell into the lowest rainfall wet season range).

Image classification method

A Geographic Object Based Image Analysis (GEOBIA) approach was used to classify the Landsat 5 Thematic Mapper (TM) and PALSAR (Phased Array type L-band Synthetic Aperture Radar) ScanSAR data using multi-resolution segmentation.

Two band ratios, based on published literature on techniques to extract water coverage from optical satellite imagery, were used to identify open water (flooding) in the Landsat 5 TM data. The first of these band ratios, The Normalised Difference Water Index (NDWI), was developed to delineate open water in satellite imagery. The second ratio, the Modified Normalised Difference Water Index (MNDWI), is based upon the principle of the NDWI but further suppresses the signal from built-up areas and cleared regions in the imagery by substituting the near-infrared (NIR) with the middle-infrared (MIR) band.

Mapping results and recommendations

Maximum inundation extent for the Daly River floodplain was mapped using both Landsat 5 TM and PALSAR ScanSAR imagery. Three flood classes were produced: open water; flooded *Melaleuca* swamp; and flooded grasses and sedges. Maximum inundation extent is displayed in Figure 3.12.1. A summary of the areal extent of the three flooded classes is shown in Figure 3.12.2 for three months during the 2009 wet season. It should be noted that the open water class includes the near shore environment due to the data used to subset imagery. Therefore, the open water class mapped using this method extends beyond the floodplain proper.

The methodology for providing reliable and robust flood inundation mapping in Australia, and in particular northern Australia, is still in its developmental phase. The type of satellite sensors used for reliably identifying areas of inundation is critical for mapping flood classes in northern Australia. This is due to occurrence of ubiquitous cloud cover during the wet season and coverage of floodplains by grasses and aquatic plants etc following rain, followed in the dry season by fire and associated smoke. The effect of cloud cover and smoke in optical imagery is not the only factor limiting reliable classification of images. The optical properties of fire scars from early dry season burning (as early as May) can be confused with flooded areas, in particular flooded vegetation (even with the inclusion of SAR data).

Combining L-band SAR data with optical data, as was done in this study, substantially improves the ability to map flooded classes during the wet season. Flooded *Melaleuca* swamp areas are particularly well distinguished by the SAR data. It is recommended that the optical and SAR data should be acquired concurrently to facilitate the most robust discrimination between flooded area types. Unfortunately, owing to limitations in availability of satellite L-band SAR, and the available frequency of image acquisition by the SAR-capable platforms, this is not often possible.

The MNDWI data analysis method was found to be particularly useful for mapping open water areas. Combining the Shuttle Radar Topography Mission Digital Elevation Data (SRTM DEM) data into the classification process may further improve classification results, and is an aspect requiring further investigation.

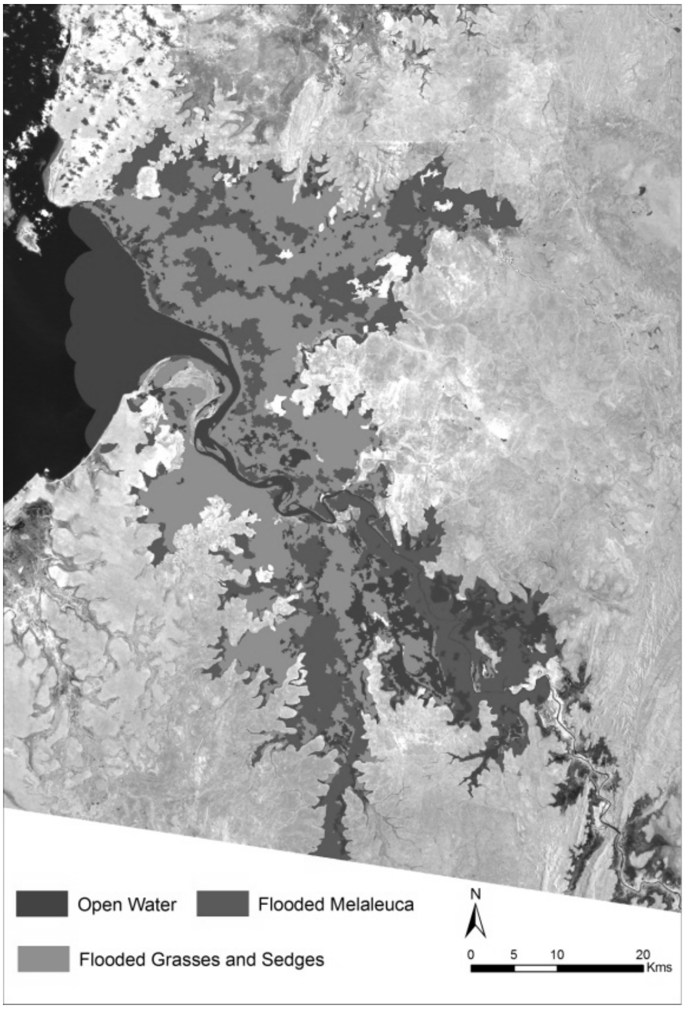


Figure 3.12.1 Maximum inundation extent during March 2009 for the Daly River floodplain

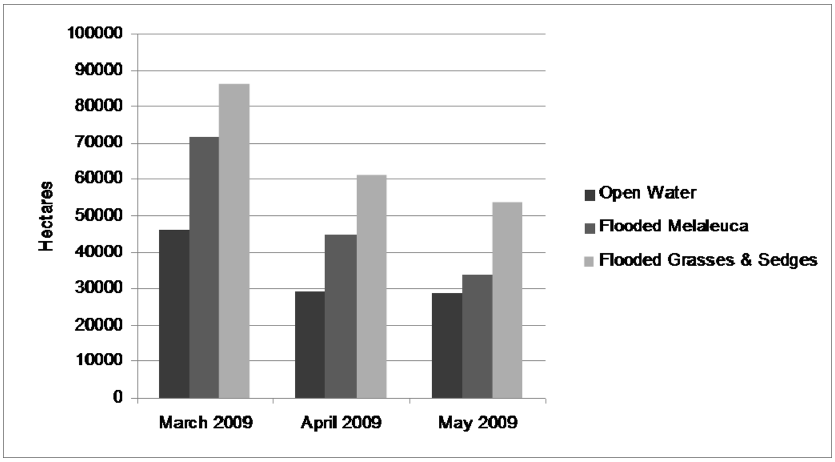


Figure 3.12.2 Summary of the areal extent of flooded classes during March-April 2009 for the Daly River floodplain

The outputs from this work provided boundary conditions for the seasonal catchment water balance models that were developed for the Daly and Mitchell River catchments. The techniques that were developed will be further refined and applied to delineating the extent of flood inundation on the Magela Creek floodplain.

4 STATUTORY COMMITTEES

4.1 Introduction

During 2010–11, the Supervising Scientist Division 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 discussion and information exchange between stakeholders in relation to the division's environmental supervision and assessment activities, and facilitating peer review of associated scientific research activities.

