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

SUPERVISING SCIENTIST

Annual Report

2011–2012

This report should be cited as follows:

Supervising Scientist 2012. *Annual Report 2011–2012*. Supervising Scientist, Darwin.

ISSN 0 158-4030
ISBN-13: 978-1-921069-20-8

The Supervising Scientist is part of the environmental program of the Australian Government Department of Sustainability, Environment, Water, Population and Communities

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Annual Report address: www.environment.gov.au/ssd/publications/ss11-12/index.html

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

Australian Government

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

16 October 2012

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-fourth Annual Report of the Supervising Scientist on the operation of the Act during the period of 1 July 2011 to 30 June 2012.

Yours sincerely

Alan Hughes
Supervising Scientist

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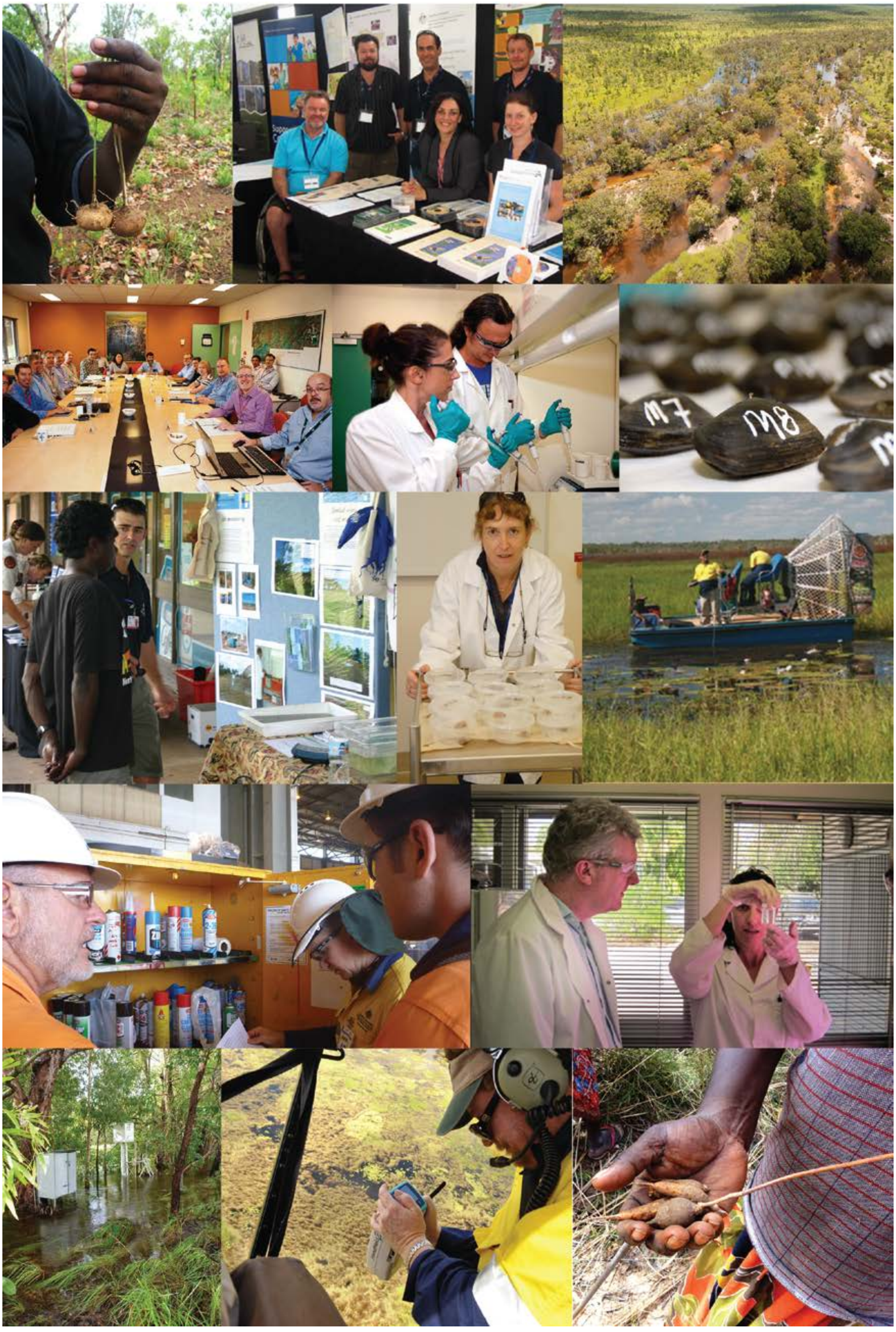

Photos (from top left): Bush potato; NT Spatial 2012 Northern Exposure 'Science and Applications' Conference; Gulungul Creek; ARRAC meeting April 2012; Mudginberri mussel collection analysis; wet acid digest of passive dust samples from Magela Land Application Area; World Wetlands Day 2012 display Jabiru; mussel samples; collecting samples for ecotoxicology monitoring; Ranger audit heavy vehicle workshop; Minister Burke visits SSD; Ngarradj monitoring station, Jabiluka; Magela floodplain spectral sampling; traditional owner holding bush carrot.

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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 through the conduct of research into the possible impact of uranium mining on the environment of the Region.

Ranger is currently the only operational uranium mine in the Region, and is owned and operated by Energy Resources of Australia Ltd (ERA). Production commenced at Ranger in August 1981, and current plans will see open cut mining of the Ranger 3 deposit cease at the end of 2012, with milling of stockpiled ore expected to continue through until 2020. A proposal to develop a heap leach facility at Ranger was lodged in 2009 but was formally withdrawn by ERA in August 2011.

As the time for completion of mining operations draws closer, the work of the Supervising Scientist includes an increased level of engagement with stakeholders in discussions and research activities associated with rehabilitation and closure of the Ranger site. In particular, during the period ERA commenced a major Closure Pre-feasibility Assessment project. The timelines associated with acquiring the specific technical knowledge for this project has resulted in a re-prioritisation and refocusing of a number of the closure-related research projects being conducted by the Supervising Scientist.

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.

The 2011–12 wet season was close to average and this lower rainfall, combined with increased storage capacity in the tailings storage facility created by raising the dam wall in the 2011 dry season, meant that there was excess capacity available to ensure compliance with authorised maximum operating levels in the process water system. SSD reviewed three-dimensional groundwater flow and solute transport modelling provided as part of ERA's application to raise the tailings storage facility walls and was satisfied that the increase in the maximum operating level will not produce increases in seepage that would adversely impact on the downstream environment of Kakadu National Park.

As this report is being prepared ERA is in the process of further raising the wall of the tailings storage facility to provide contingency capacity for the 2012/13 wet season. Changes to the maximum operating level of the facility 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. In June 2012 the Minesite Technical Committee agreed to revised wording of the maximum operating level requiring ERA to ensure that at all times there was sufficient freeboard and/or pumping capacity within the tailings storage facility to ensure that the relevant probable maximum precipitation event could be contained within the total available on site storage capacity.

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

As reported previously, delays in sourcing and commissioning an effective process water treatment facility means that the process water inventory at the mine remains an acute focus. During 2011–12 ERA undertook pilot scale testing of its preferred brine concentrator technology for the treatment of process water. The positive conclusions from this test, including the findings from an ecotoxicological assessment conducted by the SSD (reported in Chapter 3), lead to the approval from ERA's Board to install this technology on site. It is currently planned that the brine concentrator will be operational in the second half of 2013 with a treatment capacity of around 1.8 GL/y.

In April 2009 ERA submitted a referral for the proposed construction of an exploration decline to provide exploration access to mineralisation in the Ranger 3 deeps area. This proposal was deemed not to be a controlled action therefore not requiring further assessment under the *Environment Protection and Biodiversity Conservation Act*. The Ranger Minesite Technical Committee considered an application for construction of the decline from ERA. Satisfied that all aspects of this application had been adequately addressed by ERA, SSD advised the Northern Territory Government of its support for the approval of this application on 30 June 2011. Construction of the box cut for the exploration decline commenced on 1 May 2012, with the works expected to be completed in October 2012.

The 2011–12 wet season represents the second season for which continuous monitoring of pH, electrical conductivity (EC) and turbidity in Magela and Gulungul Creeks upstream and downstream of the Ranger mine has been the primary early warning monitoring method employed by the SSD. The monitoring stations are equipped with autosamplers that collect water samples triggered by in-stream events such as increases in EC or turbidity exceeding defined threshold levels. The SSD's surface water monitoring results, together with explanatory notes, were posted weekly on the internet throughout the wet season. Overall, the water qualities measured in Magela and Gulungul Creeks for the 2011–12 wet season were comparable with previous wet seasons, with the results indicating that the aquatic environment in the creek has remained protected from mining activities.

In situ toxicity monitoring using fresh water snails in Magela and Gulungul Creeks upstream and downstream of the mine, with test organisms deployed in containers immersed in the creek water, is a biological-based method that complements the finding from the continuous monitoring. The measured responses of the snails during the 2011–12 wet season were consistent with that observed from past seasons. The results from monitoring of fish and macroinvertebrates conducted in the recessional flow period towards the end of the wet season continue to confirm that the downstream aquatic environment remains protected from the effects of the mining of uranium at Ranger.

Work is continuing on further enhancing interpretation of the results from the Supervising Scientist's surface water monitoring program. It may be somewhat surprising to note that magnesium (Mg) is the solute most likely to approach or exceed its water quality trigger value in Magela Creek, based on many years of measurements. The aim has been to establish a quantitative relationship between the trigger value for Mg and exposure durations, such that the applicable trigger value can be derived for any given pulse duration and magnitude detected by the continuous water quality monitoring system. The final chapter of this story is presented in this report (Chapter 3), with the development of a functional Mg versus pulse duration relationship. It is anticipated that this fundamental work will pave the way for the development of a new compliance framework to assess conformance against Mg and electrical conductivity trigger values in Magela Ck.

Determination of radionuclide levels in mussels from Mudginberri Billabong has been a continuing element of the SSD assurance monitoring program downstream of Ranger. The results from the most recent sampling and analysis conducted in October 2011 show that the levels of uranium and radium in mussels collected downstream of Ranger continue to pose no risk to human or ecological health.

The Jabiluka project remains in long-term care and maintenance, with the next stage of the project being 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 limited exploration and rehabilitation activities at Nabarlek. SSD participated in stakeholder inspections and audits of these activities and there were no significant environmental issues identified.

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

The Alligator Rivers Region Technical Committee (ARRTC) continues to play a vital role in assessing the key knowledge required, and the robustness of the science used, to make judgements about the protection of the environment from the impacts of uranium mining. Professor Paul Boon (aquatic ecology) and Ms Jane Coram (hydrogeology) attended their first two meetings during the period. Their appointments bring back to full strength the range of science disciplines covered by the independent members of the committee.

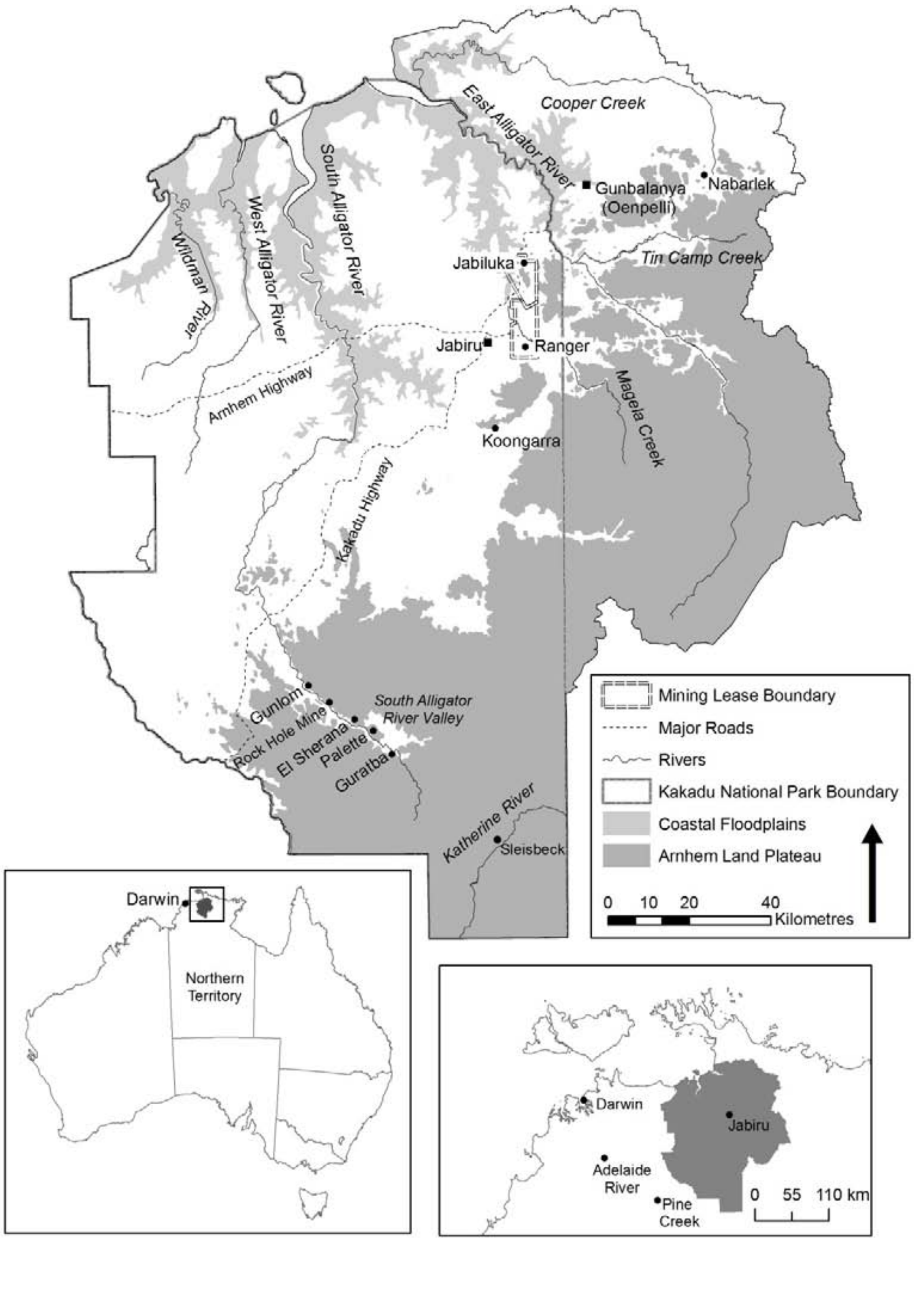
Detailed outcomes from the Environmental Research Institute of the Supervising Scientist (***eriss***) research program are published in journal and conference papers and in the Supervising Scientist and Internal Report series. Highlights of this work are described in this annual report.

During the reporting period, SSD provided advice to the Environmental Approvals and Compliance Division of the Department on referrals submitted in accordance with the *Environment Protection and Biodiversity Conservation Act* for proposed new and expanding uranium mines.

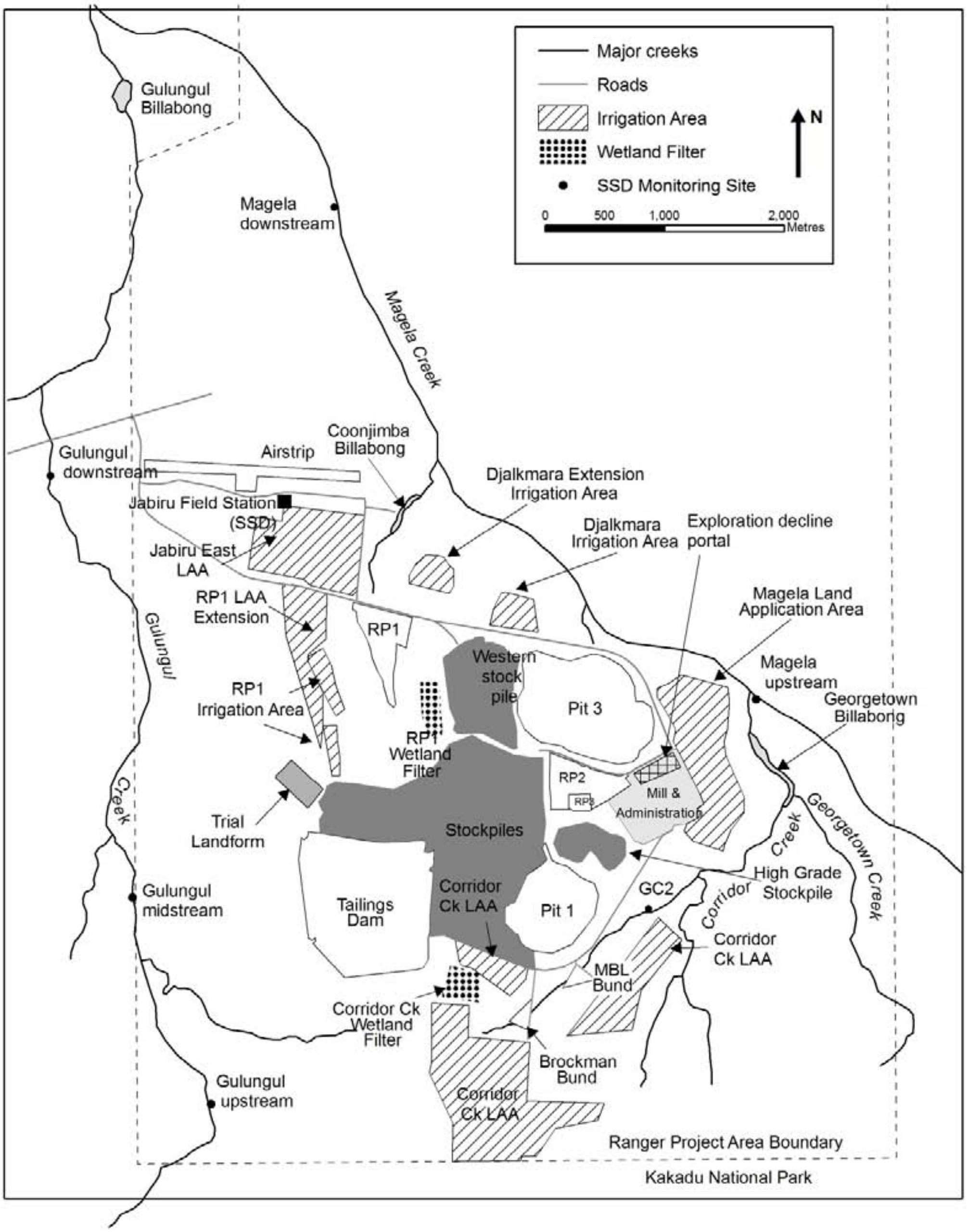
Funds were provided in the 2009–10 Federal Budget for a four-year program to progress and implement environmental maintenance activities, conduct appropriate environmental monitoring programs and develop contemporary site rehabilitation strategies at Rum Jungle under a national partnership agreement between the Northern Territory and the Australian Governments. The Rum Jungle Technical Working Group comprises representatives from the Northern Territory Department of Resources, Northern Territory Department of Natural Resources, Environment, the Arts and Sport, Australian Government Department of Resources, Energy and Tourism, the Northern Land Council and SSD. SSD contributed to the work of the Rum Jungle Technical Working Group during the reporting period, including reporting the findings from a major SSD project assessing the radiological status of the footprint of the former Rum Jungle South mine area.

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

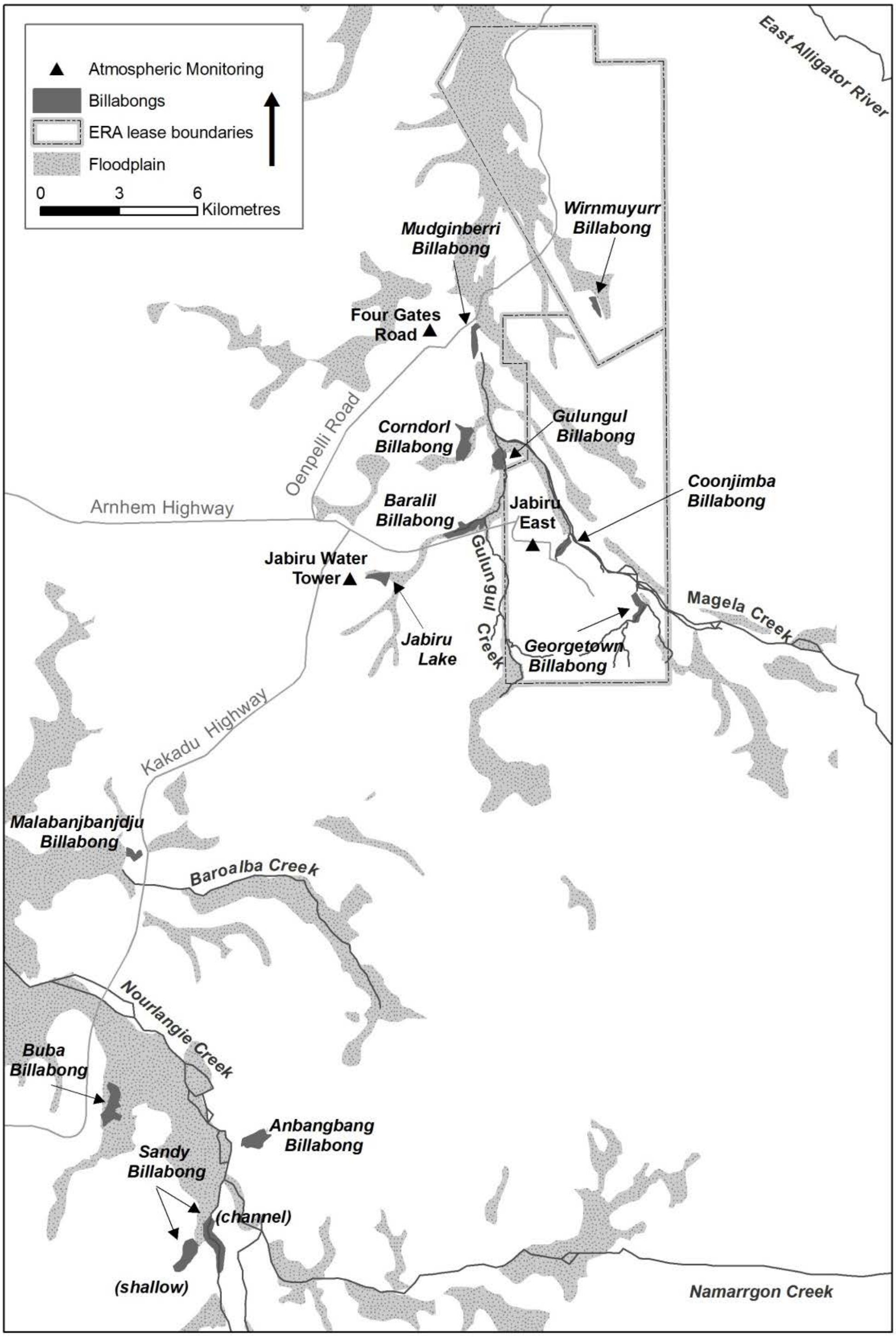
Dr David Jones
Acting Supervising Scientist



Map 1 Alligator Rivers Region



Map 2 Ranger minesite



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

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
BoM	Bureau of Meteorology
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
GC2	Georgetown Creek 2 (ERA monitoring site)
GCDS	Gulungul Creek downstream site
GCMBL	Georgetown Creek Mine Bore L (ERA monitoring site)
GCUS	Gulungul Creek upstream site
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
KKN	Key Knowledge Needs
LAA	Land Application Area
MCUGT	Magela Creek upstream site
MCDW	Magela Creek downstream site
MTC	Minesite Technical Committee
NERP	National Environmental Research Program
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
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.
ALARA	As low as reasonably achievable
alpha radiation (α)	A positively charged helium (He^{2+}) nucleus (two protons + two neutrons) that is spontaneously emitted by an energetically unstable heavy atomic nucleus (such as ^{226}Ra or ^{238}U).
application	A document stating how the mining operator proposes to change the conditions set out in the mining Authorisation. These changes need to be approved by all MTC stakeholders.
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.
closure criteria	Performance measures used to assess the success of mine-site rehabilitation.
concentration factor	The metal or radionuclide activity concentration measured in biota divided by the respective concentration measured in the underlying soil (for terrestrial biota) or water (for aquatic biota).
damp-proof course	A waterproof barrier comprising bitumen and aluminium.
DataSonde	A DataSonde is a multi-parameter sensor for monitoring water quality in ground and surface waters.
direct seeding	Vegetation is established by broadcasting seed across the area to be revegetated.
dissolved organic carbon	Natural organic material from plants and animals that has broken down and is able to pass through a very fine (0.45 micrometre) filter.
dose coefficient	The committed tissue equivalent dose or committed effective dose Sievert [Sv] per unit intake Becquerel [Bq] of a radionuclide. See definition of Sievert and Becquerel.
dose constraint	The International Commission on Radiation Protection (ICRP) defines dose constraint as '*a prospective restriction on anticipated dose, primarily intended to be used to discard undesirable options in an optimisation calculation*' for assessing site remediation options.
early detection	Measurable early warning biological, physical or chemical response in relation to a particular stress, prior to significant adverse effects occurring on the system of interest.
Electrical conductivity (EC)	A measure of the total concentration of salts dissolved in water.
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.
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 $Joule{\cdot}kg^{-1}$. 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).
LiDAR	Light Detection and Ranging
MOL	Maximum Operating Level. The maximum level at which a liquid containing impoundment can be operated.
Near Infrared	0.7 to 1.3 µm
ore	A type of rock that bears minerals, or metals, 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.
solute load	Total mass of a solute delivered over a defined period of time.
speciation (of an element)	The forms in which an element exists within a particular sample or matrix.
stable lead isotopes	Lead has four stable isotopes, three of which, ^{206}Pb, ^{207}Pb and ^{208}Pb, are end members of the natural uranium, actinium and thorium decay series, respectively. ^{204}Pb is primordial only.
tailings	A slurry of ground rock and process effluents left over once the target product, in this case uranium, has been extracted from mineralised ore.
thoriferous	Containing thorium.
toxicity monitoring	The means by which the toxicity of a chemical or other test material is determined in the field over time. The monitoring comprises field toxicity tests which are used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical).

trigger values	Concentrations (or loads) of the key performance indicators measured for an ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should 'trigger' some action, either further ecosystem specific investigations or implementation of management/remedial actions.
tube stock	Young seedlings (usually wrapped in plastic tubes 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. The Division comprises two Branches.

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

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

1.2 Performance summary

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

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

Outcome 5 is divided into two programs. During the 2011–12 financial year, the Supervising Scientist contributed to Program 5.2 Environmental Regulation.

Further details on SSD activities during 2011–12 contributing to Program 5.2 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 Aboriginal people living in the Alligator Rivers Region. Further details on SSD communications activities during 2011–12 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 mine sites in the South Alligator River Valley that operated during the 1950s and 1960s. The Australian Government has funded the rehabilitation of these former mines, with the work being completed in 2009.

1.4.1 Ranger

Energy Resources of Australia Ltd (ERA) operates the Ranger uranium mine, which is located 8 km east of the township of Jabiru. The mine lies within the 78 km^2 Ranger project area and is adjacent to Magela Creek, a tributary of the East Alligator River. Ranger is an open cut mine and commercial production of uranium concentrate (U_3O_8) has been under way since 1981. Orebody No 1 was exhausted in late 1994 and excavation of Orebody No 3 began in 1997.

Current ERA planning is for mining at Ranger to cease in 2012 with processing of stockpiled ore to continue until 2020. In May 2012, ERA commenced construction of an exploration decline at Ranger to enable underground drilling to further define the Ranger 3 Deeps ore body. In June 2012, ERA announced the commencement of a prefeasibility study into the viability of developing an underground mine at the site. Any proposal to develop an underground mine at Ranger would be subject to comprehensive environmental assessment and approval under relevant Commonwealth and Northern Territory government legislation.

1.4.2 Jabiluka

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

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

Development work at Jabiluka took place in the late 1990s but ceased in September 1999, at which time the site was placed in an environmental management and standby phase that lasted until 2003.

During 2003, discussions commenced between ERA, the Commonwealth and Northern Territory Governments, the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) which represents the area's traditional Aboriginal owners, the Mirarr people. Following these discussions, an agreement was reached between the parties that resulted in Jabiluka being placed in long-term care and maintenance. This agreement included an undertaking by ERA not to engage in mining activities at Jabiluka without the consent of the Mirarr people. The agreement was endorsed by the NLC in 2004 and was approved by the then Australian Government Minister for Immigration and Multicultural and Indigenous Affairs in 2005.

1.4.3 Nabarlek

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

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

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

1.4.4 Koongarra

The Koongarra deposit is about 25 km south-west of Ranger, in the South Alligator River catchment. The Koongarra deposit is owned by Koongarra Pty Ltd, a subsidiary of AREVA Australia Pty Ltd. The site is subject to the provisions of the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976*, which requires that traditional owner approval must be obtained before any application for a mining title can be made to the Northern Territory Government. 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. In May 2006, the Australian Government provided funding over four years for the rehabilitation of a number of these sites.

During 2011–12, SSD continued to assist Parks Australia with technical advice related to the ongoing monitoring of these rehabilitated sites. Further details on SSD involvement in this work are provided in Section 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 Department of Resources (DoR) and the Northern Land Council (NLC), to supervise uranium mining operations in the Alligator Rivers Region (ARR). The outcomes of these activities are considered by the Supervising Scientist, together with environmental monitoring data and other information, to draw conclusions regarding the effectiveness of environmental management at uranium mining sites.

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 (SSD) staff, to discuss technical environmental management issues, especially in connection with the assessment of applications and reports submitted by mining companies for approval under Northern Territory and Commonwealth legislation. During this reporting period, the Gundjeihmi Aboriginal Corporation (GAC) was approved as a full member of the Ranger and Jabiluka MTCs. As such, each Ranger and Jabiluka MTC is made up of representatives from DoR (which provides the Chair), SSD, NLC, GAC and Energy Resources of Australia (ERA). Representatives from the Australian Government Department of Resources, Energy and Tourism (RET) also participate in the Ranger and Jabiluka MTCs. Other organisations or experts may be co-opted from time to time as required to assist MTC members. The Nabarlek MTC is made up of representatives from DoR, NLC, SSD and the relevant mining company (currently Uranium Equities Limited).

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 the Ranger mine, the Jabiluka Mineral Lease and the 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 mine in the region, and quarterly at Jabiluka, which is currently in long-term care and maintenance. The RPIs are intended to provide a snapshot of the adequacy of environmental management activities on site as well as an opportunity for the inspection team to discuss current environmental management issues with staff on site. The discussions that occur during RPIs may include addressing any unplanned events or reportable incidents and any associated follow-up actions. The inspection team is made up of representatives from the SSD, DoR and the NLC. Representatives from GAC are now invited to participate in the Ranger and Jabiluka inspection and audit process as they are formal members of the MTC.

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

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

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

The audit outcomes for 2011–12 are described later in this annual report.

2.1.3 Assessment of reports, plans and applications

The Authorisations for Ranger mine and the Jabiluka Mineral Lease 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 SSD, NLC and now also GAC have assessed the proposal and provided feedback. This provides the primary mechanism for the Supervising Scientist's participation in the regulatory processes of the Northern Territory Government and is supported by section 34 of the Act which requires the Northern Territory Government to act in accordance with the advice of the Commonwealth Resources Minister.

The main reports and plans assessed by the Supervising Scientist during 2011–12 included:

- Ranger Amended Plan of Rehabilitation No 37
- Ranger Mine Water Management Plan
- Ranger Mine and Jabiluka Annual Environmental Reports
- Ranger Mine and Jabiluka Wet Season Reports
- Ranger Mine Annual Tailings Dam Inspection Report
- Ranger Mine and Jabiluka Radiation Protection Monitoring Program quarterly and annual reports
- Jabiluka Plan of Rehabilitation No 15
- ERA weekly environmental monitoring data and quarterly reports submitted in accordance with the Authorisations
- Applications by ERA for amendments to their Authorisations (refer to 2.2.2.5 and 2.3.2.4)

2.2 Ranger

2.2.1 Developments

Following the six-month plant shut down from late January 2011 ERA commenced cold commissioning of the plant on 15 June 2011 and recommenced milling in early July 2011. ERA utilised the shut down period to perform extensive maintenance works on the plant and associated infrastructure. Throughput and production levels returned to normal levels following the start up of processing, with higher than normal levels of production achieved in the 2011 dry season before the wet season inflows of water prevented mining in the base of the pit. The mill produced 3282 tonnes of uranium oxide (U_3O_8) during 2011–12 from 2 404 000 tonnes of 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 2011–2012 BY QUARTER

	1/07/2011 to 30/09/2011	1/10/2011 to 31/12/2011	1/01/2012 to 31/03/2012	1/04/2012 to 30/06/2012	Total
Production (drummed tonnes of U_3O_8)	1010	1029	612	631	3282
Ore treated ('000 tonnes)	611	623	594	576	2404

TABLE 2.2 RANGER PRODUCTION ACTIVITY FOR 2007–2008 TO 2011–2012

	2007-2008	2008–2008	2009–2010	2010–2011	2011–2012
Production (drummed tonnes of U_3O_8)	4926	5678	4222	2679	3282
Ore treated ('000 tonnes)	2001	2042	2283	1305	2404

2.2.1.1 On-site activities

Ranger Exploration Decline Project

In April 2009 ERA submitted a referral for the proposed construction of an exploration decline to provide exploration access to mineralisation in the Ranger 3 deeps area. This proposal was deemed not to be a controlled action therefore not requiring further assessment under the EPBC Act. The Ranger MTC considered an application for construction of the decline from ERA. Satisfied that all aspects of this application had been adequately addressed by ERA, SSD advised the Northern Territory Government of its support for the approval of this application on 30 June 2011. Construction of the box cut for the exploration decline commenced on 1 May 2012. SSD, in conjunction with DoR and NLC, inspected the construction works at the June 2012 RPI.

Tailings Storage Facility MOL raise

On 3 August 2011 ERA submitted an application to raise the maximum operating level (MOL) of the Tailings Storage Facility (TSF) to 57.0mRL for the dry season and 56.5mRL for the wet season. In response to this application DoR, with the support of SSD, commissioned a review of probable maximum precipitation (PMP) data for the Jabiru region from the Bureau of Meteorology (BoM). This study was commissioned with a view to adopting a more conservative PMP-based approach to setting the TSF MOL. SSD believes that a PMP based approach provides a greater level of confidence that the environment will remain protected during the most extreme rainfall events. Whist this information was being considered the MTC agreed to an interim MOL of 56mRL which was reflected in Authorisation 0108-13 issued on 29 November 2011.

In June 2012 the MTC agreed to revised wording of the MOL requiring ERA to ensure that at all times there was sufficient freeboard and/or pumping capacity within the TSF to ensure that the relevant PMP event could be contained within the total available on site storage capacity (TSF plus Pit 3).

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

RP5 and RP6

To provide increased capacity for pond water storage on site to assist with ongoing water management, and the transfer of Pit 3 from the pond water system to the process water system in the future, ERA submitted an application to stakeholders in March 2012 outlining the details for construction and use of a new retention pond on site (RP6). The pond is designed to hold approximately 1000 ML and will be lined with two x 2 mm HDPE liners, with leak detection, overlaying a compacted clay base. Water will be transferred from RP2 via dedicated HDPE transfer lines and the pond has contingency overflow capacities back to the pond water system. SSD reviewed the application and requested further information in relation to water management and contingency strategies for operation of the new pond. SSD advised DoR of support for the application on 5 April 2012.

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

TSF Wall Raise to 60.5m RL

On 1 June 2012 ERA presented stakeholders with an application to conduct a centre-line lift on the TSF to raise the height of the wall by 2.2 m from 58.3mRL to 60.5mRL during the 2012 dry season. In response to this application SSD commissioned an independent geotechnical review of the design and was awaiting this report at the end of June 2012.

Brine concentrator

As part of its strategy to manage and reduce the process water inventory on site, ERA proposes to construct a brine concentrator on site to treat process water. The brine concentrator will be located at the site of the now-demolished acid plant adjacent to the power station. The brine concentrator is expected to be commissioned in the second half of 2013 and will have the capacity to treat process water at a rate of 1.83 GL per year. The release of treated process water (distillate) from the site will be contingent on approval of an application from ERA, further ecotoxicological testing and assessment by the MTC. SSD has undertaken a range of ecotoxicology tests on distillate produced from a brine concentrator pilot plant campaign that was run at Rio Tinto's research centre in Melbourne using process water transported by tanker from the mine. The findings from this work are discussed further in Chapter 3.

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 MTC before approval. The 2011–12 Water Management Plan was submitted for approval by ERA on 3 October 2011. SSD endorsed the plan on 25 January 2012 and the document was formally approved by DoR on 1 February 2012. The plan describes the systems for routine and contingency management of the three categories of water on site: process, pond and potable.

As shown in Figure 2.1, the 2011–12 wet season was an average rainfall year with a total of 1524 mm recorded at Jabiru Airport to 30 June 2012 (annual average 1536 mm). Despite the average rainfall recorded this year, water management – especially that of process water – remains a critical issue at Ranger.

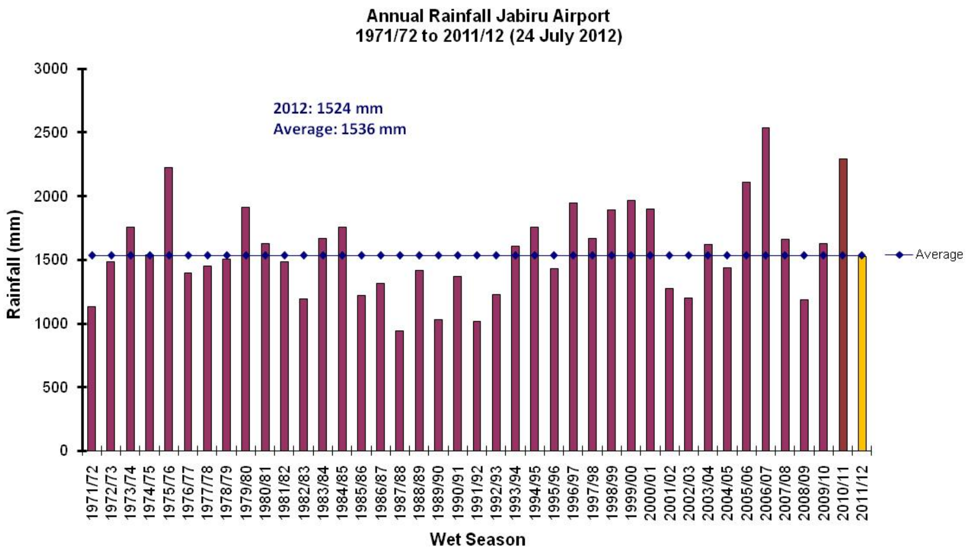


Figure 2.1 Annual rainfall Jabiru Airport 1971–72 to 2011–12 (data from Bureau of Meteorology)

Process water system

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

ERA does not currently have the capacity to treat and release process water on site and as such all process water is stored in Pit 1 and the TSF. As discussed in section 2.2.1.1 above , ERA is currently in the process of constructing a brine concentrator on the site to treat process water at a rate of 1.83 GL per year. The brine concentrator is expected to be commissioned in the second half of 2013.

On 30 June 2012, the process water inventory was 10 493 ML, of which 10 054 ML was stored in the TSF. This represents a decrease of 201 ML over the previous year's total of 10 694 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. ERA has previously committed that pond water will not be released without prior treatment through wetland filtration or the on site microfiltration/reverse osmosis treatment plants. At the end of the reporting period 1032 ML was contained within the within the pond water system, representing a large decrease in the volume stored at the same time last year (4133 ML). The decreased pond water inventory is due to the lower rainfall received on the site during the 2011–12 wet season compared with the 2010–11 wet season, combined with the effect of a third pond water treatment plant (WTP) commissioned on 20 July 2011.

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

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. Due to reduced performance, ERA did not utilise the RP1 wetland filter to polish pond water during the reporting period.

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

An interception trench was installed around the western and northern perimeter of the western stockpile in 2010 to capture very poor quality seepage that was previously reporting to RP1, and to redirect stockpile runoff away from RP1. This measure, combined with input of pond water permeate into RP1, has resulted in a substantial improvement to water quality in RP1 over the past two years. Water is passively released from RP1 via a sluice gate when the water level in RP1 exceeds the height of the spillway. In Corridor Creek, passive release of waters originating from upstream of GC2 occurred throughout the 2011–12 wet season.

Managed release water

Controlled discharge of RP1 via siphons/pumping over the weir occurred from January through to mid-April 2012 to reduce the overall pond water inventory during periods of higher flow in Magela Creek. ERA manually controls the discharge of runoff from areas adjacent to Pit 3 via four sluice gates along the Ranger access road. Release from these gates occurred on several occasions during the 2011–12 wet season.

ERA was again granted interim approval through the Water Management Plan for the discharge of RP1 water to Magela Creek from the MG001 site (see Map 2 for location) over the 2011–12 wet season. Discharge is managed to ensure electric conductivity within Magela Creek is maintained within limits. Controlled discharge occurred periodically throughout the 2011–12 wet season under high-flow conditions in Magela Creek. A total volume of approximately 150 ML of RP1 water was released via MG001.

Pond water treatment

Pond water is treated via three microfiltration/reverse osmosis water treatment plants (WTP), with WTP1 and WTP2 having a 7 ML/day capacity and WTP3 an 11 ML/day capacity. WTP3 commenced operation on 20 July 2011.

All three water treatment plants were in operation during the reporting period. Volumes of water treated and permeate produced are reported in Table 2.3.

TABLE 2.3 POND WATER TREATMENT PLANT (WTP) VOLUMES

WTP	Volume treated (ML)	Permeate produced (ML)
1	2295	1482
2	1996	1446
3	2791	1882

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

Land application areas

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

All land application areas, other than the Magela land application area which was taken out of service to use for rehabilitation trials, were utilised during the 2011 dry season and have been prepared for use during the 2012 dry season. Irrigation had not commenced for the 2012 dry season prior to the end of the reporting period.

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 ceased in December 2008 when tailings reached the maximum permitted level of 12mRL, and deposition of tailings in the TSF resumed. Tailings are discharged to the TSF via a floating discharge pipe that is moved regularly to achieve an even deposition across the footprint of the dam.

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

ERA further progressed plans for closure of Pit 1 during the reporting period. Installation of wicks to facilitate tailings consolidation in Pit 1 commenced in Q2 2012.

The average density of tailings in Pit 1 at June 2012 was 1.37 t/m^3, which exceeds the minimum target density of 1.2 t/m^3. The average density of tailings in the TSF at the end of reporting period was 1.0 t/m^3.

2.2.2.3 Audit and Routine Periodic Inspections (RPIs)

Eleven inspections and one audit were undertaken at Ranger during the 2011–12 reporting period. The grading system used in the audit, shown in Table 2.4, is the same as that used by DoR. Use of this ranking system ensures the outcomes of the Ranger auditing process are consistent with other mines in the Northern Territory.

Findings from the May 2011 environmental audit were reviewed through the RPI process. An audit of a selection of management plans and Schedule 4 of Authorisation 0108-13 was undertaken in May 2012. RPIs were carried out for each month of the 2011–12 reporting year with the exception of May. Table 2.5 shows the focus areas for the audit and RPIs for the year.

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.