4.2 Alligator Rivers Region Advisory Committee

The Alligator Rivers Region Advisory Committee (ARRAC) was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978.* ARRAC facilitates communication between government, industry and community stakeholders on environmental issues associated with uranium mining in the Alligator Rivers Region.

ARRAC members are appointed by the Minister for Sustainability, Environment, Water, Population and Communities. ARRTC comprises an independent Chair and representatives from the following stakeholder organisations:

- NT Department of Resources
- NT Department of Natural Resources, Environment, the Arts and Sport
- NT Department of Health and Families
- Office of the Administrator of the NT
- Australian Government Department of Resources, Energy and Tourism
- Australian Radiation Protection and Nuclear Safety Agency
- Energy Resources of Australia Ltd
- Cameco Australia Pty Ltd
- Uranium Equities Ltd
- Koongarra Pty Ltd (a subsidiary of AREVA Australia Pty Ltd)
- Northern Land Council
- Gundjeihmi Aboriginal Corporation
- Environment Centre Northern Territory
- West Arnhem Shire Council
- Parks Australia, Australian Government Department of Sustainability, Environment, Water, Population and Communities
- Supervising Scientist Division, Australian Government Department of Sustainability, Environment, Water, Population and Communities

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, stakeholders present information reports to ensure transparency and enhance knowledge sharing. Information reports usually include a summary and interpretation of monitoring data and details of periodic environmental reports from mining companies. SSD provides a comprehensive report to each ARRAC meeting covering the outcomes of audit and assessment activities and environmental monitoring.

ARRAC met twice during 2010–11: in Jabiru in August 2010 and in Darwin in March 2011. 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 web site at www.environment.gov.au/ssd/communication/committees/arrac/meeting.html.

4.3 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 appropriate and of the highest possible standard. ARRTC also reviews the quality of the science underpinning regulatory assessment and approval of proposals by uranium mining companies in the Alligator Rivers Region.

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 the Federation of Australian Scientific and Technological Societies (FASTS);
- representatives from the Northern Land Council, the NT Department of Resources, Energy Resources of Australia Ltd (for Ranger and Jabiluka), Uranium Equities Ltd (for Nabarlek) and Parks Australia.

Two new independent scientific members with expertise in mine site rehabilitation (Professor David Mulligan) and radiation and health physics (Mr Andrew Johnston) were appointed to ARRTC in September 2010. The first ARRTC meeting scheduled for late 2010 was cancelled due to extended delays in finalising nominations for remaining vacant independent scientific member positions resulting in insufficient members available to hold the meeting. The only ARRTC meeting within the reporting period was held in Darwin in early April 2011.

Prior to this meeting, ARRTC members visited the Ranger Uranium Mine operated by Energy Resources of Australia Limited (ERA). Members were provided an overview of proposed exploration activities and major construction projects and inspected the water treatment plant and new stockpile interception trenches. Members also visited the trial landform site to review the success of the experimental revegetation plots.

The key issues considered by ARRTC at this meeting included:

- current and proposed scientific research activities for ***eriss*** and ERA, in the context of the ARRTC Key Knowledge Needs;
- outcomes of chemical, biological and radiological research and monitoring being undertaken by DoR, ERA and SSD;
- 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 the various stakeholder organisations.

Key outcomes from this meeting included ARRTC's endorsement of the direction and quality of the ***eriss*** and ERA research programs. ARRTC also agreed to revise the Key Knowledge Needs document on a rolling basis and address other knowledge gaps (including data management/groundwater database issues) out-of-session. The ARRTC 2008–10 Key Knowledge Needs are included in Appendix 1 of this annual report.

ARRTC meeting minutes are available on the ARRTC web site at www.environment.gov.au/ssd/communication/committees/arrtc/index.html.

5 COMMUNICATION AND LIAISON

5.1 Introduction

Effective communication with all stakeholders is an integral component of the Supervising Scientist Division's functions. Keeping traditional owners and other Aboriginal people living in the Alligator Rivers Region informed about SSD activities including the supervisory activities of the Office of the Supervising Scientist (***oss***) and the research and monitoring programs undertaken or managed by the Environmental Research Institute of the Supervising Scientist (***eriss***) is especially important. Communication with research partners and other stakeholders within government, industry, science and the general community is also vital in the context of the research and supervisory functions of the division.

5.2 Research support and communication

SSD has been involved in community engagement activities such as festivals and school visits within local communities in Kakadu National Park and the Alligator Rivers Region. These activities strengthen SSD's relationship with local indigenous stakeholders, research organisations, non-governmental environmental groups and the general public.

General SSD communications activities are coordinated through the Business Support Unit and communication with indigenous stakeholders is managed by the Jabiru-based Community Liaison Officer (CLO) in conjunction with Jabiru Field Station and other SSD staff.

Events undertaken in the reporting period include community liaison and information, scientific education activities, reviews and workshops, and conference organisation and presentations.

Specific and targeted liaison with traditional owners and other indigenous stakeholders continued to be a priority.

The 2010–11 program of community engagement activities included display booths at the Mahbilil Festival and World Wetlands Day in Jabiru, school talks and participation in careers expo, interactive informal information sessions on country with local traditional owners, a series of presentations to Kakadu district rangers and hosting visits at the Jabiru Field Station.

The SSD web site is another important means of raising community awareness of the work of the division and providing public access to some of the division's scientific data and reports, such as the results of the SSD environmental monitoring program.

Of note, all Supervising Scientist Reports, Research Reports and Technical Memoranda, and those Internal Reports that are not restricted or commercial-in-confidence, are now available online in PDF format.

5.2.1 Indigenous employment and consultation

Indigenous employment for activities such as field research projects gives SSD staff the opportunity to work alongside landowners on their country, sharing knowledge and gaining greater insight into traditional cultural values. It is also an opportunity for indigenous people to gain firsthand knowledge and valuable technical skills and understanding of SSD's research and monitoring program.

Having applied for permission to research on Aboriginal land, engaged the help of residents in undertaking fieldwork and invited the local Aboriginal people to view the work done by SSD, we have a responsibility to follow up with results of these projects. We do this in a number of ways. For example, the same water chemistry control charts that are posted on the SSD web site are taken by the Community Liaison Officer (CLO) to Aboriginal communities in the Alligator Rivers Region to show the levels of uranium and other things we measure in the local creeks. Explanation of the significance of the levels and any variations is provided to local residents in a 'hands-on' practical manner. The results are also presented at local communities and are published in the local newsletter.

SSD has maintained 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 – affording greater opportunity to communicate our role and function, and helping us keep the local communities well informed about our monitoring and research programs. Informal contact has also involved visits to and from local communities in the Region, including interested indigenous people observing our monitoring and research activities both in the field and in the laboratory.

SSD staff continued to collect bush tucker, complete permit applications and make regular contact with local Aboriginal organisations and communities.

The CLO liaises with stakeholders on a regular basis, including Energy Resources of Australia Ltd (ERA) community relations staff, Parks Australia staff, local Aboriginal corporations, the Northern Land Council and indigenous residents, to ensure there is a continuous flow of information on current SSD activities and liaison with local people to explain SSD projects and seek permission to carry out research on indigenous land.