TABLE 2.5 AUDIT AND RPI

Date	Foci
19 July 2011	Management of change procedure, waste hydrocarbon storage area, new water treatment plant, tailings B&C pumps, general bund repairs, heavy vehicle workshop
18 August 2011	Corridor Creek land application area, waste hydrocarbon storage area, water treatment plant 3, Ranger 3 Deeps exploration, tailings corridor, Corridor Road sump and booster station, oily water separator at diesel fuel bund
22 September 2011	Acid plant demolition project, Djalkmara land application area, GC2, Sleepy-cod dam, waste hydrocarbon storage area
20 October 2011	Assessment of procedure ERP003, waste hydrocarbon storage area
17 November 2011	Southern stockpiles, acid plant demolition, clay borrow areas, landfill and bioremediation areas
20 December 2011	TSF sumps, western stockpile seepage interception sumps, clay borrow areas, removal of Jabiru East land application area bunds, Djalkmara release point
19 January 2012	Trial landform, Magela land application area rehabilitation, process water return line, MG001
16 February 2012	Corridor Creek and RP1 wetland filters, GCBR, western stockpile seepage interception trench, TSF southern and western wall sumps, acid plant demolition, waste hydrocarbon storage area
28 March 2012	Radiation protection

19 April 2012	TSF, controlled area vehicle access at the gatehouse, waste hydrocarbon storage area
14–16 May 2012	Audit : Land Use Zoning and Land Use Management Plan, Fauna Management Plan, Hazardous Materials and Contamination Control Management Plan, Weed Management Plan 2012-2016, Schedule 4 of Authorisation 0108-13
21 June 2012	Exploration decline box cut, Pit 1 wick installation, exploration

Audit outcomes

Closeout of findings from the May 2011 environmental audit

The May 2011 audit of the Ranger Authorisation (Schedules 5, 6, 7 & Annex C) delivered 8 significant findings (see Table 2.4 for definitions), ranked:

- 1 x category 1 non-conformance
- 4 x category 2 non-conformance
- 3 x conditional

These findings were followed up via the monthly RPI process with the category 2 non-conformances and conditional findings closed out prior to the 2012 annual audit. The remaining category 1 non-conformance, related to the control of Controlled Area vehicles, was closed out during the 2012 audit.

May 2012 environmental audit

The 2012 environmental audit of Ranger mine was held on 14-16 May 2012. The audit team was made up of representatives from the NLC, DoR and SSD. The following documents were the subject of the 2012 audit:

- Schedule 4 of Authorisation 0108-13
- Land Use Zoning and Land Use Management Plan
- Fauna Management Plan
- Hazardous Materials and Contamination Control Management Plan
- Weed Management Plan 2012-2016

One hundred and twenty-two (122) commitments were audited against the grading system shown in Table 2.4.

The following 6 conditional significant findings were determined from the 122 commitments audited:

- The land classification system
- The currency of the Land Use Zoning and Land Use Management Plan
- Frequency of management reviews of the Environment, Safety and Health Management System
- Implementation of actions in the Fauna Management Plan

- Chemical storage system
- Internal auditing of hazardous chemical management

In addition 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. SSD will continue to follow up on all identified issues 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 seven times during 2011–12, including one out-of-session special MTC on February 17 to consider aspects of tailings and process water management. Dates of meetings and issues discussed are shown in Table 2.6. Significant agenda items discussed at MTCs included updates from ERA on site activities including water management and inventories, exploration decline and brine concentrator projects, updates from the Ranger Closure Criteria Working Group 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 3 times during 2011–2012.

TABLE 2.6 RANGER MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items in addition to standing items
7 July 2011	Application to optimise the radiation and atmospheric monitoring program, TSF groundwater issues, lease boundaries, process water capacity, water sampling methodologies, potable water non-return valves
9 September 2011	Application to optimise the radiation and atmospheric monitoring program, lease boundaries, water sampling methodologies, mine closure plan
10 November 2011	GAC membership to the MTC, optimisation of water quality reporting, annual amended plan of rehabilitation No.36, application to raise the TSF MOL, exploration activities
20 January 2012	GAC membership of the MTC, Ranger water management plan 2011–12, Ranger lease camp
17 February 2012	Special MTC: ERA's best practicable technology options evaluation tool for process water, tailings and closure pre-feasibility study, TSF MOL and the probable maximum precipitation document provided by DoR
5 April 2012	GAC membership of the MTC, tailings dam wall lift to RL60.5 centreline lift, TSF MOL, best practicable technology discussion paper, water sampling methodologies, optimisation of water quality reporting, Closure Criteria Working Group, exploration activities, RP6
1 June 2012	Exploration management plan, RP6, TSF crest raise, TSF MOL, Ranger Independent Surface Water Working Group.

2.2.2.5 Authorisations and approvals

There was one change to the Ranger Authorisation during the reporting period. The current version of the Authorisation (0108-13) was issued on 29 November 2011 and included the revised requirements for radiation and atmospheric monitoring and reporting. Authorisation 0108-13 also set an interim TSF MOL of 56 mRL. The requirement for the operator to demonstrate capacity within the process water circuit for a 1 in 1000 year rainfall event was removed but the requirement to demonstrate capacity to contain the largest wet season on record as recorded at Jabiru airport was retained.

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 to seeking further information from the mine operator before making such a decision. In those cases where immediate action is not considered to be required, the situation is again reviewed on receipt of a formal incident investigation report from the operator.

Prior to each RPI (see section 2.1.2), the inspection team reviews the previous month's environmental incident report summary (EIRS) and any open issues. Where an incident is considered to have any potential environmental significance or represents a repetition of a class of occurrences, an on-site review of the circumstances is scheduled as a part of the routine inspection agenda.

SSD determined that no incidents that occurred during the reporting period were of a serious enough nature to warrant a separate independent investigation. However, the incidents below were followed up through the RPIs to inspect the locations of the incidents and to gain further information and understanding of remedial actions taken by ERA to prevent future recurrence of similar incidents.

Dead fish in RP2

On 6 February 2012 ERA advised stakeholders that approximately 40 fish (measuring between 60–100 mm each) were observed dead in a shallow, stagnant and isolated section of RP2. SSD followed up on this incident through the RPI process and regular correspondence with relevant personnel. Requested water quality monitoring data showed that general parameters were within the normal expected range prior to and after the incident. ERA concluded that the incident was likely caused by increased temperature and low dissolved oxygen levels in that part of RP2 at the time. SSD was satisfied with ERA's investigation and conclusions.

Fire fighting deluge foam to RP2

ERA advised that on 8 February 2012 approximately 1000 L of fire fighting deluge foam reported to RP2 during maintenance of the fire system. There was no fire at the time of the incident. ERA collected samples for analysis from RP2 and reported that the foam is an organic product and highly biodegradable. SSD followed up on this issue at the March RPI and ERA reported that no water quality impact to RP2 was observed through the water sample analysis.

Ammonia release

ERA reported a minor release of ammonia on 26 May 2012 during planned maintenance works. The Emergency Response Team immediately responded to the ammonia release and staff reported to the ammonia safe rooms. ERA advised there was no harm to persons or the environment as a result of the release.

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 the Ranger mine. Specific water quality objectives must be achieved in Magela Creek.

The Authorisation specifies the sites, the frequency of sampling and the analytes to be reported. Each week during the wet season ERA reports the water quality at key sites, including Magela and Gulungul Creeks upstream and downstream of the mine, to the major stakeholders (the Supervising Scientist, 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 throughout the wet season on the Internet at www.environment.gov.au/ssd/monitoring/index.html. The highlights of the monitoring results from the 2011–12 wet season are summarised below.

Chemical and physical monitoring of Magela Creek

From 2010–11, SSD's routine wet season monitoring program moved to the continuous monitoring of EC, turbidity and water temperature coupled with event-triggered automatic sampling as the primary water quality monitoring method. Due to the time taken to retrieve samples, automatically collected samples are analysed for total metals, rather than filtered. This procedure replaced the weekly grab sampling undertaken prior to 2010–11. The change in method has 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 (MGUGT) and downstream (MCDW) monitoring sites and key Ranger mine features.

Flow was first recorded at the Magela Creek upstream and downstream monitoring stations on 23 November 2011. Flow remained low until December when flows increased due to increasing rainfall, which resulted in several peaks in turbidity at both the upstream and downstream monitoring stations (Figure 2.2) typical of first flush conditions.

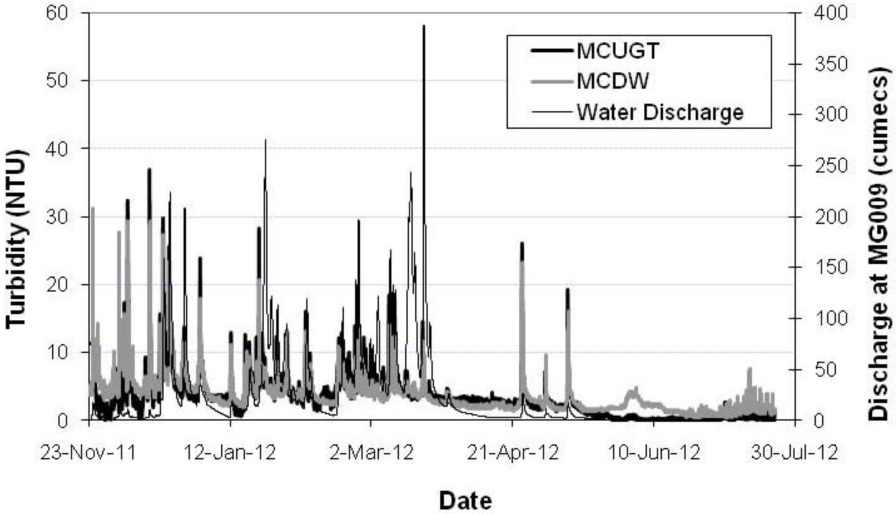


Figure 2.2 Continuous turbidity and discharge in Magela Creek between November 2011 and July 2012

A peak in EC occurred at the downstream monitoring site (MCDW) on 4 December 2011 (Figure 2.3). The peak duration was 7 hours and 10 minutes; reaching a maximum EC of 54 µS/cm. The source of the contamination was identified as solute-laden groundwater expressing from a creekline within Djalkmara Land Application Area. This was exacerbated by low flow conditions, and hence low dilution capacity, within Magela Creek.

EC levels decreased during periods of increased flow between mid to late December 2011. Low rainfall during early January 2012 resulted in low flow conditions with EC remaining less than 20 µS/cm at both the upstream and downstream monitoring sites through early January 2012; with the exception of a rainfall event on 12 January 2012 (26.6 mm of rain was recorded at Jabiru Airport). During this rainfall event EC at MCDW reached 23 µS/cm prior to and 22 µS/cm following the event peak flows. A 38.2 mm rainfall event (recorded at Jabiru Airport) on 18 January 2012 resulted in a peak in EC at MCDW, associated with the rising hydrograph of the water flow, where EC reached 35.8 µS/cm.

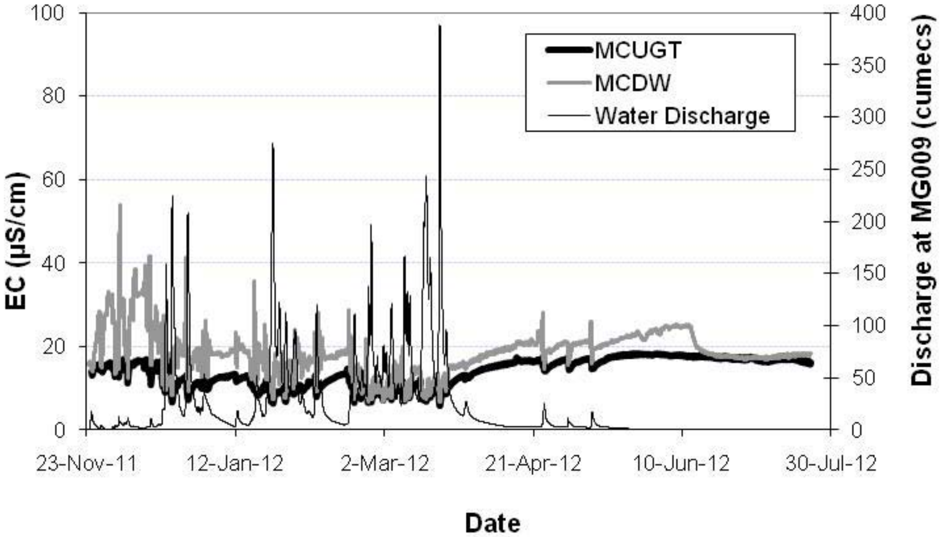


Figure 2.3 Continuous electrical conductivity and discharge in Magela Creek between November 2011 and July 2012

During the 2011–12 wet season, the maximum total uranium concentration measured downstream from the Ranger mine was 0.4 µg/L, a value similar to the relative filterable uranium concentration results from previous years. This value is approximately 7% of the local ecotoxicologically-derived limit of 6 µg/L for protection of aquatic ecosystems, and approximately 2% of the 20 µg/L guideline for potable water (Figure 2.4).

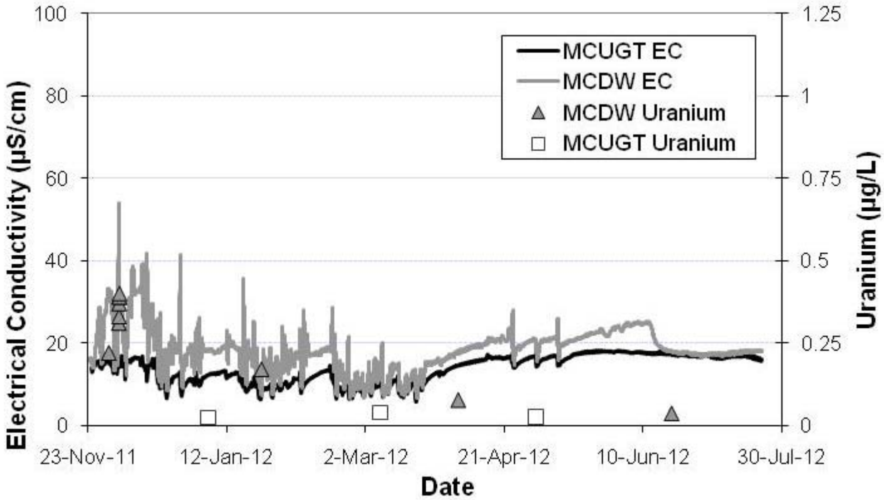


Figure 2.4 Total uranium concentrations in event-triggered samples and continuous electrical conductivity in Magela Creek between November 2011 and July 2012

The maximum uranium concentration occurred during the EC event of 4 December 2011. Manganese concentrations were also elevated, reaching 24 µg/L during the beginning of the event (Figure 2.5). This value is below the guideline trigger value of 26 µg/L for manganese. An earlier routine quality assurance/quality control (QA/QC) water sample taken on 30 November 2011 recorded a manganese concentration of 28 µg/L. However, surface water flows on this date were less than 0.5 cumecs, noting that the manganese guideline trigger value only applies when surface water flows are greater than 5 cumecs.

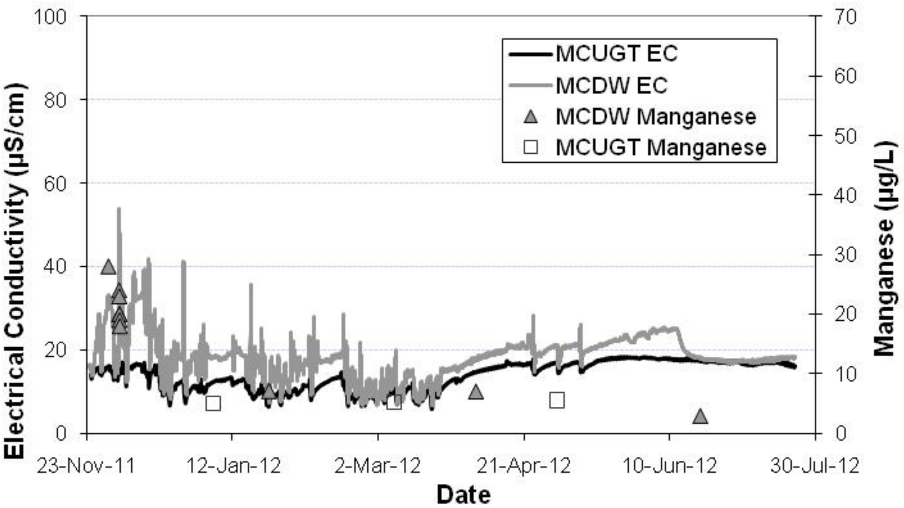


Figure 2.5 Total manganese concentrations in event-triggered samples and continuous electrical conductivity in Magela Creek between November 2011 and July 2012

Magnesium and sulfate concentrations measured in the automatically collected water samples closely followed the EC continuous monitoring data with concentrations peaking during the EC event on 4 December 2012 at 3.8 mg/L and 13 mg/L, respectively (Figures 2.6 & 2.7). Automatic samples were not triggered for any other EC peaks during the 2011–12 wet season as these did not exceed the 42 µS/cm (corresponding to 3 mg/L magnesium) guideline.

Recessional flow conditions became established in Magela Creek during April 2012. These conditions are typified by a falling hydrograph, with EC initially stabilising and then rising slowly as higher EC groundwater input becomes the dominant contributor to flow.

Continuous monitoring continues until cease to flow is agreed by stakeholders or until the measuring equipment is 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 2011–12 wet season is comparable with previous wet seasons, with the results indicating that the aquatic environment in the creek has remained protected from mining activities (Figure 2.8).

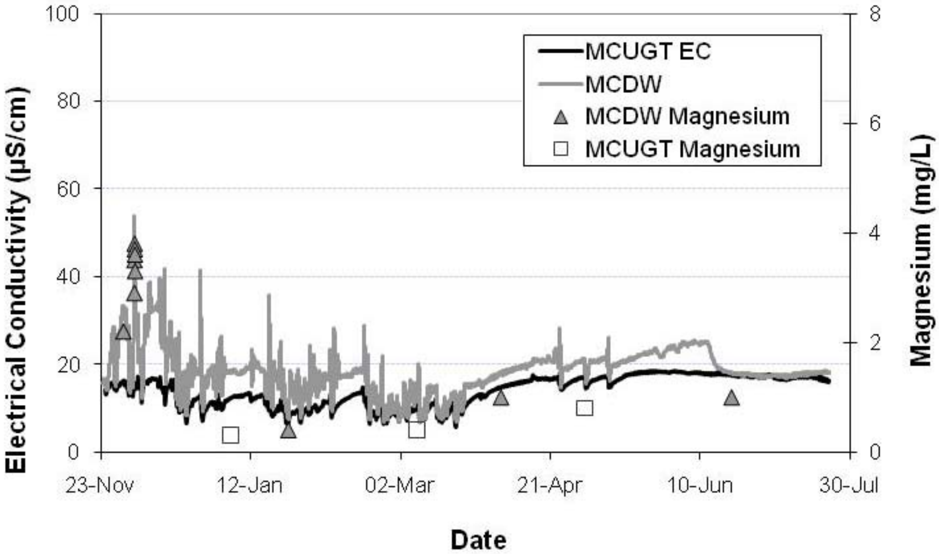


Figure 2.6 Total magnesium concentrations in event-triggered samples and continuous electrical conductivity in Magela Creek between November 2011 and July 2012

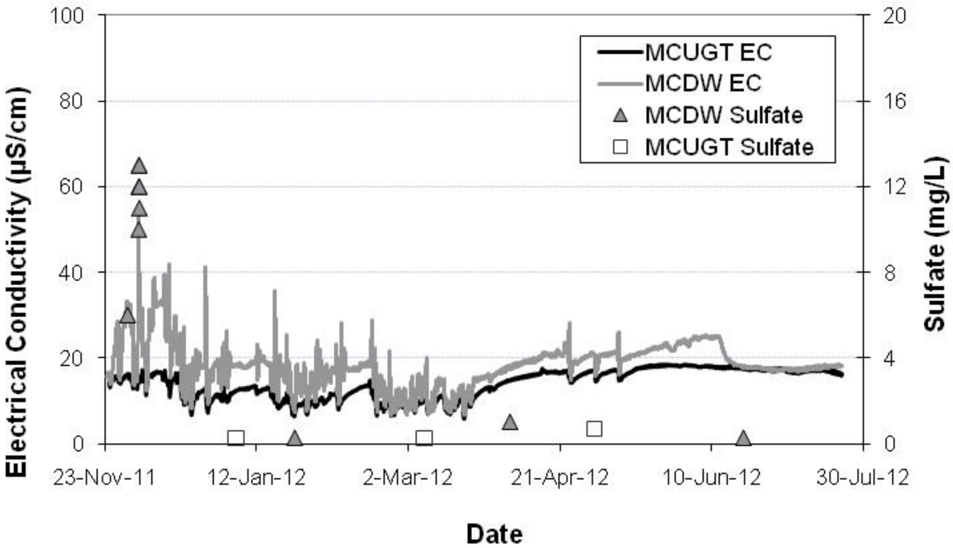


Figure 2.7 Total sulfate concentrations in event-triggered samples and continuous electrical conductivity in Magela Creek between November 2011 and July 2012

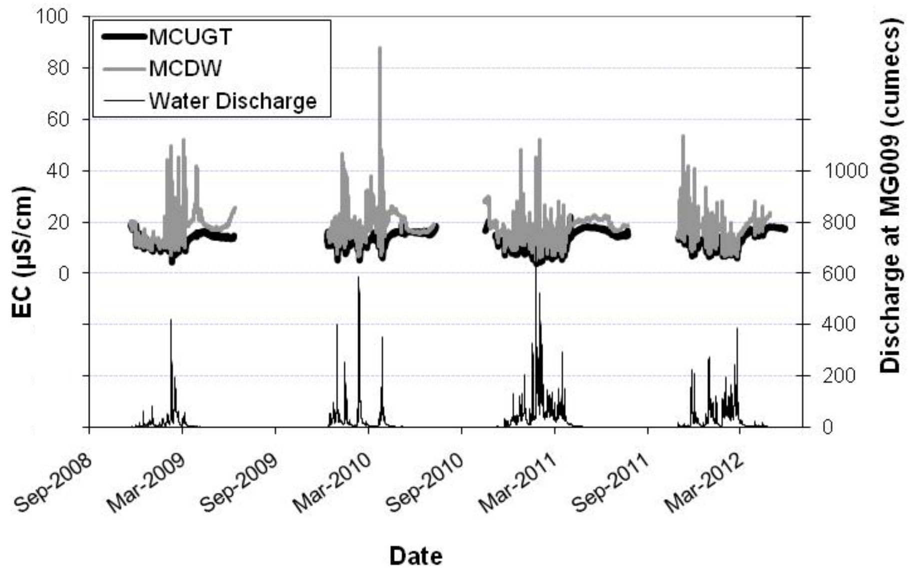


Figure 2.8 Continuous electrical conductivity and discharge (lower trace) in Magela Creek for each wet season between December 2007 and July 2012 (values averaged over a 1 hour period of measurement)

Radium in Magela Creek

Surface water samples are collected weekly from Magela Creek upstream and downstream of the Ranger mine. The weekly samples are combined to give monthly composite samples. Total radium-226 (^{226}Ra) is measured in these samples and results for the 2011–12 wet season can be compared with previous data ranging back to the 2001–02 wet season (Figure 2.9).

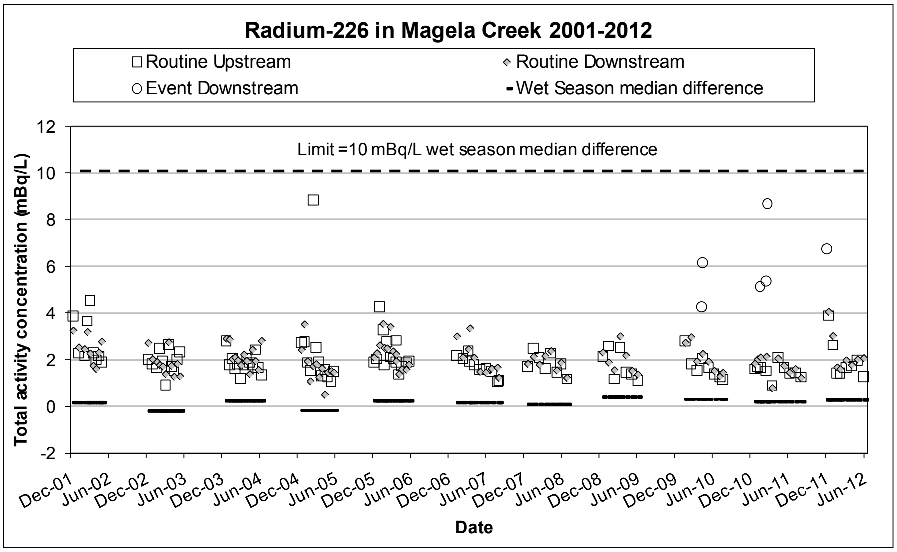


Figure 2.9 Radium-226 in Magela Creek 2001–2012

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

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

A wet season median difference of 10 mBq/L would result in a mine origin ingestion dose from ^{226}Ra bioaccumulated in mussels of about 0.3 mSv, if 2 kg of mussels were ingested by a 10 year old child. Wet season median differences (shown by the horizontal lines in Figure 2.9) from 2001 to 2012 are close to zero, indicating that the majority of ^{226}Ra is coming from natural sources of Ra located in the catchment upstream of the mine. The wet season median difference for the entire monitoring period (2001–2012) is only 0.1 mBq/L.

Since 2010, ^{226}Ra analyses of a composite of samples collected by autosampler during individual EC-triggered events have also been performed. The results are shown in Figure 2.9, together with the results from the routine radium analyses. The data are not included in the calculation of the wet season median difference, because these EC events are short-lived and their impact on seasonal ^{226}Ra loads is very small.

The higher radium activity concentrations seen for the event downstream samples in Figure 2.9 are a consequence of the new automated sampling procedure, which is triggered only at times of higher EC values. There was one (4 December 2011) such event-triggered sample obtained for ^{226}Ra analysis during the 2011–12 wet season. The maximum uranium concentration measured in event samples collected for 2011–12 occurred during this EC event (see Figure 2.4 above). There was no corresponding upstream (reference) sample collected at the same time since there was no elevated EC pulse upstream to trigger the autosampler at that location. To enable the activity difference of 4.9 mBq/L to be estimated for this December sample, the median of all previous upstream routine ^{226}Ra results (2001–2011) was used as a reference and subtracted from the ^{226}Ra result for this EC triggered sample.

Chemical and physical monitoring of Gulungul Creek

Flow was first recorded at the Gulungul Creek upstream and downstream monitoring stations on 24 November 2011. There was a peak in EC of 29 µS/cm on 3 December 2011 at the upstream monitoring site (GCUS) (Figure 2.10), which was associated with first flush conditions. The peak in EC was followed by a turbidity event which reached 117 NTU (Figure 2.11). Increased rainfall during mid-late December 2011 resulted in water levels remaining above 0.8 m at the downstream monitoring site (GCDS).

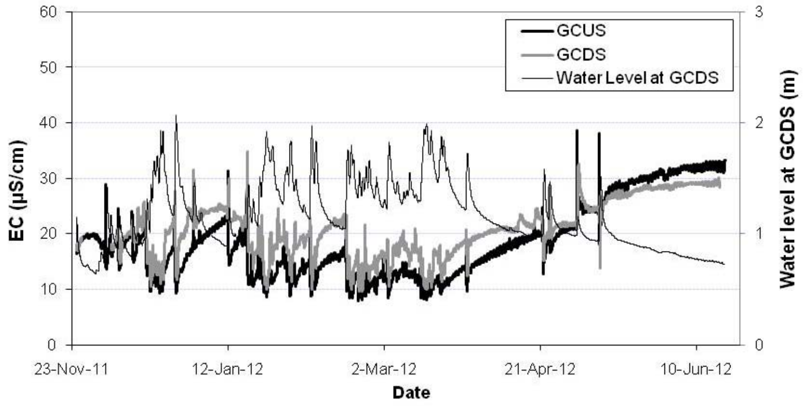


Figure 2.10 Electrical conductivity and water level in Gulungul Creek between November 2011 and June 2012

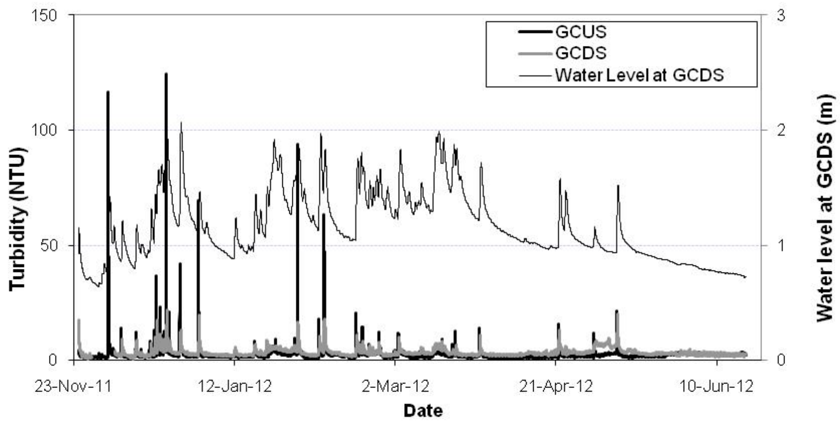


Figure 2.11 Turbidity and water level in Gulungul Creek between November 2011 and June 2012.

During late December 2011/early January 2012 there was a steady decline in water level and a corresponding increase in EC, although EC remained less than 25 µS/cm at both the upstream and downstream monitoring sites. On 12 January 2012, 27 mm of rainfall was recorded at Jabiru Airport. Prior to the peak in water flow the EC reached 31 µS/cm at GCUS and 29 µS/cm at GCDS. A 38 mm rainfall event (recorded at Jabiru Airport) on 18 January 2012 also resulted in peaks in EC associated with the rising hydrograph. EC reached 33 µS/cm at GCUS and 35 µS/cm at GCDS. EC-triggered automatic samples from GCUS and GCDS show conformance between uranium, and to a lesser extent, magnesium concentrations between the upstream and downstream sites. Differences between upstream and downstream EC, and magnesium and sulfate concentrations suggest a localised source of run-off between GCMID monitoring station (data not shown) and GCDS. However, further work is required to determine the mine-related contribution to solute loads in Gulungul Creek.

Water levels increased and EC levels decreased during subsequent rainfall events throughout late January, February and early March 2012. An increase in discharge on 15 and 16 March 2012 related to monsoonal activity resulted in a decrease in EC at both the upstream and downstream sites. Recessional flow conditions became established in April with low water levels and rising, converging EC levels at both the upstream and downstream monitoring sites. Late wet season rainfall events during late April and early May 2012 resulted in short-term peaks and troughs in EC and turbidity. Continuous monitoring continued until 17 June 2012 when water levels fell below the level of the sensors.

During the 2011–12 wet season, the maximum total uranium concentration of 0.52 µg/L (Figure 2.12) was actually measured at GCUS upstream from the Ranger mine. This value is approximately 9% of the local ecotoxicologically-derived limit of 6 µg/L, and approximately 2.6% of the 20 µg/L guideline for potable water.

Manganese concentration peaks of 14 µg/L were recorded at both the upstream and downstream sites (Figure 2.13). Magnesium and sulfate concentrations closely followed the EC continuous monitoring trace (Figures 2.14 & 2.15).

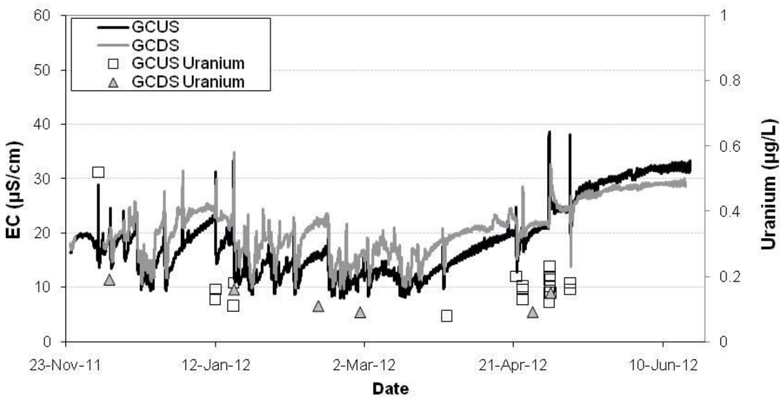


Figure 2.12 Electrical conductivity and total uranium concentrations in Gulungul Creek between November 2011 and June 2012

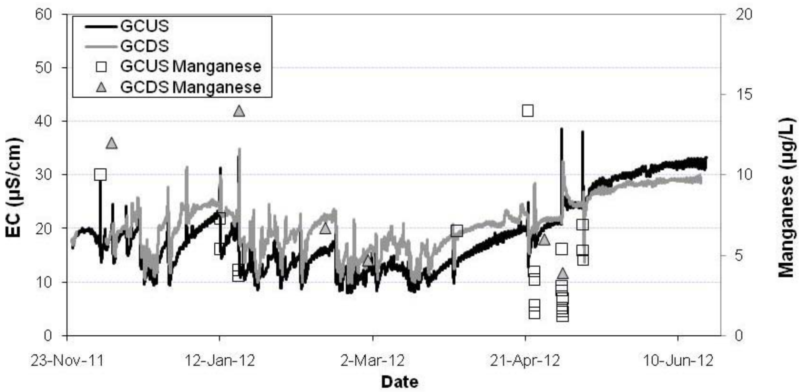


Figure 2.13 Electrical conductivity and total manganese concentrations in Gulungul Creek between November 2011 and June 2012

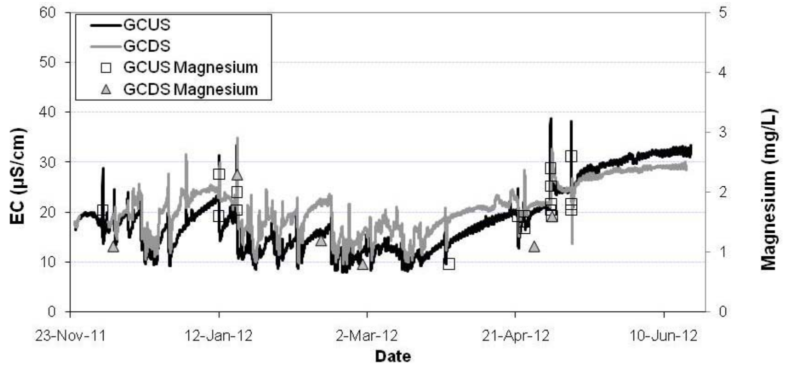


Figure 2.14 Electrical conductivity and total magnesium concentrations in Gulungul Creek between November 2011 and June 2012

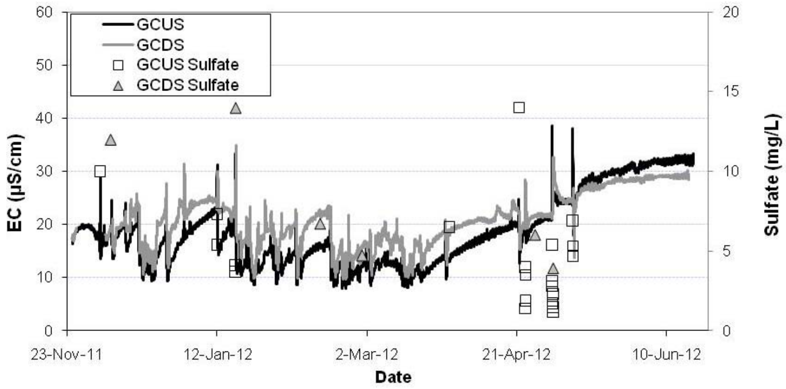


Figure 2.15 Electrical conductivity and total sulfate concentrations in Gulungul Creek between November 2011 and June 2012

Overall, the water quality measured in Gulungul Creek for the 2011–12 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 2.16). See section 3.2 for a more detailed analysis of solute loads in Gulungul Creek.

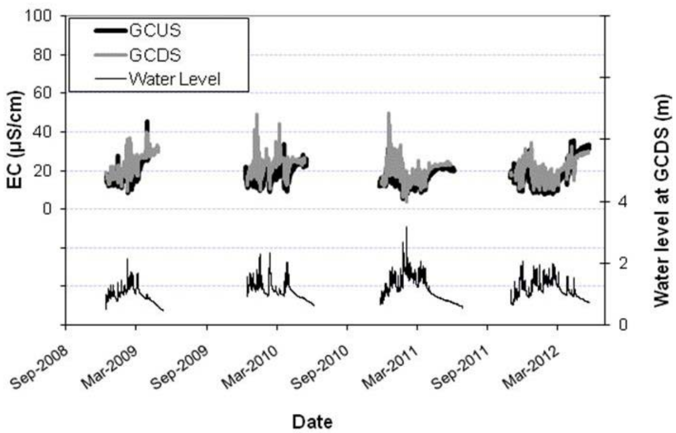


Figure 2.16 Electrical conductivity measurements and discharge (lower trace) in Gulungul Creek between December 2007 and July 2012 (values averaged over a 1 hour period of measurement)

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: (1) early detection, and (2) assessment of overall ecosystem-level responses at the end of the wet season.

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

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

The findings from toxicity monitoring, bioaccumulation, and fish and macroinvertebrate community studies conducted during the 2011–12 reporting period are summarised below.

In situ toxicity monitoring

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

For the 1990–91 to 2007–08 wet seasons, toxicity monitoring was carried out using the ‘creekside’ methodology. 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.

Testing was conducted fortnightly in each creek in the 2011–12 wet season, alternating each creek on a weekly basis (as such, testing was not conducted in both creeks in the same week.)

The first of 18 toxicity monitoring tests (both creeks combined) for the 2011–12 wet season commenced in Magela Creek on the 1 December 2011, once moderate creek flows were established. Tests were then conducted every other week over the 2011–12 wet season with the ninth and final test commencing 5 April 2012. The first of nine Gulungul tests commenced on 8 December 2011 and the final test commenced on 29 March 2012. The second Gulungul test deployed on the 16 December was deemed invalid due to an excess amount of debris that had collected on the equipment, restricting water flow to the snails during the test period (Figure 2.17B). Consequently, data from this test were not included in subsequent analyses. Upstream and downstream egg production and difference values for both creeks are displayed in Figure 2.17B.

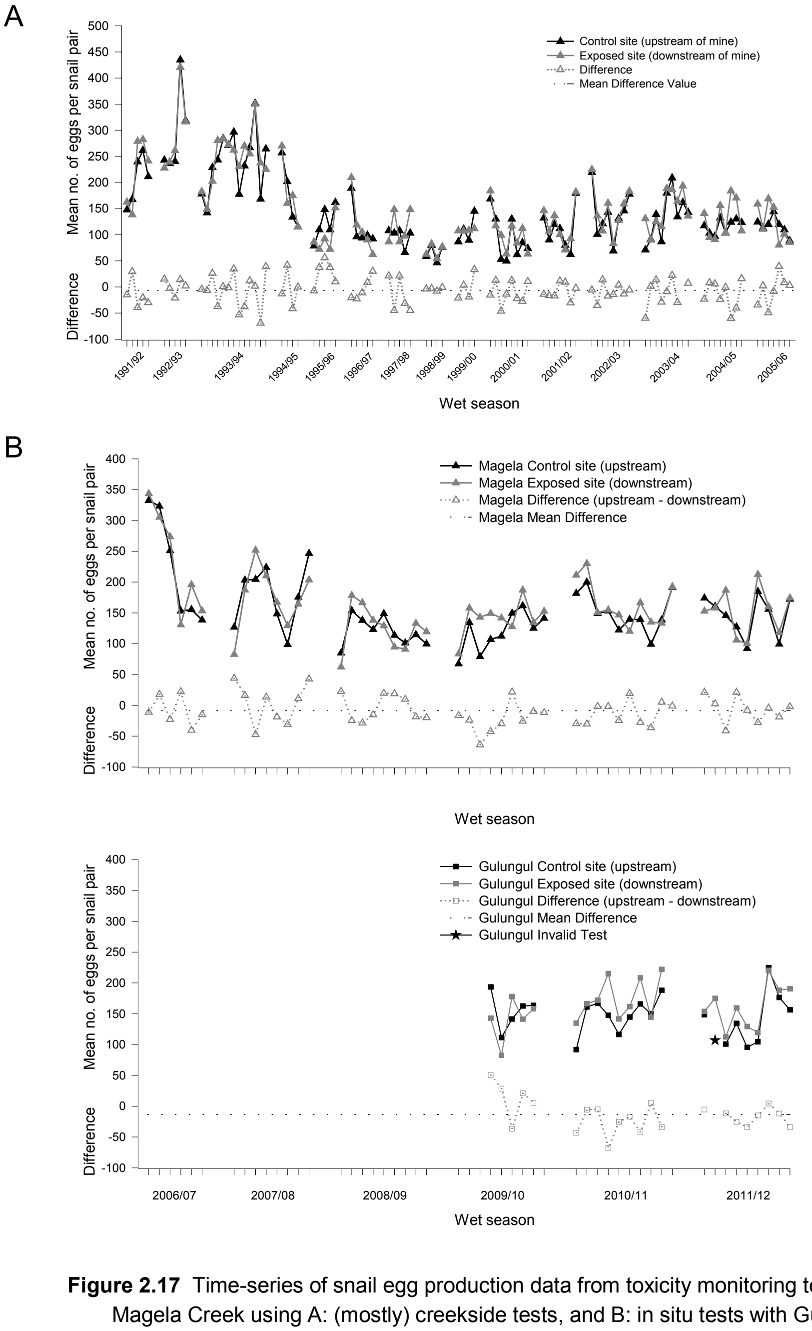


Figure 2.17 Time-series of snail egg production data from toxicity monitoring tests conducted in Magela Creek using A: (mostly) creekside tests, and B: in situ tests with Gulungul tests commencing in 2009–10.

Analysis of Magela Creek results

After each wet season, toxicity monitoring results for the tests are analysed, with differences in egg numbers (the 'response' variable) between the upstream (control) and downstream (exposed) sites tested for statistical change between the wet season just completed and previous wet seasons.

The mean number of eggs produced each test at the upstream and downstream sites for 2011–12 fell within previously-recorded ranges in values for the in situ method (Figure 2.17B). The difference values recorded during the 2011–12 wet season continue the trend of greater egg production downstream since inception of toxicity monitoring, with an average difference value of -8.2 (Figure 2.17A&B). This is much closer to the historical mean of -5.8 (pre 2009–10), than to the means recorded in the previous two years (2009–10 = -22.3, 2010–11 = -12.8), resulting in a new mean difference value across the complete time series of -8.0.

Unlike the previous two wet seasons (see 2010–11 Supervising Scientist annual report and Table 2.7), Analysis Of Variance (ANOVA) testing found no significant difference between the results (upstream-downstream difference values) of the wet season of interest (2011–12) and those from previous years (Table 2.7, P = 0.907). See also section 3.4 of this report, 'Analyses of toxicity monitoring and associated water quality data for Magela and Gulungul Creeks' where additional interpretation of Magela Creek toxicity monitoring results from recent years is provided.

TABLE 2.7 RESULTS OF ANOVA TESTING COMPARING MAGELA 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	0.043	at 5% level
2010–11 compared with all previous seasons	0.434	NS
2010–11 compared with previous seasons excl 2009-10	0.315	NS
2010–11 + 2009–10 compared with previous seasons	0.044	at 5% level
2011–12 compared with all previous seasons	0.907	NS
2011–12 compared with previous seasons excl 2009-10	0.989	NS

NS = Not significant

Analysis of Gulungul Creek results

Gulungul Creek results for the 2011–12 wet season show consistently higher snail egg production at the downstream site compared to the upstream site, with seven of the eight valid tests producing a negative difference value (Figure 2.17B). Thus the results for this wet season are similar to those observed for the previous season (2010–11; eight of the nine tests with a negative difference value) but are in contrast to those observed during the initial wet season (2009–10) when four out of the five tests resulted in positive difference values, indicating higher upstream egg production.

ANOVA testing found no significant difference between the upstream-downstream difference values for the wet season of interest (2011–12) and those from the previous two years (Before period, 2009–10 and 2010–11; P =0.813). However, when data from 2010–11 and 2011–12 wet seasons are combined and compared with 2009–10 data, the ANOVA result is close to significant (P = 0.055) reflecting interannual variability in Gulungul Creek upstream-downstream difference values that has not been encountered in Magela Creek. Gulungul Creek toxicity monitoring results from recent years are discussed in more detail in section 3.4 of this report, 'Analyses of toxicity monitoring and associated water quality data for Magela and Gulungul Creeks'.