Regular meetings with the Gundjeihmi Aboriginal Corporation (GAC) have discussed matters such as employment, day labour payment details and updating of GAC's employment register. In the period, Mirarr people have worked 53 days on research and monitoring projects, including bush tucker collection, field equipment maintenance and Jabiru Field Station ground and facilities maintenance.

Further indigenous communication and liaison activities during the reporting period included hosting information sessions 'on country' while research projects are being carried out in order to engage indigenous people and visiting indigenous outstations to discuss SSD projects. Permits for access to Aboriginal lands, such as Jabiluka permits, and other research work on Aboriginal lands continues with stakeholder and TO consultations.

Figure 5.1 **H**elping out with site regeneration at Jabiru Field Station

Figure 5.2 Collecting bushtucker in the Alligator Rivers Region

Figure 5.3 ***eriss*** staff and day labour involved in the Mudginberri mussel collection

Day labourers made a major contribution to the regeneration of the Jabiru Field Station compound and continue to assist with grounds maintenance. During 2010–11, the centre of the Field Station's compound was transformed. What was formerly the site of a demountable building was regenerated into a park-like area. Much of the work was undertaken by Gundjeihmi Aboriginal Corporation day labour who were able to see the transformation right through from start to finish.

Bush tucker was collected alongside the Arnhem Highway out to the South Alligator River, and adjacent to and on the mining lease. The samples were sent to the Environmental Radioactivity group in ***eriss*** for analysis and the results are used in the bush tucker database. Collecting bush tucker gives indigenous people the opportunity to discuss any concerns they have about mining and the local environment, and the travel time affords SSD staff opportunities to talk about SSD's role with the indigenous workers.

In October, Gundjeihmi workers helped collect mussels at Mudginberri billabong for the Environmental Radioactivity Bioaccumulation Project. The mussel collection at Mudginberri provided an opportunity to invite the local community to see the work in progress and to attend a BBQ so we could discuss the project with them.

eriss has been conducting research into endemic isopods (many of them hitherto undescribed) around the Gunbalanya area for several years. SSD researchers have sought to name the isopods using traditional names relating to the waterholes and springs where they have been found. The locations were in the stone country and some are rarely visited. Photos and descriptions of the places failed to positively identify the locations so the traditional owners accompanied SSD communication staff to the sites to establish the correct names in the local language.

5.2.2 Research protocols for Kakadu National Park

Details of proposed 2011–12 SSD research and monitoring activities within Kakadu National Park were circulated to relevant stakeholders in April 2011, 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.

5.2.3 Internal communication

The division supports effective internal communication between staff of all levels through regular staff and section meetings. Various working groups (eg Monitoring Support, Spatial Users and Technical Data Management) are convened as required to address important strategic business issues within the division.

IiP (Investor in People) activities undertaken during 2010–2011 are described in Chapter 6.

SSD's internal newsletter *Newsbrief* is produced fortnightly and is available on the Intranet. It provides information on current divisional activities in the Darwin and Jabiru offices, including articles on research, conferences attended, field trips and communication activities. Each SSD program reports on a selection of activities twice a year.

SSD continues to make extensive use of the Intranet. More than half of SSD staff have received intranet training, and sections manage their own uploads and edits. The Intranet is used for new staff inductions and for important internal announcements.

The Intranet continues to be used for sharing maps and for staff access to continuous monitoring data from our telemetered stations in the Magela Creek catchment (see previous year's annual report for more information).

5.2.4 Communication with technical stakeholders and the general community

Coordination of other communication and general public relations activities was facilitated by SSD staff throughout the year.

Two meetings of the Alligator Rivers Region Advisory Committee (ARRAC) and one meeting of the Alligator Rivers Region Technical Committee (ARRTC) were held during the period. Further information on ARRAC and ARRTC activities is provided in Chapter 4 of this report.

Indigenous stakeholders and the traditional owners of Kakadu National Park are also kept informed on SSD activities through their involvement in these committees. Gundjeihmi Aboriginal Corporation and the Northern Land Council are both members of ARRAC.

A focus for liaison activities has been to inform Kakadu National Park Rangers what SSD has been doing. There have been several new initiatives as well as some proven strategies used to communicate the SSD message. Staff have been travelling to each district Ranger Station to give a short presentation, enter into some discussion and report any concerns the Rangers may have. So far, issues that have been raised included the impact mining has had on the Jabiluka Billabong and the food it provides to local indigenous people, and an issue relating to environmental damage from an old mine that sits outside the boundary of Kakadu National Park. This concern was passed to the Northern Territory Department of Resources who acted on the report. These talks will be conducted with the operational parks staff based in Jabiru including the natural resource management group and the weeds and feral animal management team. The talks aim to build SSD's profile with the on-ground staff in Kakadu and promote open communication and reassurance that independent research and monitoring is being conducted to protect the region from the effects of uranium mining.

Involvement in the Mahbilil festival is one of the major communication activities in our year. A few years ago the Jabiru Town Council and then the Mirarr people took over the running of the Wind Festival as it used to be known. 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. At some point the name was changed to Mahbilil, the Gundjeihmi name of a myth related to the afternoon breeze that occurs in Gurrung (the local calendar name for that time of year). SSD again hosted a booth – the displays focussed on water and air monitoring, spatial science and mapping and regeneration and the trial landform.

Locals and visitors browsed the displays, dabbled in the macroinvertebrate trays, and discussed science topics related to our role with our staff. It is important that SSD continues to have a presence at Mahbilil to respond to community concerns and provide reassurance to the public.

Figure 5.4 Images from Mahbilil 2010

Each year Parks Operations and Tourism Branch, in conjunction with the West Arnhem College, runs a Junior Ranger Program for schoolchildren. 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 and SSD's Jabiru Field Station traditionally provides the tutorial and venue. This year's activity simulated the monitoring of fish in channel billabongs and involved counting fish in a fish tank. The students counted (monitored) each type of fish and took a temperature reading, the data were graphed along with some mock data from the channel billabong program over the previous five years, and the junior rangers were able to conclude from their research that a possible rise in temperature had increased the number of fish in the tank.

World Wetlands Day is held on 2 February each year. This year SSD and Parks combined to celebrate the day and presented school talks on the importance of wetlands and the significance of the Magela floodplains as a recognised wetland under the international Ramsar Convention. This was followed by a street stall in Jabiru along with other organisations to promote the day and highlight each group's work and association with wetlands.

Figure 5.5 (left) SSD staff and young school students at Jabiru School for the world wetlands day activity and (right) showing the students some preserved water bugs

SSD was invited by Group Training NT to host a stall at a Schools Careers Expo 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.

These activities served to enhance awareness and understanding of the work and role of the division and to raise SSD's profile within the local and wider community. These events also enabled SSD staff to provide information to local residents in a 'hands-on' practical manner.