Conclusions

Concordance in the snail egg production responses between upstream and downstream sites in Magela and Gulungul Creeks for the 2011–12 wet season was high (Figure 2.17) with difference values consistent with, and not significantly different from, long-term mean values. Further analysis of the data is provided in section 3.4 of this report in the context of discerning possible effects of mine-input EC on enhancing snail egg production.

Bioaccumulation in freshwater mussels

Local Aboriginal people harvest aquatic food items including fish and mussels from Mudginberri Billabong, 12 km downstream of the Ranger mine (Map 3). It has been shown that mussels accumulate some metals and radionuclides, in particular ^{226}Ra. However nine years (2000–08) of monitoring of the levels of metals and radionuclides in fish had not shown any issues of potential concern with regards to bioaccumulation. Hence, the effort on the bioaccumulation component of the monitoring program has been reduced to analysing mussels, while the previously undertaken two-yearly fish sampling program has been discontinued since 2007.

It is essential to check that mussels are fit for human consumption and that concentrations of metals and/or radionuclides in mussel tissue attributable to mine-derived inputs from Ranger remain within acceptable levels. In addition, enhanced body burdens of mine-derived solutes in mussels could potentially reach limits that may harm the organisms themselves, as well as provide early warning of bioavailability of these 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 from Mudginberri (the potentially impacted site) and Sandy Billabongs (the control site in a different catchment, sampled from 2002 onwards). The results showed that radionuclide burdens in mussels from Mudginberri Billabong were generally about twice that in the reference Sandy Billabong. Two research projects (reported in the 2007–08 and 2008–09 Annual reports) investigating factors controlling the sources and uptake of radionuclides in the mussels along the Magela catchment concluded that this difference was due to natural catchment influences and differences in water chemistry, rather than any mining-related inputs between the upstream and downstream sites.

Thus the scope of the mussel bioaccumulation monitoring program was reduced from 2009 onwards. It now involves the annual collection and analysis of a bulk mussel sample from Mudginberri Billabong, rather than analysing age-classed mussels from both Mudginberri and Sandy Billabongs. This is done primarily to provide re-assurance that the consumption of mussels does not present a radiological risk to the public. Every three years (starting with the October 2011 collection reported here) a detailed study (analysis of aged mussels from Mudginberri and Sandy Billabongs) is conducted and results compared with those from previous years.

Uranium in freshwater mussels

Uranium concentrations in mussels, water and sediment samples collected concurrently from Mudginberri and Sandy Billabongs over the years are shown in Figure 2.18.

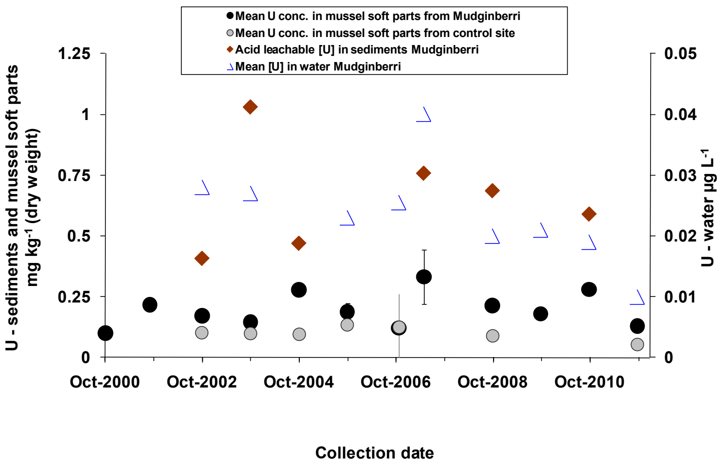


Figure 2.18 Mean concentrations of U measured in mussel soft-parts and sediment (dry weight basis) and in water samples collected from Mudginberri and Sandy Billabongs since 2000

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 2.18. 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 2011, indicates absence of any mining influence.

^{226}Ra and ^{210}Pb in mussels

Radionuclide activity concentrations in mussels collected from Mudginberri and Sandy Billabongs in 2011 are compared with the average radionuclide activity concentrations measured in previous years in Figure 2.19. The graphs show that ^{226}Ra activity concentrations in aged mussels from Sandy Billabong are lower than from Mudginberri

Billabong, as reported in previous years, and that activity concentrations were no different in 2011 compared with the average from previous collections.

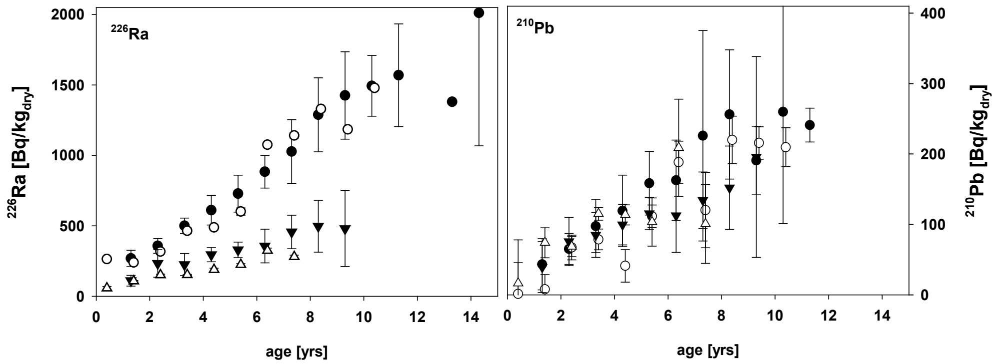


Figure 2.19 ^{226}Ra and ^{210}Pb activity concentrations measured in dry mussels flesh from Mudginberri (circles) and Sandy (triangles) Billabongs. The average of previous end of dry season collections (2000–2008) is shown as solid symbols, open symbols show the results from the 2011 collection.

Based upon the activity concentrations of ^{226}Ra and ^{210}Pb in mussel flesh and the age distribution of mussels collected, the average annual committed effective dose can be calculated for a 10-year old child who eats 2 kg (wet weight) of mussel flesh from Mudginberri Billabong. The average of all collections from 2000 to 2010 is 0.18 mSv. In 2011, the committed effective dose was slightly lower at 0.14 mSv.

This dose is almost exclusively from natural background contributions and would be received irrespective of the operation of the Ranger mine. This assertion can be made since: (1) the difference between ^{226}Ra activity concentrations measured in Magela Creek upstream and downstream of the Ranger mine is only very small (see section 2.3.1), and (2) the findings from previously reported research show that mussel radionuclide activity loads in Mudginberri Billabong are currently due to natural catchment rather than mining influences. Figure 2.20 shows the doses estimated for individual years, and the median, 80 and 95 percentiles for all collections. For Sandy Billabong mussels the inferred ingestion dose for 2011 was 0.06 mSv.

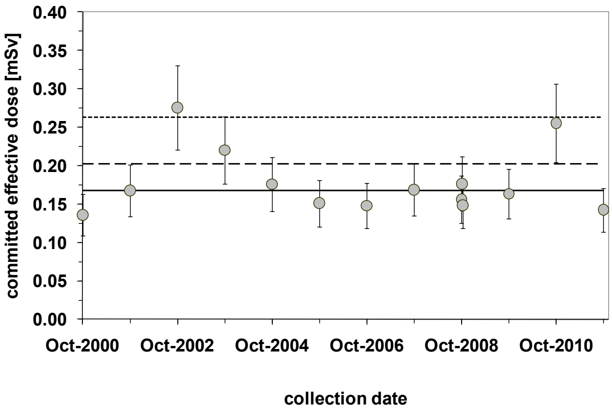


Figure 2.20 Annual committed effective doses (point data) from ^{226}Ra and ^{210}Pb for a 10 year old child eating 2 kg of mussels collected from Mudginberri Billabong. The median for all the data (solid line), the 80th percentile (dashed line) and 95th percentile (dotted line) are shown for reference.

Monitoring using macroinvertebrate community structure

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

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

Disturbed sites may be associated with significantly higher dissimilarity values compared with undisturbed sites. Compilation of the full macroinvertebrate dataset from 1988 to 2011, and data from the paired sites in the two 'exposed' streams, Magela and Gulungul Creeks, for 2012, 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 wet season of interest. For this multi-factor ANOVA, only data gathered since 1998 have been used. (Data gathered prior to this time were based upon different and less rigorous sampling and sample processing methods, and/or absence of sampling in three of the four streams.)

At the time of preparing this annual report and as noted above, only samples from Magela and Gulungul Creeks from the 2011–12 wet season were available for analysis. Without comparable data from the two control streams, it is not possible to run the full ANOVA testing for 2012. Instead, a modified ANOVA model was run using the factors Before/After (BA; fixed), Year (nested within BA; random) and Stream (upstream vs downstream paired dissimilarities; random) examining just the exposed creeks, Magela and Gulungul, to determine if any change in these streams has occurred. The ANOVA showed no significant change from the before (pre 2011–10) to after (2011–10) periods in the magnitude of upstream-downstream dissimilarity across both 'exposed' streams and this was consistent between both streams (BA and BA*Stream interaction not significant respectively).

These results confirm that the dissimilarity values for 2012 for both Magela and Gulungul Creeks do not differ from previous years. While the Year*Stream interaction is significant in the same analysis ($p = 0.014$), this simply indicates that dissimilarity values for the two streams show natural differences through time (also evident in the control streams). This variation over time is evident in Figure 2.21, particularly for recent years in Gulungul Creek, and is further considered below.

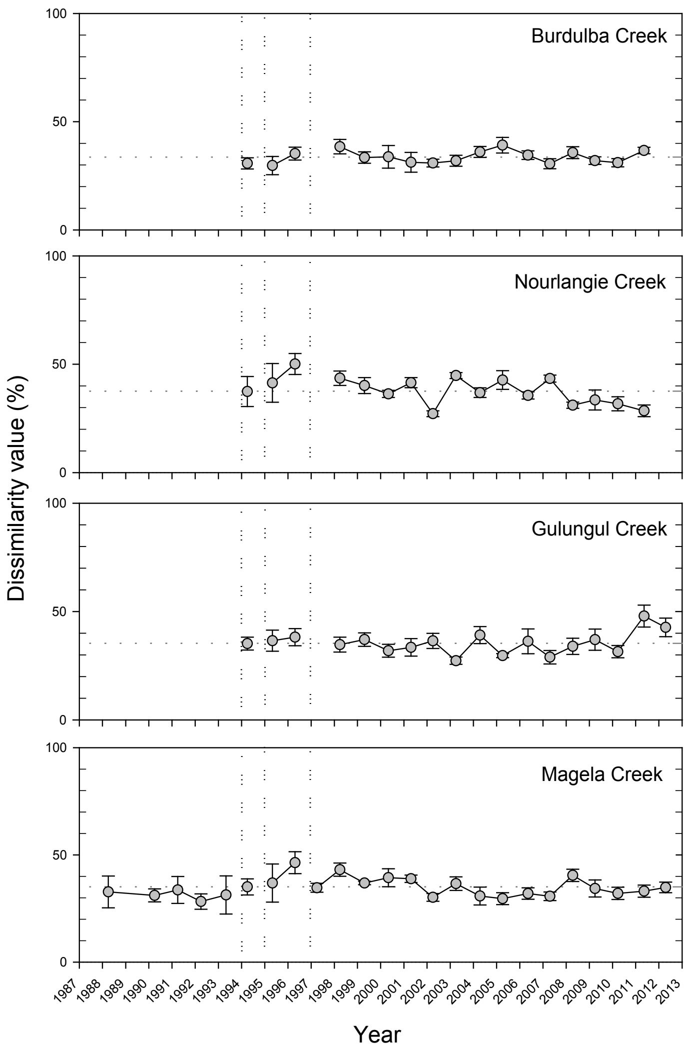


Figure 2.21 Paired upstream-downstream dissimilarity values (using the Bray-Curtis measure) calculated for community structure of macroinvertebrate families in several streams in the vicinity of the Ranger mine for the period 1988 to 2012. The dashed vertical lines delineate periods for which a different 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.

In ***eriss***'s Annual Research Summary for 2010–11, a sharp rise in dissimilarity for Gulungul Creek following the 2010–11 wet season was reported[1] (see 2011 Gulungul dissimilarity value in Figure 2.21). Accompanying multivariate analyses showed that the *upstream* Gulungul site in 2011 was significantly different from the before (pre 2010–11) to after (2010–11) periods and that was related to an unusually higher proportion of taxa with a preference for high velocity waters (ie so-termed 'flow-dependent' taxa). The magnitude of paired-site dissimilarity for Gulungul Creek in 2012 has declined from its peak in 2011, but remains elevated compared with data prior to 2011 (see Figure 2.21). Despite the non-significant

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

before versus after ANOVA result for 2012, the slightly elevated dissimilarity has been examined further to ensure mine-related change was not occurring.

Figure 2.22 depicts the multivariate ordination derived using replicate within-site macroinvertebrate data. Data points are displayed in terms of the sites sampled in Magela and Gulungul Creeks downstream of Ranger for each year of study (to 2012), relative to Magela and Gulungul Creek upstream (control) sites for 2012, and all other control sites sampled up to 2011 (Magela and Gulungul upstream sites, all sites in Burdulba and Nourlangie). Samples close to one another in the ordination indicate a similar community structure.

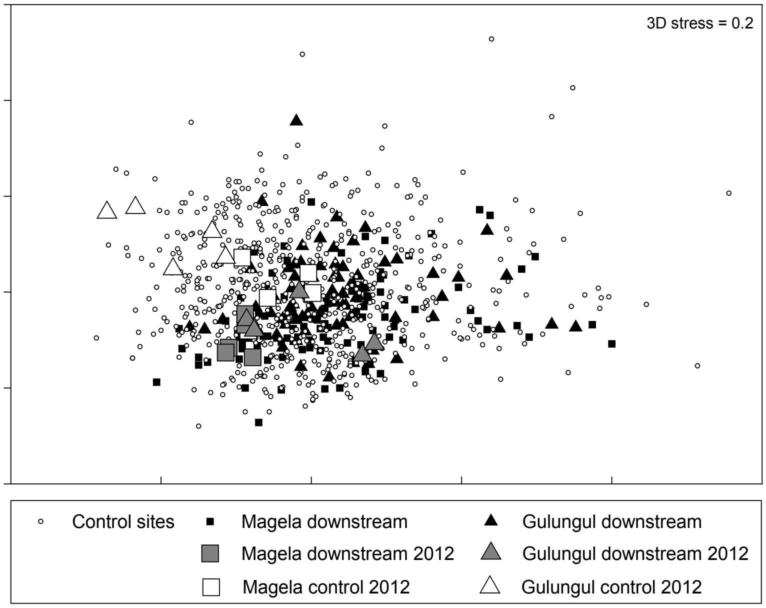

Figure 2.22 Ordination plot (axis 1 and 2) of macroinvertebrate community structure data from sites sampled in several streams in the vicinity of Ranger mine for the period 1988 to 2012. Data from Magela and Gulungul Creeks for 2012 are indicated by the enlarged symbols.

Examination of the three-dimensional ordinations for all paired axes combinations (results not shown) indicated that Gulungul Creek communities from the upstream site still differed in 2012 from other sites and times (Figure 2.22). However, the separation of the upstream replicate values was not as marked as that observed in 2011 (Supervising Scientist annual report for 2010–11, Figure 2.22). Data points associated with the 2012 Gulungul and Magela downstream sites are generally interspersed among the points representing the control sites, indicating that these 'exposed' sites have macroinvertebrate communities that are similar to those occurring at control sites. This was confirmed by PERMANOVA (PERmutational Multivariate ANalysis Of Variance) testing on the *individual sites* (cf paired site dissimilarity for the ANOVA above) of the exposed streams (Magela and Gulungul) which showed no significant difference between the downstream data from 2012 with downstream data from previous years, and no significant difference between the upstream data from 2012 with upstream data from previous years.

Collectively, these graphical and statistical results provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2012 have not adversely affected macroinvertebrate communities.

Monitoring using fish community structure

Assessment of fish communities in billabongs is conducted between late April and July each sampling year, the precise time of the monitoring being dependent on flow regime, using non-destructive sampling methods at 'exposed' and 'control' locations. Two billabong types are sampled: deep channel billabongs every year, and shallow lowland (mostly backflow) billabongs dominated by aquatic plants every two years. Details of the sampling methods and sites were provided in the 2003–04 Supervising Scientist annual report (Supervising Scientist annual report 2004, chapter 2, section 2.2.3). These programs were reviewed in October 2006 and the refinements to their design are detailed in Supervising Scientist annual reports 2007 and 2008 (chapter 2, section 2.2.3).

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

Channel billabongs

The similarity of fish communities in Mudginberri Billabong (directly exposed site downstream of Ranger in Magela Creek catchment) to those of Sandy Billabong (control site in the Nourlangie Creek catchment) (see Map 3) are determined using multivariate dissimilarity indices calculated for each annual sampling occasion. A plot of the dissimilarity values from 1994 to 2012 is shown in Figure 2.23.

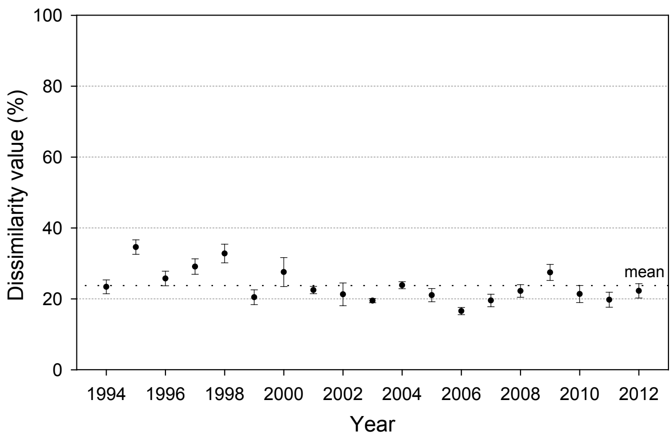

Figure 2.23 Paired control-exposed dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in Mudginberri ('exposed') and Sandy ('control') Billabongs in the vicinity of the Ranger Mine over time. Values are means (± standard error) of the 5 possible (randomly-selected)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

The paired-billabong dissimilarity values have been analysed using a two-factor ANOVA (ANalysis Of VAriance), with Before/After (BA; fixed) and Year (nested within BA; random) as factors. In this analysis the 'BA' factor tests whether values for the year of interest (2012) are consistent with the range of values reported in previous years (1994 to 2011) while the factor 'Year' tests for differences amongst years within the before or after periods. The ANOVA results showed no significant difference between 2012 and other years (BA factor not significant, $p = 0.758$), indicating the relationship between Mudginberri and Sandy Billabong fish communities has remained consistent with relationships observed in previous years. However, the variation in fish assemblage dissimilarities between the two billabongs amongst years (tested by factor Year) was significantly different over the 1994 and 2012 period ($p < 0.001$). This variation over time is evident in Figure 2.23 and is further considered below.

In previous reports, possible causes of trends in the annual paired-site dissimilarity measured 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 (Supervising Scientist annual report 2004, chapter 2, section 2.2.3). Thus, effort has been directed at understanding the possible causes of interannual variations in the abundance of this fish species in Magela Creek.

In previous Supervising Scientist annual reports, negative correlations between annual rainbowfish abundance in Mudginberri Billabong and the magnitude of wet season discharge (total for the wet season, January total and February total, GS8210009) have been observed in Magela Creek. The negative relationships between rainbowfish in Mudginberri Billabong and wet season conditions have been further tested using rainfall data (Jabiru airport records). Rainfall data have been used in place of discharge data because it is considered more representative of regional wet season conditions. The results support those from previous years with negative relationships observed between rainbowfish abundance in Mudginberri Billabong and both the total annual rainfall ($p = 0.019$) and the rainfall total for January ($p = 0.039$).

To this end, the results from 2012 continue to support previous suggestions that reduced rainbowfish abundances occur after larger wet season rainfalls which potentially allow greater upstream migration of rainbowfish past Mudginberri Billabong, thereby reducing the concentration of fish in the billabong during the recessional flow period. The relationship between annual rainfall and rainbowfish abundance in Mudginberri Billabong can be visualised in Figure 2.24.

Collectively, the analyses described above provide good evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2012 have not adversely affected fish communities in channel billabongs.

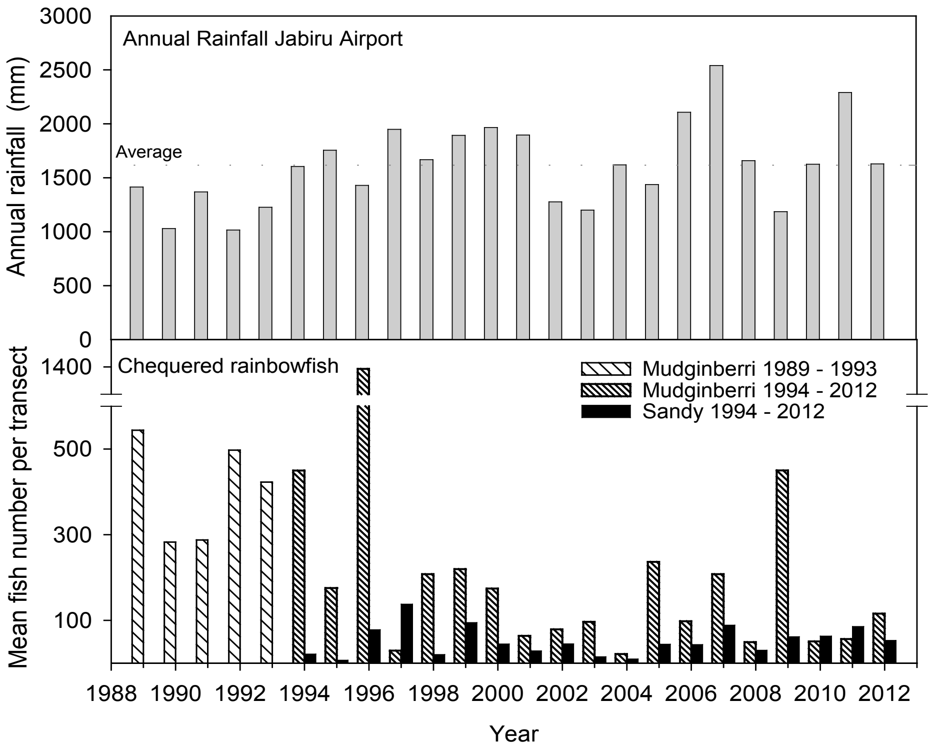

Figure 2.24 Relative abundance of chequered rainbowfish in Mudginberri and Sandy Billabongs from 1989 to 2012 with associated total discharge in Magela Creek (gauging station G8210009)

Shallow lowland billabongs

Monitoring of fish communities in shallow lowland billabongs has previously been conducted every two years (see Supervising Scientist annual report 2007, chapter 2, section 2.2.3). The last assessment of fish communities in these billabongs occurred in May 2009 with results reported in the Supervising Scientist annual report 2009 (section 2.2.3). The scheduled sampling of fish communities in 2011 was postponed to enable staff resources to be dedicated to an intensive sampling of other biota (phytoplankton, zooplankton and macroinvertebrate communities) in these billabong habitats. Results from sampling conducted in June 2012 are discussed below.

The monitoring program for fish communities in shallow billabongs is conducted in six billabongs, comprising three 'control' versus 'exposed' billabong pairs. In a similar manner to fish communities in channel billabongs (discussed above), the similarity of fish communities in the directly exposed sites downstream of Ranger on Magela Creek (Georgetown, Coonjimba and Gulungul billabongs) to those of the control sites (Sandy Shallow and Buba billabongs on Nourlangie Creek and Wirnmuyurr Billabong – a Magela floodplain tributary) (see Map 3) is determined using multivariate dissimilarity indices calculated for each sampling occasion. A plot of the dissimilarity values of the control-exposed site pairings – Coonjimba-Buba, Georgetown-Sandy Shallow and Gulungul-Wirnmuyurr Billabongs – from 1994 to 2012, is shown in Figure 2.25.

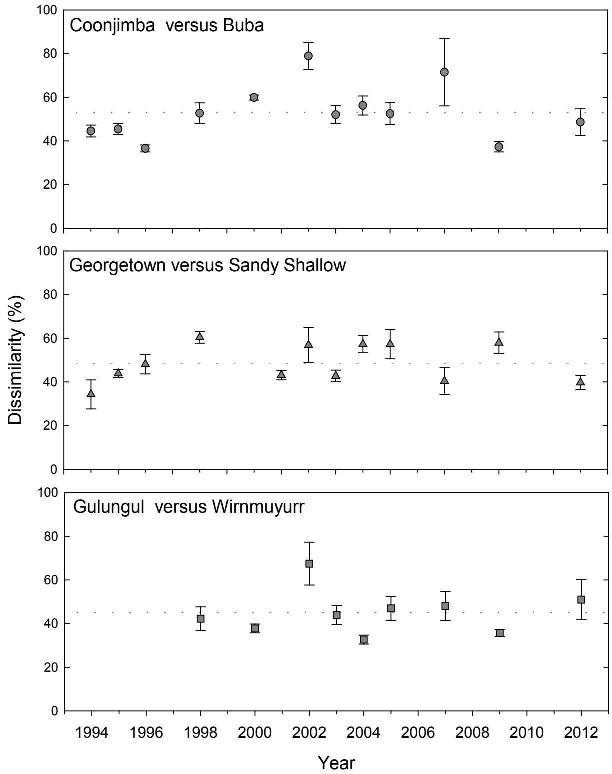

Figure 2.25 Paired control-exposed site dissimilarity values (using the Bray-Curtis measure) calculated for community structure of fish in 'exposed' Magela and 'control' Nourlangie and Magela Billabongs in the vicinity of Ranger mine over time. Values are means (± standard error) of the 5 possible (randomly-selected) pairwise comparisons of average trap enclosure data between the pairwise billabong comparisons, Coonjimba-Buba, Gulungul-Wirnmuyurr and Georgetown-Sandy Shallow billabongs.

The three sets of paired-billabong dissimilarity values measured since 1998 (when sampling of all three site-pairs commenced) have been analysed using a three-factor ANOVA with Before/After (BA; fixed), Year (nested within BA; random) and Site-pair (Fixed) as factors. In this analysis the BA factor tests whether values for the year of interest (2012) are consistent with the range of values reported in previous years (1998 to 2011), the factor 'Year' tests for differences amongst years within the before or after periods and the 'Site-pair' factor tests for differences amongst the three paired-billabong dissimilarities. The ANOVA results showed that across all three site-pairs there was no significant change from 2012 to other years (BA factor, $p = 0.508$) and that the change between 2012 and previous years within the individual site-pairs was consistent (BA*Site-pair interaction, $p = 0.433$). These results confirm that dissimilarity values for 2012 for all three site-pairs do not differ from those values from previous years. Significant differences do occur over time within site-pairs (Year*Site-pair interaction, $p = 0.001$) which reflects (natural) changes through time. This variation over time is evident in Figure 2.25 and is further considered below.

The paired-site dissimilarities shown in Figure 2.25 average between 40 and 60% indicating fish communities in each of the billabongs comprising a site-pair are quite different from one another. The dissimilarity values appear to reflect differences in aquatic plant communities of the site-pair billabongs. In the Supervising Scientist annual report 2007 (section 2.2.3) it was identified that the particularly high dissimilarity values observed in the Coonjimba-Buba pairing for 2002 and 2007, and the Gulungul-Wirnmuyurr site pairing for 2002 (Figure 2.25) were attributable to high densities of particular aquatic plant types in one or both of the billabongs. Excessive plant densities are unfavourable for fish communities as fish movement, and hence residency, is physically prevented. The influences of aquatic plant communities in billabongs and their influence in turn over fish communities is being further assessed.

Collectively, the 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 2012 have not adversely affected fish communities in shallow billabongs.

2.3 Jabiluka

2.3.1 Developments

The site continues to be maintained under a 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.

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 2011–12 (Table 2.8). An environmental audit was held in May 2012 and RPIs were held in August, November and February.

TABLE 2.8 RPI FOCUS DURING THE REPORTING PERIOD

Date	Inspection type	Foci
18 August 2011	RPI	Interim water management pond (IWMP) and drop structure, vent raise, access road, hardstand area, portal area revegetation
17 November 2011	RPI	IWMP and telemetry, Djarr Djarr
16 February 2012	RPI	IWMP and drop structure, hardstand revegetation, helipad area, Djarr Djarr (fly over only)

2011 Audit review outcomes

The conditional finding from the 2011 Environmental Audit relating to rehabilitation of redundant boreholes in Mine Valley was followed up through the RPI process. This criterion was also graded conditional at the 2010 audit of the Jabiluka Authorisation. ERA is engaged in discussions with the NLC and GAC to progress works and obtain necessary permits for access to the area to complete the works. Negotiations between traditional owners and ERA regarding final rehabilitation of remaining bores are ongoing.

2012 Audit outcomes

The annual environmental audit of Jabiluka was held in May 2012 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 a category 2 non-conformance and one conditional. The Category-2 non-conformance was due to the late submission of the Annual Amended Plan of Rehabilitation for the site. At the time of the audit ERA had not applied for an extension to the submission date and the plan was overdue. The conditional finding relates to the ongoing works to finalise rehabilitation of redundant bore holes in Mine Valley and ERA is progressing necessary permits through the Aboriginal Areas Protection Authority.

2.3.2.3 Minesite Technical Committee

The Jabiluka MTC met six times during 2011–12. Dates of meetings and significant issues discussed are shown in Table 2.9.

TABLE 2.9 JABILUKA MINESITE TECHNICAL COMMITTEE MEETINGS

Date	Significant agenda items
7 July 2011	Annual Plan of Rehabilitation no.14, Djarr Djarr rehabilitation, lease boundaries, routine periodic inspections
9 September 2011	Wildlife death, Djarr Djarr rehabilitation, Annual Plan of Rehabilitation no.14, 2010–11 Wet Season Report, installation of continous monitoring equipment at IWMP
10 November 2011	Installation of monitoring equipment at IWMP, Annual Plan of Rehabilitation no. 14, 2010–11 Wet Season Report, options for removal of IWMP
20 January 2012	Installation of monitoring equipment at IWMP, Annual Plan of Rehabilitation no. 14, 2010–11 Wet Season Report, options for removal of IWMP
5 April 2012	Installation of monitoring equipment at IWMP, Annual Plan of Rehabilitation no. 14, 2010–11 Wet Season Report, options for removal of IWMP, installation of a pump at IWMP
1 June 2012	Plans for removal of IWMP, Djarr Djarr rehabilitation, 2010–11 Wet Season Report, 2010–11 Annual Interpretive 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 reported environmental incidents reported for the 2010–11 reporting period. During the August stakeholder inspection at Jabiluka, a juvenile bird of prey was observed deceased in the Interim Water Management Pond (IWMP). This was recorded in ERA's animal deaths register.

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 met. 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

Flow was first recorded at the Ngarradj (Swift Creek) monitoring station on 4 December 2011. EC remained less than 20 µS/cm throughout the 2011–12 wet season and decreased to less than 15 µS/cm with increased water levels during mid-late December 2011 (Figure 2.26). The decline in water levels observed during late December 2011/early January 2012 was accompanied by a corresponding increase in EC, with notable decreases in EC associated with the rainfall events throughout late January, February and March 2012. Recessional flow conditions became established in April 2012 with low water levels and rising EC. Data were lost between 5 and 12 April 2012 due to a build-up of sand around the sensors combined with a communications malfunction with the local data logger. Rainfall events during late April and early May 2012 resulted in short-term peaks and troughs in EC. Continuous monitoring continued until 26 June 2012 when cease to flow was agreed by stakeholders.

Overall, the water quality measured in Ngarradj for the 2011–12 wet season is comparable with previous wet seasons (Figure 2.27).

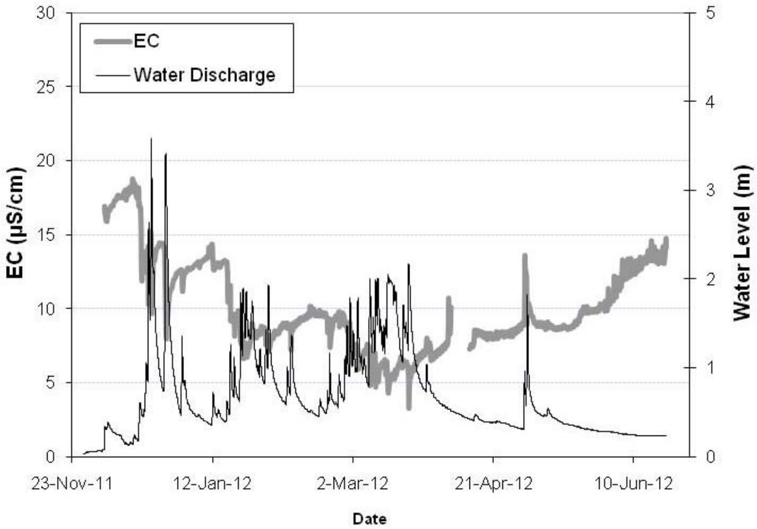

Figure 2.26 Continuous electrical conductivity in Ngarradj between November 2011 and June 2012

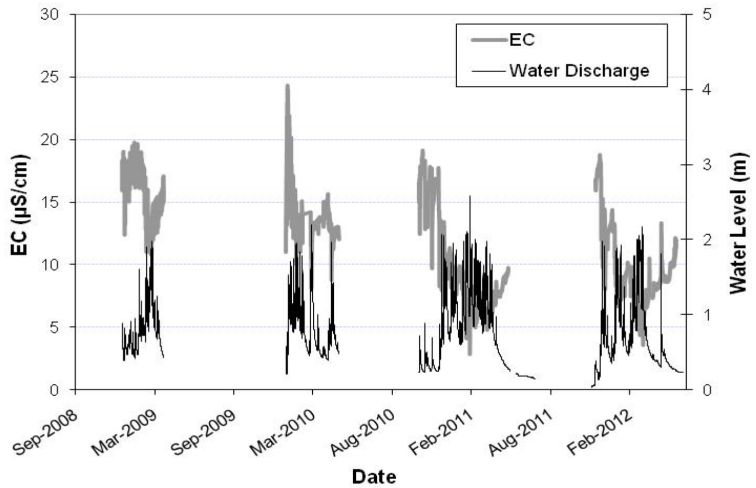

Figure 2.27 Electrical conductivity measurements at the downstream monitoring station in Ngarradj for each wet season between November 2008 and June 2012

2.4 Nabarlek

2.4.1 Developments

In early 2008, Uranium Equities Limited (UEL) bought Queensland Mines Pty Ltd, thereby acquiring the Nabarlek lease (MLN 962). UEL has since developed plans to further explore the lease, clean up the site and continue revegetation and rehabilitation works. Authorisation 0435-01 was granted to UEL on the 28 May 2008 allowing exploration and rehabilitation works at Nabarlek to proceed. Since this time UEL has undertaken significant works to clean up several areas of the site including the old camp and re-contouring of the waste rock dump runoff pond. A Mining Management Plan (MMP) for the 2012 dry season exploration works was submitted to DoR in June 2012 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 28 July 2011:

- Rehabilitation
- Proposed drilling program for 2011 dry season
- Groundwater review
- Development of closure criteria

2.4.1.2 Authorisations and approvals

There was no change to the Authorisation during 2011–12.

2.4.1.3 Incidents

There were no environmental incidents reported at Nabarlek during 2011–12.

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 2011 audit was held on 5 October 2011 and tested compliance with commitments taken from the 2011 Nabarlek Mining Management Plan as submitted by UEL. Of the commitments tested all were found to be acceptable (as per the grading system detailed in Table 2.4) with the exception of four (4) conditional findings. Some commitments were unable to be verified as they related directly to active drilling programs which had ceased prior to the commencement of the audit. The four conditional findings were related to:

- Vehicle wash down bay record keeping
- Storage and bunding of hazardous materials and chemicals
- Monitoring the condition of bores
- A minor amendment to the MMP

The audit also followed up on outstanding commitments from the 2010 audit. All outstanding commitments were found to be acceptable with the exception of one conditional finding. This commitment related to implementation of appropriate weed identification and fire training for personnel which was yet to be developed and finalised at the time of the 2011 audit.

2.4.2.2 Post-wet season inspection

The post wet-season inspection of the Nabarlek site was held on 3 July 2012 and therefore falls outside this reporting period. The inspection will be reported in the 2012–13 annual report.

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. No works on the RAA were undertaken during this reporting period.

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.

oss staff carried out the annual inspection of the containment facility on 12 June 2012. Revegetation is progressing well over the old containment areas and some erosion was noted in parts of the cap. A report was provided to Parks Australia following the inspection.

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 leads and/or participates in audits of the following exploration sites in Western Arnhem Land:

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

Each operation was audited against commitments from their approved Mining Management Plan and criteria tested were graded in accordance with the classifications presented in Table 2.4.

2.5.2.1 Cameco King River Camp

The annual environmental audit of Cameco's Arnhem Land project was held in conjunction with DoR on 21 September 2011. The audit assessed compliance with Cameco's approved Mine Management Plan (MMP) for the 2011 dry season campaign and was also used to determine if observations made during the 2010 audit had been incorporated into the operations.

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

The audit found no non-conformances. There was one observation which noted Cameco could improve rehabilitation methods at drill sites. This observation will be followed up during the 2012 audit.

2.5.2.2 Alligator Energy Myra Camp

The first environmental audit of Alligator Energy's operations based at Myra Camp was held on 20 September 2011 in conjunction with DoR. The audit aimed to assess Alligator Energy's compliance with stated commitments in their approved MMP. During the audit the Myra Camp, Two Rocks and Caramal prospects were inspected. Stakeholders noted a high standard of environmental controls at the vehicle wash down and core cutting area at Myra Camp.

The audit found no high level non-conformances and produced two conditional findings. The conditional findings related to drill rig inspections and potential environmental harm on a cleared slope on the Caramal prospect. On 27 October 2011, Alligator Energy provided correspondence and photographic evidence of the resources and effort allocated to revegetate and stabilise the slope for the coming wet season. Alligator Energy provided a further update on progress of revegetation of this slope in their 2012 MMP and this, along with the conditional finding relating to drill rig inspections, will be followed up at the 2012 audit.

2.5.2.3 UXA Nabarlek Project

The first environmental audit of UXA Resources Limited's Nabarlek project was undertaken in conjunction with DoR and the NLC on 6 October 2011. The focus of the audit was Schedule 5 (Environmental Management Plan) and Schedule 6 (Exploration Rehabilitation) of the approved MMP.

The audit resulted in six category 2 non-conformances and eight conditional findings. The category 2 non-conformances related to:

- Lack of information in the environmental management system
- Incomplete information on local statutory requirements
- Lack of vehicle cleaning and wash down procedures
- Lack of an incident reporting and follow-up system
- Inadequate record keeping of internal environmental audits and inspections
- Lack of an adequate system to account for surface disturbances

The audit team was unable to inspect any operational drill rigs or rehabilitation sites during the audit, as drilling had been completed prior to the audit and rehabilitation was yet to commence. This resulted in nine criteria being graded as not verified.

These above issues, along with the conditional findings from the audit have been discussed further between UXA and DoR. SSD, along with DoR and the NLC, will follow up these issues at the 2012 audit.

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.
>
> 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 (originally submitted to the MTC in November 2008) was approved with the issue of Authorisation 0108-13 on 29 November 2011. Approval of this application resulted in a change to the quarterly reporting requirements for ERA and instead of a quarterly report, SSD and other stakeholders are now provided with summary data that are then discussed during a meeting with ERA. This change first came into effect for the Q1/2012 reporting period. All quarterly reports and summary data due during the reporting period were received and reviewed by the Supervising Scientist Division.

Approval of the application to optimise the radiation and atmospheric monitoring program also required ERA to present a revised dose constraint, consistent with the ALARA (as low as reasonably achievable) principle, to stakeholders. This was presented in the 2011 Annual Report on Radiation and Atmospheric Monitoring and, following review and further discussion with ERA, was acceptable to SSD.

2.6.2 Onsite and offsite radiation exposure at 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 2.10 shows the annual doses received by designated and non-designated workers in 2011, 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 2011 calendar year were approximately 3.4% and 19.5% 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 2.10 ANNUAL RADIATION DOSES RECEIVED BY WORKERS AT RANGER MINE

	Annual dose in 2010		Annual dose in 2011	
	Average mSv	Maximum mSv	Average mSv	Maximum mSv
Non-designated worker	Not calculated[1]	0.57	Not calculated	1.2
Designated worker	0.67	3.93	1.0	5.5

1 A hypothetical maximum radiation dose to non-designated employees is calculated using the gamma exposure results of employees of the Emergency Services Group, and dust and radon results measured at the Acid Plant. Consequently, the dose is conservative and would exceed actual doses received by non-designated employees, and are hence considered maximum doses.

Processing and electrical maintenance workers received the majority of their radiation dose from long-lived alpha activity (1.2 mSv and 0.66 mSv respectively), attributable to the increased maintenance activities undertaken at the plant in the first half of 2011. Average doses for mine and processing production workers remained relatively constant compared with 2010 results. The majority of the radiation doses received by workers in the processing production and mine production areas were from external gamma. Radon decay product concentrations continue to be the highest for workers in mine production and mine maintenance, forming an average contribution of 0.19 mSv in 2011 (similar to 0.17 mSv in 2010).

2.6.2.2 Radiological exposure of the public

National radiation protection standards require that the annual radiation dose received by a member of the public from practices such as uranium mining and milling must not exceed 1 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.

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

Inhalation pathway

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

Figures 2.28 and 2.29 show hourly radon progeny potential alpha energy concentration (PAEC) monitoring data from Jabiru town and near Mudginberri community, respectively, for calendar year 2011. Gaps in the data are due to instrument maintenance and data quality issues.

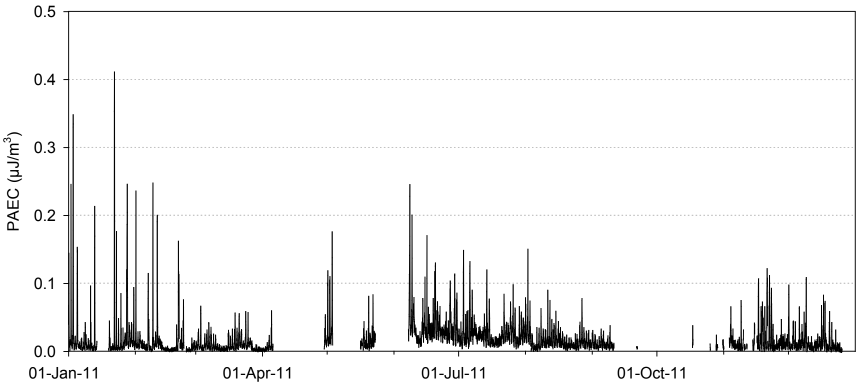

Figure 2.28 Hourly radon progeny PAEC in air at Jabiru town in 2011

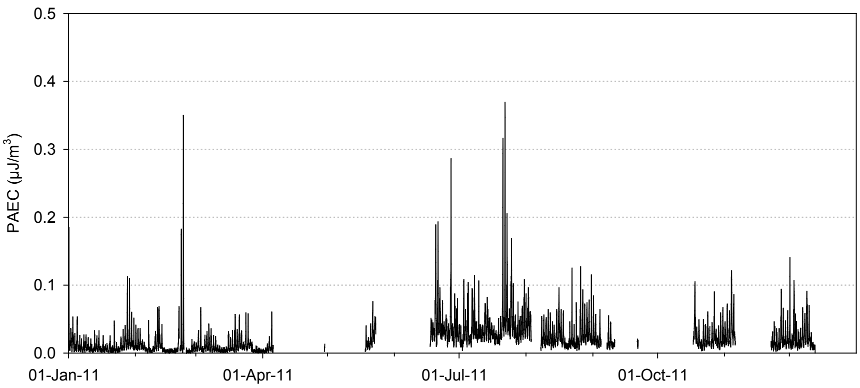

Figure 2.29 Hourly radon progeny PAEC in air at Four Gates Road radon station near the Mudginberri community in 2011

Table 2.11 provides a summary of annual average radon progeny PAEC in air and estimated doses to the public, as well as comparison with values reported by ERA for Jabiru town.