5.2.6 Australia Day awards

Andrew Esparon received a Department of Sustainability, Environment, Water, Population and Communities Australia Day Award this year. Andrew's award was for the development and implementation of an Electronic Document and Records Management System (EDRMS) using the program SharePoint to solve a business critical need for SSD. Andrew's excellent technical execution coupled with active engagement with end users resulted in a platform that was intuitive to use and rapidly adopted. Department IT/IM specialists regard this as a model for the development of a SharePoint-based EDRMS for the department as a whole.

5.3 National and international environmental protection activities

5.3.1 The IAEA's EMRAS II program

The International Atomic Energy Agency's (IAEA) EMRAS (Environmental Modelling for Radiation Safety) program was launched in 2003, to continue the work of previous international programs in the field of radioecological modelling. The overall objective of the program was '*to enhance the capabilities of Member States to model radionuclide transfer in the environment and, thereby, to assess exposure levels of the public and biota 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*'. EMRAS was followed by EMRAS II, which was established in January 2009 and will continue to 2011, with a follow up program to be launched in March 2012.

The work of the EMRAS II program is gathered into three themes, under which nine Working Groups are established. Dr Andreas Bollhöfer from SSD has attended meetings of Working Groups 4 (Biota Modelling) and 5 (Wildlife Transfer Coefficient Handbook) in September 2010, and the Third EMRAS II Technical Meeting, at the IAEA headquarters in Vienna in January 2011. He has presented radionuclide uptake data gathered by SSD over the past 30 years, and contributed data from the Alligator Rivers Region to be included in the Wildlife Transfer Coefficient Handbook. The Handbook is due to be released as an IAEA Technical Report in 2011. ***eriss*** also contributed to a comparative wetland biota dose modelling exercise of Working Group 4 of the EMRAS II program, which was presented at the Working Group 4 meeting in Hamilton, Canada, in June this year. SSD will continue its involvement with the EMRAS II program in 2011–12, which provides an international forum of research and information exchange on developments of models and approaches to assess the transfer of radionuclides in the environment and radiological impact to man and the environment.

5.3.2 Revision of National Water Quality Guidelines

Two ***eriss*** research scientists, Dr Rick van Dam and Dr Chris Humphrey, continued to provide the technical coordination, and undertake other roles, for the current revision of the *2000 Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (the Guidelines). The Guidelines, which constitute Guideline 4 of the National Water Quality Management Strategy, represent a key source document in Australia and New Zealand for managing natural water quality and protecting aquatic ecosystems. Six Working Groups have been established to oversee revisions to specific parts of the Guidelines. By 30 June 2011, the majority of Phase 1 tasks (developing a detailed scope of works for the main revision phase – ie Phase 2, and undertaking high priority straightforward revision tasks) had been completed. The technical coordination role being undertaken by ***eriss*** provides assurance that cross-cutting issues are addressed and integrated across the activities of the Working Groups. Drs van Dam and Humphrey are also members of four of the six Working Groups. ***eriss*** will continue to work with SEWPaC's Water Reform Division during 2011–12 on this project as technical coordinators responsible for overall project management/coordination of the Phase 2 revision activities.

5.3.3 Basslink

SSD staff Drs Chris Humphrey and Mike Saynor, as Australian Government representatives on the Gordon River Scientific Reference Committee (GRSRC), provided comment on the 2009–10 Gordon River Basslink Monitoring Annual Report which evaluates the monitoring program after the fourth year of Basslink operations. In the 2010–11 reporting period, an SSD GRSRC member also accompanied Hydro Tasmania staff on a Gordon River site familiarisation visit and SSD members also assisted SEWPaC Heritage Division in answering parliamentary questions related to Basslink.

5.3.4 Northern Australian Water Futures Assessment (NAWFA)

The Northern Australia Water Futures Assessment is a multidisciplinary program being managed by the Environmental Water and Natural Resources Branch within SEWPaC. The objective is to provide an enduring knowledge base to inform development of northern Australia's water resources, so that development proceeds in an ecologically, culturally and economically sustainable manner.

During 2010–2011, Dr Renée Bartolo from ***eriss*** continued to assist the department in the Knowledge Base working group convened to address the priority areas being covered by the Assessment.

Project work is being undertaken by Dr Bartolo for the Ecological Program in collaboration with a team of researchers led by the University of Western Australia. The project is titled 'Assessing the likely impacts of development on aquatic ecological assets in northern Australia' and builds on the ecological risk assessments previously undertaken by ***eriss*** staff for the Tropical Rivers Inventory and Assessment project (TRIAP).

More information about the NAWFA and the products that are being produced by the program can be found at www.environment.gov.au/water/policy-programs/northern-australia/index.html.

5.3.5 Tropical Rivers and Coastal Knowledge Research Program

The Tropical Rivers and Coastal Knowledge Research Program (TRaCK) research hub headquartered at Charles Darwin University (CDU) in Darwin is one of the major components of the Commonwealth Environmental Research Facility (CERF) program being managed by SEWPaC. Staff from ***eriss*** contributed to the 'Material Budgets' theme, through flood inundation mapping for the Mitchell and Daly River catchments.

eriss staff will be involved in collaborative projects focused in the Alligator Rivers Region in the coming year through the newly formed National Environmental Research Program (NERP) Northern Australia Hub, also headquartered at CDU. The NERP is also being managed by SEWPaC and is the follow-on program from CERF.

More information about NERP can be found at www.environment.gov.au/about/programs/nerp/index.html.

5.3.6 Kakadu Research Advisory Committee

The Director of ***eriss*,** Dr David Jones, and the leader of the Spatial Sciences and Data Integration Group, Dr Renée Bartolo, are members of the Kakadu Research Advisory Committee. Members of the committee are appointed by the Parks Board of Management to advise the Board on matters relating to the conduct and scoping of research activities in the Park. One meeting (16–18 May 2011) of the committee was held during the period. The focus of the meeting was to identify the key values of the Park that would provide the strategic framework for prioritising research activities for the Park, and reviewing changes proposed for the assessment and approvals process for applications to conduct research in the Park. It was agreed that at least one (and usually two) meeting of the committee be held each year.

5.3.7 EPBC compliance audits

oss staff provided assistance to the Environment Assessment and Compliance Division of the department in the conduct of compliance audits against approval conditions issued under the *Environment Protection and Biodiversity Conservation Act*, including conducting an audit of the Browns Oxide Project in May 2011.

5.3.8 Rum Jungle collaboration

The Rum Jungle legacy uranium and copper mine site is located close to the town of Batchelor, approximately 80 km south of Darwin. Rehabilitation work was initially undertaken between 1982 and 1986. However, the site has remained an ongoing source of metal load to the Finniss River, as well as being in a state that is not currently suitable for return to the local traditional owners. 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 consists of representatives from the NT Department of Resources, NT Department of Natural Resources, Environment, the Arts and Sport (NRETAS), Australian Government Department of Resources, Energy and Tourism (DRET), the Northern Land Council (NLC) and the Supervising Scientist Division (SSD). Mr Alan Hughes (Supervising Scientist) and Dr David Jones (Director ***eriss***) are the SSD representatives.

In the 2009 federal budget an allocation of $7 M of special purpose funds was made to progress assessment of the site over a period of four years, with the objective of developing a costed rehabilitation plan consistent with contemporary best practice. The program is being managed by the NT Government Department of Resources (DoR) under the terms of a ‘National Partnership Agreement (NPA) on the management of the former Rum Jungle mine site’ between DoR and the Australian Government Department of Resources, Energy and Tourism. The RJTWG provides technical advice and oversight of the projects commissioned to address the terms of the NPA. Details of activities under the NPA are reported to the RJTWG. Background material and project updates have been published by DoR 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/index.cfm?header=Rum%20Jungle%20Home.

During 2010–11, SSD produced a report for the RJTWG on the results from orientation soil sampling of some surficial radiological anomalies located at and downstream of the Rum Jungle site, and provided advice on the content of scopes of work for several projects that were put out to tender, assistance with the tender selection process when requested by DoR, and comments on draft project reports submitted by consultants.

5.3.9 Other contributions

Dr David Jones continued to provide an independent review function for the Murray Darling Basin Authority and for the department on the development of national guidance for the assessment and management of inland acid sulfate soils. He was also a member of the organising committees for the EnviroTox 2011 (see below) and the 7th Australian Acid and Metalliferous Drainage conferences, held in Darwin in April and June 2011, respectively.

Supervising Scientist Mr Alan Hughes is a member of the Mt Todd Minesite Rehabilitation Reference Group that has been established by the Northern Territory Department of Resources. 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.

Mr Hughes has been appointed by the Northern Territory Minister for Natural Resources, Environment and Heritage as a member of the Water Resources Review Panel, under the NT *Water Act* as the representative under the category of Mining. The Review Panel is required to advise 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. Mr Hughes participated in one panel review case during the year.

Dr Renee Bartolo continued as a Director of the Surveying and Spatial Sciences Institute Board. Other roles within the Institute included Remote Sensing and Photogrammetry Commission Chair. She was also a member of the organising committees for the 15th Australasian Remote Sensing and Photogrammetry Conference (held in Alice Springs in September 2010), the 34th International Symposium for Remote Sensing of the Environment (held in Sydney in April 2011) and NT Spatial 2011 (held in Darwin in February 2011).

5.4 Workshops and reviews

5.4.1 *eriss* Planning and Communication Workshop

Every year ***eriss*** undertakes a communication and planning workshop as a key forum for communication between all eriss staff. The workshop provides the opportunity for review of past and current work programs, and for input by staff into the strategic planning process for the next financial year. The most recent workshop was held on 9 February 2011 and was divided into three parts:

i an overview of the strategic drivers of the work of the Institute;

ii outcomes of the core research and monitoring program, and the importance of these to the role of SSD, with views on future projects and directions; and

iii an overview of the external projects program of the Institute.

The presentations and synthesis of discussions of the day have been captured in Internal Report 587.

5.4.2 Independent review of *eriss* Ecotoxicology and Aquatic Ecosystems Protection Programs

The research and monitoring activities of ***eriss***'s Ecotoxicology and Aquatic Ecosystems Protection (AEP) Programs were independently reviewed in 2011 by Dr Donald Baird, an internationally recognised expert in the fields of ecotoxicology and freshwater ecology from the Canadian Rivers Institute, University of New Brunswick, and Environment Canada. The review, conducted from April to July 2011, included initial background reading, two days (14–15 April) of face-to-face discussions with the scientific staff from the Ecotoxicology and AEP Programs, and submission of a subsequent report with recommendations.

Whilst acknowledging the Programs' current research and monitoring activities as being world-class, the findings of the review also provided suggestions for internationally new and emerging approaches that would strengthen the future strategic development of both Programs. The review document will be published as an Internal Report.

5.5 Science communication (including conferences)

Results of research and investigations undertaken by the Supervising Scientist Division 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 journals and reports including the Supervising Scientist and Internal Report series – for detailed reporting on scientific projects – and the Supervising Scientist Note series used to showcase specific projects to a wider audience. Other media such as posters and educational or promotional materials are also produced 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 web site – the move towards electronic distribution supports the department's policy of reducing its environmental footprint.

A review of the web site is conducted annually so that all information remains current and relevant. The web site subscription facility – incorporating an automatic email notification when a new SSD publication is released – continues to improve the level of service to our stakeholders.

SSD staff presented papers at a number of important national and international conferences during the reporting period as follows:

Conference	Place/date (no. papers)
EnviroTox 2011: Sharing knowledge for a healthier environment (Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter)	Darwin NT, April 2011 (11 plus 1 poster)
11th South Pacific Environmental Radioactivity Conference	Surfers Paradise, Qld, August/ September 2010 (4)
NT Spatial 2011 Conference	Darwin NT, February 2011 (4)
AusIMM Uranium Conference	Perth WA, June 2011 (3)
15th Australian Remote Sensing and Photogrammetry Conference	Alice Springs NT, September 2010 (2)
U2010 Conference	Saskatoon Canada, August 2010 (2)
Meeting of state and national regulators	Saskatoon Canada, August 2010 (1)
EMRAS II Transfer Group meeting (WG5), International Atomic Energy Agency	Vienna, Austria, September 2010 (1)
US EPA 12th Superfund National Radiation Meeting	Savannah Georgia, USA, March 2011 (1)
Delegation of members of the European Union Parliament	Parliament House, Canberra ACT, February 2011 (1)
7th Australian Workshop Acid and Metalliferous Drainage	Darwin NT, June 2011 (1)
International Working Forum for the Regulatory Supervision of Legacy Sites (RSLS)	Vienna Austria, 11–15 October 2010
2010 IEEE International Symposium on Geoscience and Remote Sensing	Honolulu USA, July 2010 (1)
Thresholds and regime shifts in Australian freshwater ecosystems, Australian Centre for Ecological Analysis and Synthesis (ACEAS) Workshop for Freshwater Ecosystems Working Group	University of Queensland, St Lucia, Qld, May 2011 (1)
Water Management in Mining	Perth WA, December 2010 (1)
Australian and New Zealand Geomorphology Group Conference	Oamaru, South Island, New Zealand, January/February 2011 (1)
34th International Symposium Remote Sensing of Environment	Sydney, April 2011 (1)
31st Annual meeting SETAC North America	Portland, Oregon, November 2010 (1)
Australian Water Association NT Branch Annual Conference	Darwin NT, October 2010 (1)

EnviroTox 2011 conference

This conference was held in Darwin on 17–20 April 2011 under the joint banners of two professional societies – the Royal Australian Chemical Institute (RACI) and the Australasian Chapter of the Society for Environmental Toxicology and Chemistry (SETAC-AU). The conference was Co-chaired by Dr Rick van Dam (***eriss***) and Ms Michelle Iles (Energy Resources of Australia Ltd), while the Local Organising Committee of 14 (11 of whom are pictured in Figure 5.6) included six other ***eriss*** staff.