The total annual effective dose from radon progeny in air, which includes contribution from natural background, has been estimated to be 0.179 mSv at Jabiru town and 0.210 mSv at Mudginberri. This total annual dose has been estimated from the product of the annual average radon progeny PAEC in air, the radon progeny dose conversion factor of 0.0011 mSv per $\mu J \cdot h/m^3$ recommended by the International Commission on Radiological Protection (ICRP) and the assumed full year occupancy of 8760 hours.

TABLE 2.11 RADON PROGENY PAEC IN AIR AND ESTIMATED DOSES TO THE PUBLIC AT JABIRU TOWN AND MUDGINBERRI DURING 2011*

	Jabiru town	Mudginberri
Annual average PAEC [$\mu J/m^3$]	0.019 (0.045)	0.022
Total annual dose [mSv]	0.179 (0.434)	0.210
Mine-derived dose** [mSv]	0.021 (0.065)	0.003

* Values in brackets refer to data taken or derived from the ERA Radiation Protection and Atmospheric Monitoring Program Report for the Year Ending 31 December 2011.

** The radon progeny PAEC difference used in the SSD mine-derived dose calculation was 0.009 $\mu J/m^3$.

The mine-derived annual dose from radon progeny in air at Jabiru town has been estimated to be 0.02 mSv, which is approximately one tenth of the total annual dose via this pathway. This dose is dependent on wind direction and has been estimated from the difference in average radon progeny PAEC in air when the wind was from the direction of the mine and when the wind was from directions other than the mine, then multiplying this difference with the radon progeny dose conversion factor and the number of hours that the wind was from the direction of the mine. Hourly wind direction data for 2011 were obtained from the Bureau of Meteorology weather station at Jabiru Airport. Analysis of these data suggests that at Jabiru town the wind was from the direction of the mine (from the 90–110 degree sector) for 2090 hours during the year.

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

Figures 2.30 and 2.31 show measured concentrations of dust-bound LLAA radionuclides in air at Jabiru town and near Mudginberri community, respectively, for 2011. Gaps in the data are due to instrument maintenance and data quality issues.

The total annual effective dose from dust-bound LLAA radionuclides, which includes contribution from natural background, has been estimated to be 0.007 mSv at Jabiru town and 0.005 mSv at Mudginberri. This total annual dose has been estimated by calculating the time weighted annual average LLAA concentration from the individual samples, multiplying with a dose conversion factor of 0.0061 mSv Bq_{α}^{-1} and breathing rate of 0.75 m^3 h^{-1}, then dividing the result by the percentage up time of the dust sampler to account for data gaps.

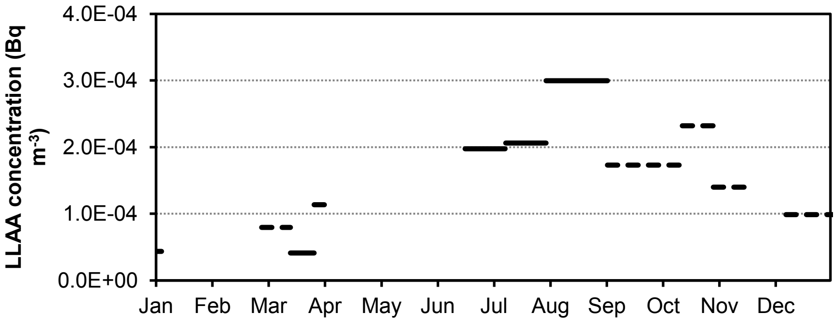

Figure 2.30 Concentrations of dust-bound LLAA radionuclides in air at Jabiru town for samples collected in 2011. The dotted lines indicate that the sampler did not collect over the entire period.

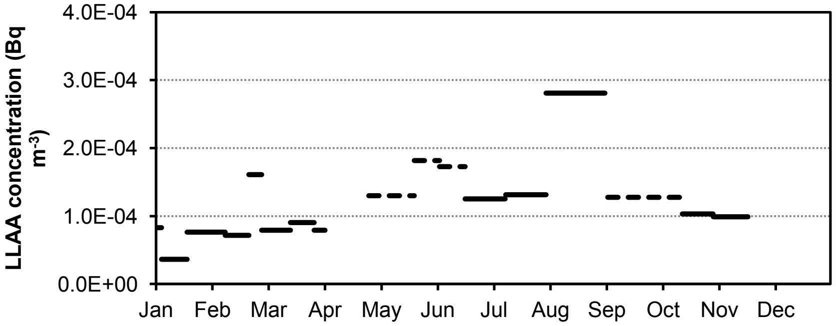

Figure 2.31 Concentrations of dust-bound LLAA radionuclides in air at Four Gates Road radon station near the Mudginberri community for samples collected in 2011. The dotted lines indicate that the sampler did not collect over the entire period.

Ingestion pathway

Radium in Magela Creek waters is routinely monitored by both ERA and SSD. The limit for radium in Magela Creek is based on potential dietary uptake of radionuclides by the Aboriginal people downstream of the mine. Local Aboriginal people have historically expressed concern about the radionuclide concentrations in mussels from Mudginberri Billabong as these are a regularly consumed bushtucker food item. Consequently, SSD routinely monitors the aquatic aspects of the ingestion pathway by collecting and analysing mussels for both radionuclides and heavy metals each year at Mudginberri Billabong (the potentially contaminated site) and every three years at Sandy Billabong (control site in the Nourlangie catchment).

Routine monitoring results show that on average the ^{226}Ra activity concentration in mussel flesh from Mudginberri Billabong is higher than at Sandy Billabong and that 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 2011 collection are presented and discussed above in section 2.3.2).

Historical time series data 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 between the 'impacted' and 'reference' sites 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. Differences in mussel growth and health may also 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 ultimate use of the land by local Aboriginal people and a shift towards terrestrial food sources. These foodstuffs include both terrestrial animals and plants. Over the last 30 years, SSD has gathered radiological concentration data on bushfoods, soils and water throughout the Alligator Rivers Region in the Northern Territory. New data, in particular for terrestrial food items, are acquired on an ongoing basis with samples analysed in 2011–12 including wallaby, buffalo, magpie geese and pig flesh and organs. The ***eriss*** data on radionuclide activity concentrations in bushfoods and environmental media from the ARR are being consolidated into a consistent, quality controlled database (see 2010–11 annual report). The intention of the database is to provide a central data repository and to facilitate calculation of radionuclide concentration ratios for bushfoods and calculation of ingestion doses for members of the public from consumption of these bushfoods.

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 Mineral Lease, the population group that may, in theory, receive a radiation dose due to future activities at Jabiluka is a small community approximately 10 km south of Jabiluka at Mudginberri.

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

Figures 2.29 and 2.31 show radon progeny PAEC and dust-bound LLAA radionuclide concentrations measured in air at Four Gates Road radon station during 2011. The measurements have been used to estimate total annual effective doses, which include contribution from natural background, of 0.21 mSv from radon progeny and 0.005 mSv from LLAA. Only a very small fraction of these doses is expected to be due to mine-derived radionuclides.

2.7 EPBC assessment advice

oss continues to provide advice to the Environment Assessment and Compliance Division of SEWPaC on referrals submitted in accordance with the EPBC Act for new and expanding uranium mines. During the reporting period ***oss*** provided coordinated responses from SSD on the Olympic Dam 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 to ensure that it does not constitute any conflict-of-interest with other work of the Division.

The content and outcomes of the ***eriss*** research program are assessed annually by 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 2011–12 ***eriss*** research program are presented in this report, with a summary introduction to each of these highlights provided below.

As noted in the last annual report, the 2010–11 wet season was a landmark one, when continuous monitoring with associated event-based automatic water sampling became SSD's primary water quality monitoring platform. In that report, substantive progress was also noted on a major project to derive electrical conductivity (EC) and magnesium (Mg) water quality trigger values (TVs) for pulse exposures to magnesium over periods of 4, 8 and 24 h. Magnesium is the solute most likely to approach or exceed water quality trigger values in Magela Creek, based on many years of measurements. The aim was 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. The final chapter of this story is presented here with the development of a functional Mg (EC) versus pulse duration relationship. It is anticipated that this fundamental work will pave the way for the development of a new compliance framework to assess conformance against Mg and EC trigger values in Magela Creek.

Continuous monitoring data also 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 load inputs are trending through time. The continuous monitoring data obtained over the past seven wet seasons for Gulungul Creek (see Map 2 for location) have been used for this purpose and the findings are reported here. This is the first time that the continuous monitoring data for Gulungul Creek have been analysed in this level of detail, and the results complement the solute load data for Magela Creek that were presented in the 2010–11 Supervising Scientist annual report.

Research is ongoing to improve knowledge about the factors that control the toxicity of uranium in the aquatic environment. Dissolved organic carbon originating from the decay of organic matter in river catchments binds strongly to uranium and reduces its toxicity. The results from a recently completed PhD project (see 2007–08 & 2008–09 annual reports) on quantifying the effects of organic carbon on uranium toxicity have been used to produce a predictive relationship between U toxicity and the concentration of organic carbon. This is an important advance because up till now it has not been possible to quantitatively account for changes in U toxicity between creeks and water bodies in the Magela Creek catchment with substantially different concentrations of organic carbon.

The deployment of aquatic snails in Magela and Gulungul Creeks comprises the in situ biological monitoring component of ***eriss***'s wet season water quality monitoring program. In previous annual reports the results have been presented of an ongoing program of research to identify the more subtle environmental factors influencing the response (based on numbers of eggs laid) of the test. This is an important activity since it enables a clearer understanding to be obtained of the factors controlling the (small) year to year variations that have been seen with this test, and better enable a distinction to be made between mining and non-mining effects.

Effective treatment of the process water inventory is the most pressing strategic water management requirement for the Ranger site. Energy Resources of Australia Ltd (ERA) concluded that brine concentration is the method of choice for treating this water and in late 2011 undertook a pilot scale trial of this technology. ***eriss*** carried out a comprehensive ecotoxicological test program on samples of water produced by the pilot plant. The objective of this test work was to identify any specific issues that might need to be addressed for the management of the purified water stream, in advance of commissioning a full scale brine concentrator on site.

The development of water quality closure criteria has been a long running focus of research activity. In this annual report the findings from a project to develop criteria for natural waterbodies on the Ranger lease are presented. These criteria are important for both guiding water management during the operational life of the mine and for assessing post-rehabilitation performance.

A progress report is presented of the ongoing findings from the four erosion plots established by ***eriss*** on an eight hectare trial landform constructed during late 2008 and early 2009 by ERA. The loads of material being exported from these plots continues to decline with time, with the 2011–12 wet season data starting to show for the first time the effects of the developing vegetation on reducing the rate of erosion. The emissions of radon from the trial landform are also being measured each wet and dry season, to assess the changes that are occurring as the landform evolves. These data will inform assessment of the possible radiological footprint of the final rehabilitated landform, and guide the design of the rehabilitation process from a radiological perspective.

An updated vegetation map for the Magela Creek floodplain has been produced from the World-View 2 high resolution satellite image acquired in May 2010; the technical details were presented in the 2010–11 annual report. Successful vegetation mapping over time can assist with identifying the key drivers of the vegetation variability and whether the change is naturally induced or the result of impacts from fire, feral animals and weeds, or impacts from the minesite. The Australian Government Departments of Sustainability, Environment, Water, Population and Communities (DSEWPaC) and Climate Change and Energy Efficiency (DCCEE) jointly funded a LiDAR (Light Detection and Ranging) data capture for the Alligator Rivers Region, the specifications for which were developed by ***eriss***. The products from this LiDAR acquisition will be high resolution digital elevation models (DEMs) that can be used for assessing consequences of sea level rise on the Magela floodplain. More specifically, ***eriss*** will produce DEMs of specific areas of relevance to uranium exploration or mining that that will inform the assessment of erosion potential and landscape stability.

More comprehensive descriptions of ***eriss*** research are published in journal and conference papers and in the Supervising Scientist and Internal Report series. Publications by Supervising Scientist Division staff in 2011–12 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 2012, is available on the SSD web site at www.environment.gov.au/ssd/publications.

3.1 Derivation of a trigger value versus exposure duration model for EC and Mg using pulse exposure toxicity data

Concentrations of mine-derived solutes in Magela Creek from the Ranger uranium mine do not occur at constant levels, but vary widely during the wet season due to changes in creek discharge, mine water discharge and mine water source. Continuous monitoring of electrical conductivity (EC) in Magela Creek since the 2005–06 wet season has confirmed the marked variability in creek water quality associated with mine water discharges.

Electrical conductivity is the key signature variable for the effect of discharges of Ranger mine water into Magela Creek. The EC is dominated by magnesium sulfate ($MgSO_4$) with a strong linear relationship having been established between EC and Mg using over five wet seasons of data (Supervising Scientist annual report 2010–11). Consequently, concentrations of Mg can be confidently predicted from EC measurements. A large body of research has been undertaken on the toxicity of $MgSO_4$ to local aquatic species, resulting in the derivation by SSD of a site-specific water quality trigger value (TV) for magnesium (Mg) in Magela Creek of 2.5 mg/L (Mg being the predominant toxic ion in $MgSO_4$; van Dam et al 2010).[2] However, the Mg toxicity data and associated TV were based on a chronic exposure regime over several days (3 to 6 days depending on the species) and, as such, are not representative of the majority of the much more transitory environmental exposures in Magela Creek.

Comparison of the proposed Mg TV with the continuous monitoring EC data from the 2005–06 to 2008–09 wet seasons revealed 43 exceedances of the TV. The median Mg concentration and exceedance duration was 3.4 mg L^{-1} and 6 h, respectively, and all except one of the exceedances were of durations much shorter than the published chronic toxicity test exposure regimes. Therefore, they were considered unlikely to be causing detrimental effects downstream of the mine, but at that time there were no quantitative data to support this assumption. Given the high conservation value of the Magela Creek catchment, it was considered necessary to better understand the potential effects of short-term exceedances of the Mg TV (ie pulse exposures of Mg).

The aims of the study were to (i) assess the toxicity to local freshwater species of Mg pulse exposures relevant to those measured in Magela Creek, and (ii) use the data to develop a model from which Mg or EC TVs can be derived for any given exposure duration.

Six local freshwater species (green alga, *Chlorella* sp; duckweed, *Lemna aequinoctialis*; snail, *Amerianna cumingi*; cladoceran, *Moinodaphnia macleayi*; green hydra, *Hydra viridissima*; and northern-trout gudgeon, *Mogurnda mogurnda*) were exposed to single Mg pulse exposures of 4 h, 8 h and 24 h (at a constant Mg:Ca ratio of 9:1, as per van Dam et al 2010), before being transferred to clean water and their responses (eg reproduction, growth, etc) monitored for the remainder of the standard toxicity test durations (3 to 6 days depending on species). At least two toxicity tests were undertaken for each species/pulse duration combination. A limited number of continuous Mg exposure toxicity tests were completed to confirm the responses and toxicity values previously derived and reported in van Dam et al (2010).

For all species, Mg toxicity increased as exposure duration increased. However, the extent to which toxicity increased differed between species, from 2-fold to 40-fold. Moreover, the nature of the positive relationship between toxicity and exposure duration differed between species, from linear to exponential. The concentrations of Mg resulting in 10% inhibition of response (IC10) for each species are summarised in Table 3.1.1. The IC10 data are considered to be reliable measures of a low/acceptable effect on species, and are presently the preferred toxicity measure for deriving TVs.

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[2] van Dam RA, Hogan AC, McCullough C, Houston M, Humphrey CL & Harford AJ 2010. Aquatic toxicity of magnesium sulfate, and the influence of calcium, in very low ionic concentration water. *Environmental Toxicology & Chemistry* 29(2), 410–421.

TABLE 3.1.1 MAGNESIUM IC10[a] VALUES FOR EACH SPECIES AND MG PULSE EXPOSURE DURATION

Species	IC10 value (mg L^{-1})			
	4-h pulse	8-h pulse	24-h pulse	Continuous exposure [b]
Chlorella sp	5950	5620	3880	818
Lemna aequinoctialis	4030	1500	80	36
Amerianna cumingi	3030	387	301	5.6
Moinodaphnia macleayi [c]	212	62	128	39
Hydra viridissima	1210	1000	709	246
Mogurnda mogurnda [d]	>4100	>4100	>4100	4010

[a] IC10: concentration at which there was 10% inhibition in response of the organism. [b] Continuous exposure toxicity data from van Dam et al (2010). [c] *M. macleayi* data for exposure at onset of reproductive maturity shown only. [d] *M. mogurnda* data represent concentrations at which there is mortality of 5% of larvae (ie LC05; due to this test being an acute test).

For one species, the cladoceran *M. macleayi*, increased sensitivity to Mg was observed following pulse exposures at the onset of reproductive maturity (ie at ~27-h old) compared with exposure of neonates (<6-h old). This increased sensitivity may be related to the coincidence of exposure with the physiological processes of moulting and/or reproductive development.

The data shown in Table 3.1.1 were used to derive 99% species protection TVs for each exposure duration, based on log-logistic species sensitivity distributions consistent with the procedure documented in the Australian Water Quality Guidelines. The resultant TVs for each pulse exposure duration are shown in Table 3.1.2.

TABLE 3.1.2 TRIGGER VALUES FOR MG AND EC FOR DIFFERENT PULSE EXPOSURE DURATIONS

Pulse duration	99% species protection trigger value	
	Mg (mg L^{-1})	EC (µS cm^{-1}) [a]
4 hours	94	1140
8 hours	14	174
24 hours	8	102
Continuous (3–6 days) [b]	3	42

[a] EC calculated based on the Mg trigger value, using an established EC versus Mg relationship.
[b] Continuous exposure trigger values taken from van Dam et al (2010), noting that the value of 3 mg L^{-1} has been rounded up from 2.5 mg L^{-1}.

The EC, and corresponding Mg, TVs presented in Table 3.1.2 were plotted against exposure duration (hours) and modelled using a 4-parameter exponential decay model (Figure 3.1.1). The model allows trigger values to be inferred for any pulse duration between 4 and 72 h. During the 2012–13 wet season, this model will form the basis of magnesium/EC trigger value framework that will provide improved interpretation of the potential for environmental effect of transient pulses of EC (and magnesium) in Magela Creek downstream of the Ranger mine. This framework may replace the current weekly grab sample-based approach that is the basis of the current regulatory compliance regime.

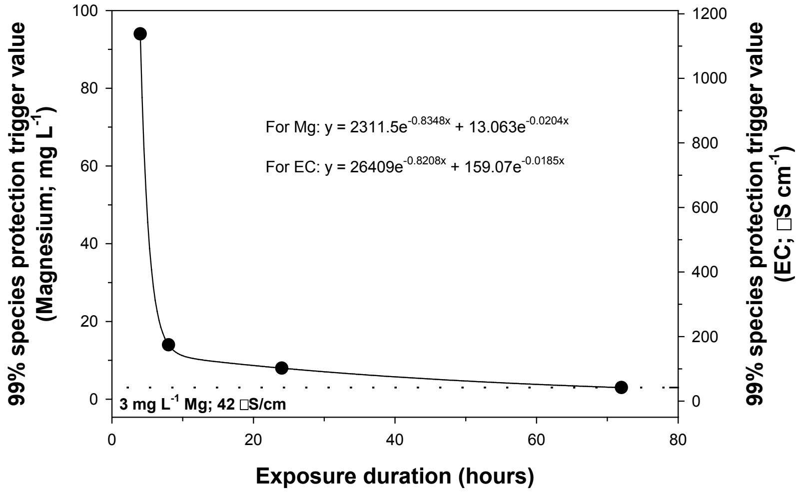


Figure 3.1.1 Relationship between trigger value, expressed as Mg (mg L^{-1}) and EC (µS cm^{-1}; after being converted from Mg concentration using an established relationship), and exposure duration. The fitted line is a 4-parameter exponential decay model. Shown for comparison (horizontal broken line) is the chronic exposure TV of 3 mg L^{-1} Mg or 42 µS cm^{-1}.

This project highlights how the Supervising Scientist Division is continuing to develop leading practice water quality assessment methods through well-targeted research.

3.2 Calculating annual solute loads in Gulungul Creek

3.2.1 Background

The Supervising Scientist Division (SSD) undertakes stream flow and water quality monitoring of surface waters around the Ranger uranium mine and the data are used in the assessment of potential impacts of mining. These data (water level, discharge and electrical conductivity [EC]) can also be used to calculate solute loads. Solute load data have been presented for Magela Creek in previous annual reports but this is the first time that annual load data have been reported for Gulungul Creek. In recent years the potential for mine impact in the Gulungul catchment has been increasing as a result of the works associated with several lifts of the wall of the tailings storage facility (TSF).

The solute load data at the upstream gauging station on Gulungul Creek (GCUS) are compared with those at the downstream station (GCDS) near the Arnhem Highway (Map 2). The upstream station is located where there is no mine impact and the downstream station is located immediately below the mine. The aim of this work is to identify whether mining activities have had a measureable impact on the solute load in Gulungul Creek.

The Gulungul Creek catchment covers an area of approximately 100 km^2, originating in the Arnhem land plateau and terminating in a backflow billabong (Gulungul Billabong) immediately upstream of where it joins Magela Creek. Current infrastructure in the catchment includes part of the TSF, mine access roads, minor tracks and three gauging stations on Gulungul Creek (Map 2). Between the upstream (catchment area 39 km^2) and downstream (catchment area 66 km^2) gauging stations there are four right bank tributaries, two left bank tributaries and numerous small anabranches of the main channel. Of the right bank tributaries, three flow from the area affected by the Ranger mine, and one flows from Jabiru airport. The left bank tributaries flow from non-mine impacted areas. Mine-site sources need to be compared with diffuse sources from the non-mine-impacted part of the catchment located between the two stations so that the contribution from the mine alone can be quantified.