Figure 5.6 Members of the EnviroTox 2011 Local Organising Committee. ERISS staff unless otherwise stated. Back row from left: Sue Codi (Australian Institute of Marine Science), Kim Cheng, Nicole Jacobsen (Energy Resources of Australia Ltd), Michelle Iles (Energy Resources of Australia Ltd), Melanie Trenfield, Paul Davey (Sinclair Knight Merz); Front row from left: Dr David Jones, Dr Andrew Harford, Alicia Hogan, Claire Costello, Dr Rick van Dam.

Around 220 delegates participated in a program comprising 120 oral presentations, including three Plenary and six Keynote lectures, and 30 poster presentations. In addition to the strong domestic support, over 20 international scientists attended, from Canada, China, USA, Fiji, New Zealand, South Africa, South Korea and the UK.

SSD’s contribution to the scientific program was also significant, with ***eriss*** staff being involved in 10 oral presentations (see Appendix 3), eight of which were presented by ***eriss*** staff. The conference abstract book can be downloaded from the EnviroTox2011 web site (http://www.envirotox2011.org/images/stories/envirotox %20book%20-%20web.pdf).

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 allowing the Supervising Scientist Division to maintain its profile as a part of the broader scientific and technical community.

eriss has continued to contribute towards the Kakadu National Park Landscape Change Symposia series being run by Parks Australia (see last year’s annual report for more information on this project). The remaining title, ‘Symposium 5: Feral animal management’, has now been published online as IR568 (www.environment.gov.au/ssd/publications/ir/index.html).

A full list of papers and reports published during 2010–11 is provided in Appendix 2. Papers presented at national and international conferences are listed in Appendix 3.

SSD hosts researchers and visitors from other organisations to undertake collaborative funded projects, for sabbatical periods, or to present seminars or training workshops (Table 5.1).

TABLE 5.1 RESEARCHERS AND OTHER VISITORS, 2010–11

Activity	Visitor/organisation	Date
Magela floodplain vegetation mapping using WorldView-2 satellite imagery	Simon Oliver (ERIN, SEWPaC)	6–17 June 2011
Impact of extreme rainfall events on stability of the rehabilitated Ranger landform using the CAESAR Landform Evolution Model	Professor Tom Coulthard, University of Hull	26 July – 6 August 2010
Impact of extreme rainfall events on rehabilitated landform – application of CAESAR to mine-impacted catchments and erosion monitoring/modelling activities (Tin Camp Creek)	Associate Professor Greg Hancock, The University of Newcastle NSW	6–10 June 2011
Face-to face visit for review of research and monitoring activities of ***eriss***'s Ecotoxicology and Aquatic Ecosystems Protection (AEP) Programs	Dr Donald Baird, Canadian Rivers Institute, University of New Brunswick, and Environment Canada	14–15 April 2011
Part of Uranium mining regulation study tour sponsored by the IAEA	Humberto Nievas from the Argentine *Comision Nacional de Energia Atomica*,	13–17 September 2010

In 2010–11, ***eriss*** staff supervised two post-graduate research projects:

- The influence of dissolved organic carbon on the bioavailability and toxicity of metals to tropical freshwater biota (PhD, The University of Queensland) (thesis has been submitted and is under examination)
- An evaluation of image and field data for vegetation community mapping in tropical savannas (PhD, The University of Queensland)

6 ADMINISTRATIVE ARRANGEMENTS

6.1 Human resource management

6.1.1 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.

6.1.2 Structure

The Supervising Scientist Division consists of two branches, the Office of the Supervising Scientist and the Environmental Research Institute of the Supervising Scientist.

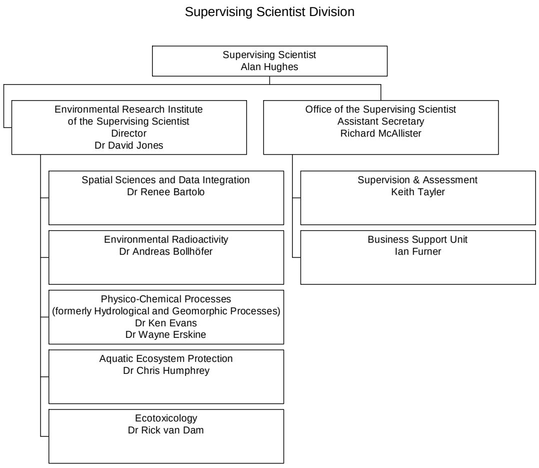


Figure 6.1 Organisational structure of the Supervising Scientist Division (as at 30 June 2011)

The Office of the Supervising Scientist (***oss***) is responsible for supervision, assessment, policy, information management and corporate support activities. Mr Richard McAllister, Assistant Secretary, is the ***oss*** Branch Head.

The Environmental Research Institute of the Supervising Scientist (***eriss***), managed by Dr David Jones, is responsible for scientific research and monitoring activities.

During the year the Hydrological and Geomorphic Processes program was renamed the Physico-Chemical Processes program to reflect the change in focus for the program. Dr Wayne Erskine also succeeded Dr Ken Evans as the leader of the program.

Average staffing numbers for 2009–2010 and 2010–2011 are given in Table 6.1.

TABLE 6.1 STAFFING NUMBERS (1) AND LOCATIONS

	2009–2010	2010–2011
Darwin	43.0	43.0
Jabiru	7.5	8.0
Total	50.5	51.0

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

6.1.3 Investors in People

The Supervising Scientist Division (SSD) has developed a culture that embraces Investors in People initiatives. The framework is embedded into strategies, policies and procedures implemented in the workplace.

The SSD IiP program is led through 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.

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 indicators within the IiP framework. 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.

Staff have been encouraged and supported by management in the development of skills through training, attendance at conferences and internal opportunities to act in higher level positions. There has also been a significant investment in leadership training and development for all executive level staff. Through the Performance Development Scheme, staff identify training requirements to help deliver their work plan outcomes. 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.

Effective communication has also been an integral part of achieving outcomes set by the organisation. SSD continues to produce a fortnightly staff newsletter, *Newsbrief*, which 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 2010–11, the health and wellbeing program offered staff access to health screenings, vaccinations for influenza, hepatitis and tetanus, team pedometer challenges, quiz events, and internal health and wellbeing seminars on respect and courtesy in the workplace, dealing with stress, conflict resolution and tools for assertive and effective communication. Display boards providing staff with information on health and wellbeing issues in the workplace have been well received by staff.

6.2 Occupational Health and Safety

SSD continued to maintain a strong commitment to Occupational Health and Safety (OH&S) during 2010–11 with a focus on working towards the introduction of the new Harmonisation legislation on 1 January 2012. This included a new contractor management process whereby all contractors were required to comply with a range of rights and obligations outlined in a comprehensive contractor management manual.

Promoting and encouraging the use of the incident and hazard reporting system saw an increase in reporting but an overall reduction in identified hazards. There was only one dangerous occurrence notification to Comcare – it did not require investigation. SSD also achieved a ‘zero harm’ rating for the year with no claims submitted.

The Occupational Health and Safety Committee (OHSC) met regularly and was responsible for reviewing and updating a number of guidelines related to road travel, field work, risk assessment, people movements, emergency evacuation and crocodile safety as well revising the current terms of reference for the committee to align with the new governance requirements of the department.

The risk register was reviewed by senior management and further controls applied to reduce or eliminate high or extreme risks. One key risk reduction strategy was the change in arrangement for delivery of hazardous and bulky goods that has eliminated the need for vehicles to park in the vicinity of the main administration building.

OH&S site inspections were undertaken every three months with senior managers required to take the lead in this activity to ensure a clear understanding of their work environment and any safety concerns of staff.

SSD is procuring new chemical management software that will enable greater control of the chemicals on site. The annual chemical audit has been undertaken to ensure compliance with the ***eriss*** labelling protocols and legislative compliance – only a few non compliances were identified.

In 2010–11 there was an emphasis on safety education for staff including:

- health and wellbeing examinations
- fire extinguisher usage
- understanding risk management

- respect and courtesy workshops
- 4WD training for all terrain vehicle operation
- workplace contact officer (WCO) roles

In addition, the OHS & Facilities Manager completed a Certificate IV in Training and Assessment in order to establish internal training programs that will ensure SSD is well placed to meet its OH&S obligations.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) renewed SSD's licence to hold radioactive and non-ionising radiation sources following a comprehensive audit of SSD's general control, safety and management plans that found two non-conformances that were subsequently rectified.

6.3 Finance

The Supervising Scientist Division is part of the Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) 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 6.2.

TABLE 6.2 SUMMARY OF DIRECT PROGRAM EXPENSES

PBS Outcome 1	2009–2010	2010–2011
Program 1.2 – Environmental Regulation, Information and Research	$8 412 344	$8 583 500
Total*	$8 412 344	$8 583 500

* Excludes departmental corporate overheads of $4 007 235 in 09–10 and $4 354 758 in 10–11.

6.4 Facilities

6.4.1 Darwin facility

The majority of the Supervising Scientist Division's staff are situated at the Department of Sustainability, Environment, Water, Population and Communities Darwin facility adjacent to the Darwin International Airport. This facility consists of office accommodation and laboratories. During the year no major works were commissioned, however there are still ongoing problems with air-conditioning and moisture intrusion into the laboratories that are expected to be rectified prior to lease renewal in mid 2012.

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.

6.4.2 Jabiru Field Station

A Field Station at Jabiru is maintained to support the activities of the Supervising Scientist Division. The staff consists of the monitoring team that carry out the Supervising Scientist's environmental monitoring program, an employee who is responsible for delivering the Supervising Scientist's community liaison program in Jabiru, an employee who undertakes administrative and financial duties, and the Field Station Manager, who has overall responsibility for managing the Field Station as well as supervisory and inspection responsibilities.

Figure 6.2 Reinstatement of area after building removal

Following demolition or relocation of unused buildings all underground utilities have been removed or decommissioned and reinstatement of the vacant area has been completed. Works have also been undertaken at the Field Station to replace the air-conditioning in the administrative building and upgrade the electrical system, lighting and ventilation in the workshop.

6.5 Information management

Information management activities provide support to staff based in Darwin and the Jabiru Field Station through library services and the co-ordination of records management activities. The library continued to provide services to staff including loans, reference services, reader education, and inter-library loans. Integration of the SSD Library collection into the department's catalogue has continued.

File and document management activities included creating a new data structure for the new Microsoft-based electronic document management system, as well as paper file creation and maintenance.

6.6 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 2010–11.

6.7 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 2010–11.

6.8 Environmental performance

The Supervising Scientist Division 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 2010–11 annual report.

6.8.1 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.

6.9 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 progress report for the project 'Larval fish for toxicity tests at ***eriss***' (ref no 97016) was submitted to the CDU AEC and approved on 8 June 2011. Individual permits for ***eriss*** staff conducting research with fish were also granted at this time. This project is due for renewal during June 2012 and the individual permits are valid for two years. No fish were collected for the project 'Monitoring mining impact using the structure of fish communities in shallow billabongs' (ref no A09001) and the approval for this project expired on 27 February 2011. A new project approval for this work will be submitted to the CDU AEC when required.

The number of fish used in toxicity tests at ***eriss*** was reported in July 2011 to the Northern Territory Government, as part of our licence requirements granted by them permitting the use of animals for research purposes.

Table 6.3 provides information on new applications, renewals of approvals and approval expiries for projects during 2010–11.

TABLE 6.3 ANIMAL EXPERIMENTATION ETHICS APPROVALS

Project title	Ref no	Initial submission	Approval/latest renewal	Expiry
Larval fish toxicity testing at ***eriss***	97016	26 May 1997	18 June 2010	18 June 2012
Monitoring mining impact using the structure of fish communities in shallow billabongs	A00028/ A09001	25 Sep 2000	8 Mar 2009	27 Feb 2011

APPENDIX 1 ARRTC KEY KNOWLEDGE NEEDS 2008–2010: 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 attributes 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

'Key Knowledge Needs 2008–2010: Uranium mining in the Alligator Rivers Region' is based on and supersedes a predecessor document, 'Key Knowledge Needs 2004–2006: Uranium mining in the Alligator Rivers Region'. KKNs 2004–2006 remained the operative set during their review and the development of KKNs 2008–2010.

While some KKNs remain essentially unchanged, others contain revised elements or are new in their entirety. Care should be exercised if using KKN numbers alone as a reference because some continuing KKNs have changed numbers in the revised document.

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, sulfate 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: KKN 5.4 will be reviewed at the November 2011 sitting of ARRTC in light of the recent inclusion of Koongarra on the World Heritage register*.]

APPENDIX 2 PUBLICATIONS FOR 2010–2011

Published[2]

Bartolo R, van Dam R & Bayliss P 2012. Regional ecological risk assessment for Australia's tropical rivers: Application of the Relative Risk Model. *Human and Ecological Risk Assessment.* (in press)

Bartolo R, Ward D & Jones D 2010. Flood inundation mapping of tropical river catchments in northern Australia using optical and Alos-Palsar data. In *Proceedings 15th Australian Remote Sensing and Photogrammetry Conference (ARSPC)*, 14–16 September 2010, Alice Springs, Published online at www.15.arspc.com/proceedings

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Bollhöfer A, Brazier J, Humphrey C, Ryan B & Esparon A In press. A study of radium bioaccumulation in freshwater mussels, *Velesunio angasi*, in the Magela Creek catchment, Northern Territory, Australia. *Journal of Environmental Radioactivity*: Available online 28 April 2010 doi:10.1016/j.jenvrad.2010.04.001.

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Harford AJ, Hogan AC, Tsang JJ, Parry DL, Negri AP, Adams MS, Stauber JL & van Dam RA 2011. Effects of alumina refinery wastewater and signature metal constituents at the upper thermal tolerance of: 1. The tropical diatom *Nitzschia closterium*. *Marine Pollution Bulletin* 62, 466–473.

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

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APPENDIX 3 PRESENTATIONS TO CONFERENCES AND SYMPOSIA, 2010–2011[3]

Akber R, Lu P & Bollhöfer A 2010. Distribution of radioactivity in the land application areas at Ranger Uranium mine. Paper presented at the 11th South Pacific Environmental Radioactivity Conference, 31 August – 3 September 2010, Surfers Paradise, Gold Coast, Australia.

Bartolo R, Staben G, Beraldo A, Lowry J & Kirrilly Pfitzner 2011. A systematic high resoloution remote sensing capture for the Magela Creek Catchment: A case study using WorldView 2. Paper presented at NT Spatial 2011 Conference, 2–4 February 2011, Darwin NT.

Batley G, Braga O, Chapman J, Fox D, Hickey C, Stauber J, Van Dam R & Warne M 2011. Recommended revisions of the Australian and New Zealand Water Quality Guidelines for toxicants. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 118.

Bollhöfer A, Esparon A, Pfitzner K, Beraldo A 2011. Groundtruthing historic airborne gamma surveys to determine pre-mining radiological conditions at Ranger Mine, Northern Territory, Australia. Paper presented at AusIMM Uranium Conference, Perth Australia 8–9 June 2011.

Bollhöfer A, Ryan B & Doering C 2010. The development of a concentration ratio database for bushfoods in Northern Australia. Paper presented at the EMRAS II Transfer Group meeting (WG5), 6–9 September 2010, International Atomic Energy Agency, Vienna, Austria.

Buckle D, Humphrey C & McGuinness K 2011. Comparison of ANOVA and PERMANOVA analysis techniques to stream community data for BACI-type impact detection designs. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 09.

Bush M 2010. Stakeholder cooperation: Regulating a uranium mine with multiple statutory approvals. Paper presented at U2010, Saskatoon Canada, 15–18 August 2010.

Bush M 2011. Uranium legacies: regulation, stakeholders and resources. Australian case studies. Paper presented at US EPA 12th Superfund National Radiation Meeting, Savannah Georgia, USA, 21–25 March 2011.

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3 Presentations to conferences and symposia that have been externally published in 2010–11 are included in Appendix 2.

Bush M 2011. Uranium legacies: regulation, stakeholders and resources. Australian case studies. Presentation to the International Working Forum for the Regulatory Supervision of Legacy Sites (RSLS), Vienna Austria, 11–15 October 2010.

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Frostick A, Bollhöfer A & Parry D 2010. Assessment of stable lead isotope ratios, radionuclides and trace metals from billabong sediments in the vicinity of a uranium mine in northern Australia. Paper presented at 11th South Pacific Environmental Radioactivity Conference, 31 August – 3 September 2010, Gold Coast, Australia.

Frostick A, Bollhöfer A & Parry D 2011. Trace metal and lead isotope dispersal from a decommissioned gold mine in the Northern Territory, Australia. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 22.

Frostick A, Turner K & Tayler K 2011. Implementing a best practice water quality monitoring program. Paper presented at AusIMM Uranium Conference, Perth Australia 8–9 June 2011.

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Hughes A 2010. The Supervising Scientist Division and regulation of uranium mining in Australia. Paper presented at a meeting of state and national regulators, Saskatoon, Canada, 19 August 2010.

Hughes A & Colreavy M 2011. Regulation and environmental management of uranium mining. Paper presented to a delegation of members of the European Union Parliament, 22 February 2011, Parliament House, Canberra ACT.

Humphrey C 2011. Thresholds and regime shifts in Australian freshwater ecosystems: A Wet-dry tropical perspective. Paper presented at *Thresholds and regime shifts in Australian freshwater ecosystems*, Australian Centre for Ecological Analysis and Synthesis (ACEAS) Workshop for Freshwater Ecosystems Working Group, University of Queensland, St Lucia, Brisbane, 23–25 May 2011.

Humphrey C, Davies C & Buckle D 2011. Drawing inference in in-stream toxicity monitoring tests used to assess mining impact in a tropical stream. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 55.

Humphrey C, Batley G, Bennett J, Davis J, Edlington C, Fox D, Hunt A, Maher B & Van Dam R 2011. An overview of key features of the revision of the *Australian and New Zealand guidelines for fresh and marine water quality* affecting aquatic ecosystems. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 117.

Jones D 2010 Understanding sustainable water management in decommissioning and rehabilitation. Paper presented at Water Management in Mining, 1–2 December 2010, Perth WA.

Jones D, Humphrey C, Van Dam R, Harford A, Turner K & Bollhoefer A 2011. Integrated water quality monitoring for an australian uranium mine a best practice case study. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 12.

Lowry J, Beraldo A & Coulthard T 2011. Integrating TLS data with a LEM to assess soil erosion. Paper presented at NT Spatial 2011 Conference, 2–4 February 2011, Darwin NT.

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Pfitzner K, Bartolo B, Esparon A & Staben G 2011. Field and laboratory spectrometry for remote sensing applications. Paper presented at NT Spatial 2011 Conference, 2–4 February 2011, Darwin NT.

Saynor M & Lowry J 2011. Trial landform research at the Ranger mine, Northern Territory, Australia. Paper presented at Australian and New Zealand Geomorphology Group Conference, Oamaru, South Island, New Zealand, 31 January – 5 Feb 2011.

Staben GW, Pfitzner K, Bartolo R, Lucieer A 2011. Calibration of WorldView-2 satellite imagery to reflectance data using an empirical line method. Paper presented at 34th ISRSE (International Symposium of Remote Sensing of Environment). 10–14 April 2011, Sydney, Australia.

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Trenfield M, Markich SJ, Ng JC, Noller B & Van Dam RA 2011. The influence of dissolved organic carbon on the speciation and toxicity of aluminium to tropical freshwater organisms. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 45.

van Dam RA 2010. Applications of ecotoxicology for predicting and assessing contaminant impacts on tropical marine environments. Australian Water Association Northern Territory Branch Annual Conference, Darwin, 22 October 2010.

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Warne M, Batley G, Braga O, Chapman J, Fox D, Hickey C, Stauber J & Van Dam R 2011. Proposed changes to methodology for the derivation of toxicant guideline trigger values. Paper presented at *EnviroTox 2011: Sharing knowledge for a healthier environment*. Joint conference of the Royal Australian Chemical Institute and the Society for Environmental Toxicology Australasian Chapter, Darwin NT 17–20 April 2011, Abstract 119.

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Feedback on the Supervising Scientist 2010–11 annual report

We hope we have presented a comprehensive and informative account of the activities of the Supervising Scientist Division during 2010–2011.

If you have any suggestions for Supervising Scientist activities that you'd like to read more about and/or different ways you'd like to see the existing information presented, we would value your feedback. Please send your views by post or by e-mail to the addresses given below.

You can also access this and previous Supervising Scientist annual reports on the Department of Sustainability, Environment, Water, Population and Communities web site:

www.environment.gov.au/about/publications/annual-report/

More Information

More information about Supervising Scientist Division is available at: www.environment.gov.au/ssd/

The full list of Supervising Scientist publications is available at: www.environment.gov.au/ssd/publications

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