The potential contribution of mine-derived solutes to Gulungul Creek include: i) surface discharge of groundwater, originating from the TSF; ii) land-disturbance by earth works undertaken for lifts of the TSF; and/or iii) overland flow from the waste rock (primarily schist) used in the construction of the walls of the TSF. During the wet season, ERA monitors water quality from the TSF area, which, depending on quality, is either captured and redirected to the on-site water management system or is released into right bank tributaries of Gulungul Creek.

Areas of black soils, salt deposits and surface sediments with elevated EC and water soluble magnesium (Mg) and sulfate (SO_4), have also been identified along drainage lines to the west of the TSF. The nature and occurrence of these deposits may be significant because soluble or secondary minerals might store solutes, such as Mg or SO_4, that can be readily released and mobilised into waterways following rainfall.

3.2.2 Methods

Continuous in situ EC and stage height (m) data have been measured in Gulungul Creek at either 5- or 6-minute intervals at GCUS and GCDS since the 2005–06 wet season. Surface water grab samples have also been collected routinely at these stations since the 2001–02 wet season. These samples were analysed for a range of solutes including uranium (U), manganese (Mn), Mg and SO_4.

The method used to calculate the solute load in Gulungul Creek involved four steps. The first step comprised a QA/QC process to assure that there was close agreement between EC values measured in situ (field) or in grab samples (laboratory) and the instantaneous values measured (at the time of water sample collection) by the continuous monitoring datasonde. This was done to determine if the EC data collected during the different water sampling campaigns are directly comparable.

The second step identified the most appropriate solute that: 1) had a good correlation with the time-series EC data from the continuous monitoring program; and 2) could be used as an indicator of a mine source. In this case, as for Magela Creek, Mg was identified as the most appropriate indicator. The grab sampling data were used to establish a quantitative relationship between EC and Mg, so that the continuous time-series EC record could be used to infer an effectively continuous concentration record for Mg concentrations in Gulungul Creek.

The third step used the results from the previous two steps to calculate the annual solute loads in Gulungul Creek by combining the concentration data with discharge.

The fourth step consisted of estimating the solute contribution from the catchment (diffuse sources) in comparison with the mine-site (point source) at the downstream gauging station on Gulungul Creek.

3.2.3 Results

Step 1 – EC relationships

For assessment and validation purposes, a comparison was made between the EC values measured in situ (field) or in grab samples (laboratory) with the instantaneous values measured by the continuous monitoring equipment (Fig 3.2.1). The straight line on the plot passing through the origin represents a 1:1 correlation between results. There is a close linear relationship between both the field and laboratory values, and the continuous EC data, from the GCUS (field: $R^2 = 0.88$, $\rho<0.001$; lab: $R^2 = 0.85$, $\rho<0.001$) and GCDS (field: $R^2 = 0.89$, $\rho<0.001$; lab: $R^2 = 0.86$, $\rho<0.001$) gauging stations in Gulungul Creek, indicating that the data are directly comparable, and hence confirming the well-maintained calibration of the in situ EC probes.

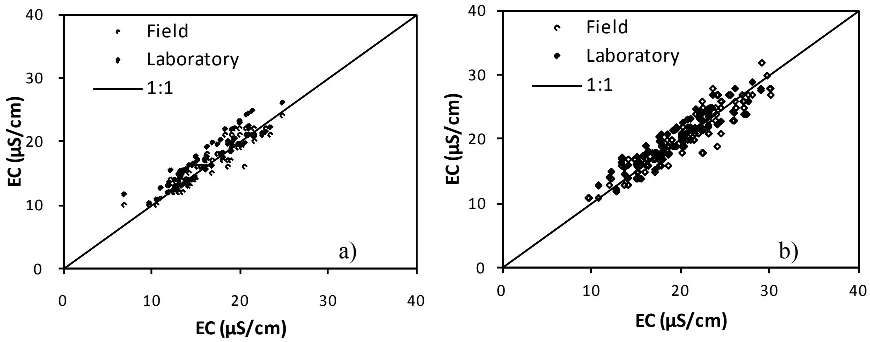


Figure 3.2.1 Relationships between electrical conductivity (EC) collected as part of the continuous monitoring program (x-axis) and EC for the field and laboratory results (y-axis) at a) GCUS and b) GCDS gauging stations on Gulungul Creek.

Step 2 – EC-Mg relationship

Magnesium sulfate ($MgSO_4$) is a major constituent of runoff and leachate produced from the weathering of waste rock and low-grade stockpiles at the mine. Magnesium sulfate has become the key indicator of mine-derived waters due to its relative contribution to the total EC measured in on-site water bodies and in Magela Creek (Supervising Scientist annual report 2010-11). Therefore, the relationship between EC and Mg concentrations was assessed for grab water samples collected through time from Gulungul Creek.

A statistically significant relationship was found between Mg and EC for GCUS ($R^2 = 0.74$, $\rho<0.001$) and GCDS ($R^2 = 0.67$, $\rho<0.01$). Therefore, the primary EC data can be used as a surrogate for predicting Mg concentrations in Gulungul Creek.

Step 3 – Mg load

The predicted Mg concentration data were used to derive loads of Mg transported by Gulungul Creek during each water year between 2005–06 and 2011–12. Magnesium load was calculated using Equation 1, where *t* is time, *i* is a defined period of time, $[Mg]$ is instantaneous predicted Mg concentration (mg/L) and Q is instantaneous discharge (L/s).

$$\text{total load} = \int_{t=0}^{t=i} [Mg]\, Q\, dt \qquad (1)$$

By multiplying the Mg concentration by the corresponding discharge for each time increment and then summing over time, the total mass of Mg over a water year can be calculated. The water year is defined as the time from September in one year to August in the next year and is used so that all data for the same wet season (late October to April) are grouped in the same water year.

The estimated Mg loads and runoff for Gulungul Creek are presented in Tables 3.2.1 and 3.2.2, respectively. The results show that between 2005–06 and 2011–12, between 37 and 148% of the Mg load transported by Gulungul Creek was contributed from sources between the upstream and downstream gauging stations.

TABLE 3.2.1 ESTIMATED Mg LOADS (t/yr) IN GULUNGUL CREEK

Water year	Gauging stations		Difference^	Percent difference#	LeGras[1] Difference^*	LeGras right-bank tribs
	GCUS	GCDS				
2005–06	32	53	21	66%	17	-
2006–07	29	72	43	148%	27	-
2007–08	19	35	16	84%	10	-
2008–09	10	17	7	70%	6	-
2009–10	17	36	19	112%	18	4.1
2010–11	37	67	30	81%	31	2.4
2011–12	30	41	11	37%	-	-
Mean	25 ± 4 (SE)	46 ± 7 (SE)	21 ± 5 (SE)	85 ± 13 % (SE)	18 ± 4 (SE)	-

1 LeGras CA 2011. *A review of research and monitoring in the Gulungul Creek catchment 1978-2011.* A report to Energy Resources of Australia.

^ Difference is calculated by subtracting the GCUS load from the GCDS load. # Percent difference is calculated by dividing the difference by the GCUS load. * Estimated mine-related loads for the calendar year not the water year.

TABLE 3.2.2 MEASURED RUNOFF (GL/yr) IN GULUNGUL CREEK UPSTREAM AND DOWNSTREAM OF THE RANGER MINE

Water year	GCUS	GCDS
2005–06	49	72
2006–07	52	120
2007–08	28	47
2008–09	11	19
2009–10	21	36
2010–11	52	86
2011–12	41	50
Mean	36 ± 6 (SE)	61 ± 13 (SE)

The load estimate for the 2006–07 water year has a potentially higher level of uncertainty than for the other years reported in Table 3.2.1 since GCDS was inundated by floodwater and the monitoring equipment was not functioning between 1–22 March in 2007. Missing stream flow data at GCDS were infilled using adjusted data from GCUS and G8210012. The missing continuous EC data were estimated using measurements from grab samples collected at the gauging stations during the period when the continuous monitoring equipment was offline. Assessment of the data interpolation and extrapolation procedures used to infill the period of missing data found that they do not introduce large errors in the derived solute load because the solute concentrations varied over a relatively small range during the post flood period.

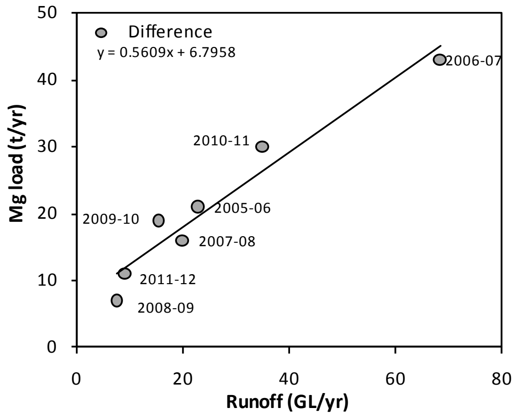


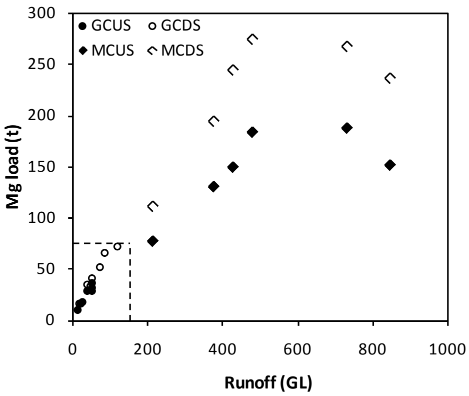
Figure 3.2.2 Relationship between difference in annual Mg load and difference in annual runoff between the upstream (GCUS) and downsteam (GCDS) gauging stations on Gulungul Creek (R^2 = 0.94, ρ<0.001)

The load calculations show that the mean difference in annual Mg load between GCUS and GCDS was 21 ± 5 (SE) t/yr (Table 3.2.1). The range was 7 to 43 t/yr (Table 3.2.1), with the smallest difference recorded for the driest year (2008–09) and the greatest difference for the wettest year (2006–07) (Table 3.2.2). A close linear relationship exists between the upstream-downstream difference in Mg load and runoff (Fig 3.2.2) demonstrating that there is a strong hydrological control on Mg load in Gulungul Creek.

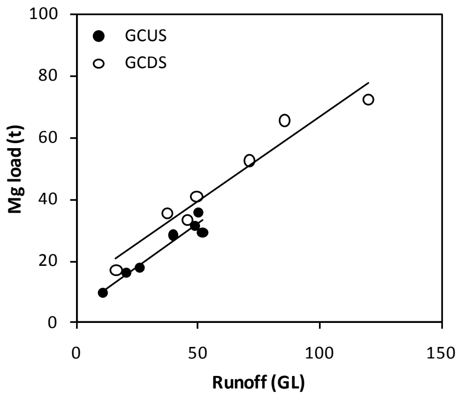
Step 4 – Significance of the Ranger mine as a potential solute source to Gulungul Creek

If mining activities were not present in the Gulungul Creek catchment then it could reasonably be assumed that there would be very similar annual Mg load-runoff relationships for the upstream and downstream gauging stations, given the similarities between the (non-mine) contributing catchments. In fact the slopes of the annual Mg load-runoff relationship for the upstream ($R^2 = 0.92$, $\rho<0.001$, slope = 0.567) and downstream ($R^2 = 0.93$, $\rho<0.001$, slope = 0.548) gauging stations (Fig 3.2.3b) are essentially the same, which supports the assumption. However, the line for the downstream station is vertically displaced from the upstream one, the difference being indicative of the mine-specific contribution.

Therefore, the approximate annual mine contribution of Mg load to Gulungul Creek between 2005–06 and 2011–12 is the difference between the two regression lines in Figure 3.2.3b. This annual mine contribution equals, on average, 7.8 t/yr of the 21 t/yr difference between the two Gulungul stations. Therefore, approximately 37% of the Mg load between the two stations is derived from the mine and 63% from diffuse sources. In the context of the Ranger minesite (Fig 3.2.3a), between 2005–06 and 2010–11 an average of 74 t of Mg was contributed annually by the minesite to Magela Creek (Supervising Scientist annual report 2010–11). Therefore, the contribution of Mg from the minesite to Gulungul Creek equates to around one-tenth of that contributed by the mine to the Magela Creek system.



(a)



(b)

Figure 3.2.3 Estimated magnesium loads (t) and annual runoff (GL) for the a) upstream (GCUS; MCUS) and downsteam (GCDS; MCDS) monitoring stations on Gulungul Creek and Magela Creek, respectively, and b) expansion of panel (a) insert for GCUS and GCDS.

3.2.4 Discussion

Previous estimates of Mg loads made by LeGras[3], including loads released from the TSF area into the right-bank tributaries, are included for comparison in Table 3.2.1. LeGras[3] estimated load by calculating mean Mg concentrations from weekly grab samples taken over a small portion of the period of annual flow, and did not use the continuous time-series data for EC and discharge, as used here. Instead, LeGras[3] estimated discharge for each calendar year between 2004 and 2011 by: i) predicting discharge at G8210012 (Map 2) from a regression relationship between rainfall at Jabiru airport and discharge; and then ii) using catchment area ratios to estimate the discharge at the upstream and downstream monitoring sites on Gulungul Creek. These data were then multiplied by the mean (based on weekly grab samples) Mg concentration to derive the annual Mg load in Gulungul Creek.

Similarly, LeGras[3] multiplied the mean Mg concentration for each swale drain along the west and south west base of the TSF by the total estimated discharge, to determine Mg load transported from the TSF area into the right-bank, mine-side tributaries of Gulungul Creek. Despite using a less rigorous method than applied here, LeGras[23] found that the difference in mean annual Mg load between the upstream and downstream stations on Gulungul Creek was essentially the same as reported here (Table 3.2.1). However, the present work greatly extends LeGras[3] by being able to more definitively estimate the extent of Mg contribution from the mine into the creek.

3.2.5 Conclusions

The above results suggest that over the past seven water years between 37% and 148% of the Mg load transported by Gulungul Creek has been contributed by sources between the upstream and downstream monitoring stations. It has only been since the commencement of the 2009–10 wet season that the Mg loads entering Gulungul Creek from the TSF area have been able to be estimated directly (Table 3.2.1) using the water quality data and flow volumes measured by ERA in the runoff collection system installed along the base of the TSF. These values are one order of magnitude less than the difference in mean annual Mg load between the upstream and downstream stations, and are consistent with the values derived here from detailed analysis of the continuous monitoring data.

The results presented here indicate that mining-related activities between 2005 and 2012 have increased the Mg load in Gulungul Creek by an average of 7.8 t/yr. This is one order of magnitude less than the average annual load contributed to Magela Creek between 2005 and 2011. However, diffuse sources between the upstream and downstream monitoring stations on Gulungul Creek also contribute on average 13.2 t/yr of Mg. The analysis to date suggests that the mine supplies 37% and diffuse sources 63% of the difference in Mg load between the upstream and downstream stations on Gulungul Creek.

However, further work is needed to provide complete verification of this and to more clearly distinguish the mining and non-mining sources and contributions as outlined

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[3] LeGras CA 2011. *A review of research and monitoring in the Gulungul Creek catchment 1978–2011.* A report to Energy Resources of Australia.

in Section 3.2.1. The issue of the contribution of Mg from diffuse sources will be investigated in more detail by collating and analysing the available concentration data for Mg in the sub-catchments of Gulungul Creek between the upstream and downstream gauging stations with further assessment using the continuous monitoring data. The propagated level of uncertainty for the Mg loads for Gulungul Creek will also be quantified as part of this subsequent work.

3.3 Incorporating the influence of dissolved organic carbon on uranium toxicity into the site-specific trigger value for uranium

The bioavailability and toxicity of uranium (U) to aquatic biota are known to be influenced by a number of environmental variables, including pH, water hardness and dissolved organic carbon (DOC). However, historically there have been insufficient data to develop predictive relationships. The data deficiency for one of the variables, DOC, has been addressed by a recently completed research project.[4] The results showed that DOC reduces U toxicity largely by complexing with U, thus reducing its bioavailability to aquatic organisms. At present, the current site-specific water quality trigger value (TV) for U in Magela Creek (6 µg/L) does not account for this effect of DOC on U toxicity. With concentrations of DOC in the Magela Creek stream channel typically in the range 2–8 mg/L, and reaching 20 mg/L in backflow billabongs, it is likely that U bioavailability and toxicity will vary considerably depending on location in the Magela Creek catchment. Consequently, an analysis was undertaken to determine whether the DOC–U toxicity relationship could be incorporated into the site-specific U TV, such that the TV could be adjusted to account for the aquatic DOC concentration.

The relationship between DOC and U toxicity was characterised using data for the five freshwater species for which this dependence has previously been investigated (based on two studies by ***eriss*** and one study by Australian Nuclear Science and Technology Organisation). These species were the green alga, *Chlorella* sp, green hydra, *Hydra viridissima*, mussel, *Velesunio angasi*, northern-trout gudgeon, *M. mogurnda* and the dinoflagellate, *Euglena gracilis*. The studies using *V. angasi* and *M. mogurnda* were based on acute U toxicity, and were included to increase species representation and to improve understanding of the DOC-toxicity response. The relationships between DOC and U toxicity based on IC50 concentrations for the above species are shown in Figure 3.3.1 and Table 3.3.1. It is evident that the relationship varies depending on the species, DOC source and exposure duration (acute versus chronic). Statistically, the slopes of these relationships (see Table 3.3.1) were significantly different (based on Analysis of Covariance). Thus, the data could not be pooled to create a single DOC versus U toxicity relationship (as per the method of the US Environmental Protection Agency for water hardness-based correction of trigger values for various metals.

[4] Trenfield MA 2012. The influence of dissolved organic carbon on the potential bioavailability and toxicity of metals to tropical freshwater biota. PhD Thesis, University of Queensland.

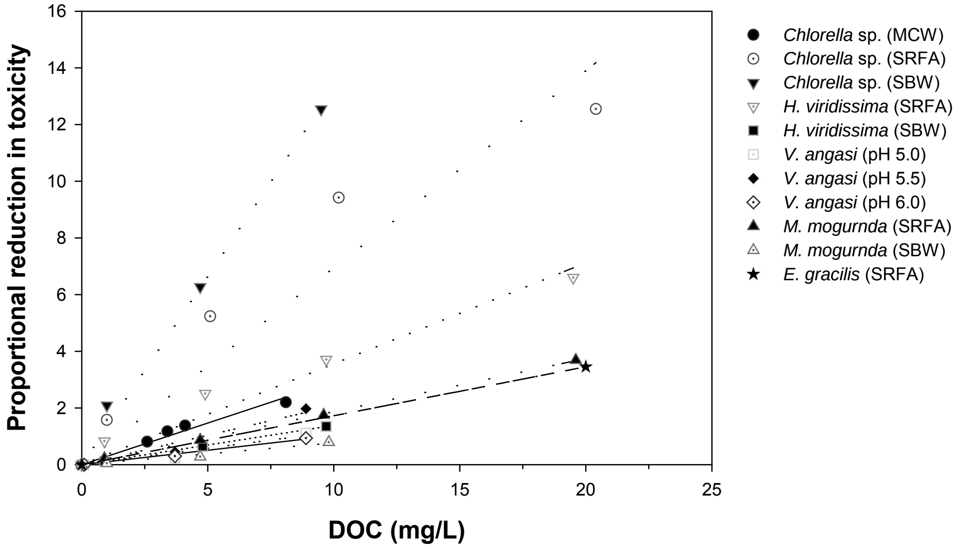

Figure 3.3.1 Linear relationships of U toxicity (expressed as the proportion reduction in IC/LC50 relative to the IC/LC50 at the background DOC concentration) versus dissolved organic carbon (DOC; from various sources) concentration for *Chlorella* sp., *Hydra viridissima*, *Velesunio angasi*, *Mogurnda mogurnda* and *Euglena gracilis*. DOC sources: MCW – Magela Creek Water; SRFA – Suwannee River Fulvic Acid; SBW – Sandy Billabong water.

TABLE 3.3.1 REGRESSION STATISTICS FOR LINEAR RELATIONSHIPS OF DISSOLVED ORGANIC CARBON (DOC; mg/L) VERSUS THE PROPORTION REDUCTION IN IC50/LC50 VALUE FOR URANIUM

Species	Acute/chronic	DOC source[1]	*n*	Slope	r^2	P value
Chlorella sp	Chronic	MCW	5	0.30	0.95	0.003
	Chronic	SRFA	5	0.69	0.86	0.014
	Chronic	SBW	4	1.3	0.99	0.003
Hydra viridissima	Chronic	SRFA	5	0.35	0.95	0.003
	Chronic	SBW	4	0.14	0.99	<0.001
Velesunio angasi	Acute	SRFA (pH 5.0)	3	0.11	0.87	0.17
	Acute	SRFA (pH 5.5)	3	0.21	0.89	0.15
	Acute	SRFA (pH 6.0)	3	0.10	0.97	0.08
Mogurnda mogurnda	Acute	SRFA	5	0.19	0.99	<0.001
	Acute	SBW	4	0.08	0.97	0.011
Euglena gracilis	Chronic	SRFA	2	0.17	n/a[2]	n/a

1 DOC sources: MCW – Magela Creek water; SRFA – Suwannee River fulvic acid; SBW – Sandy Billabong water.
2 n/a: Not applicable, due to the model being based on only 2 values.

Instead, the slopes of the relationships between DOC and (normalised) acute and chronic U toxicity were modelled using cumulative probability distributions (Figure 3.3.2). The 5th percentiles of the distributions were defined as correction factors to be applied to acute or chronic U toxicity values or to produce TVs based on the measured aquatic DOC concentration. The 5th percentiles of the slope distributions were chosen as the correction factors to ensure that they did not under-protect an unacceptably large number of species from the effects of DOC on U toxicity. Moreover, this choice is consistent with the use of 5% hazardous concentrations for contaminants in risk assessments.

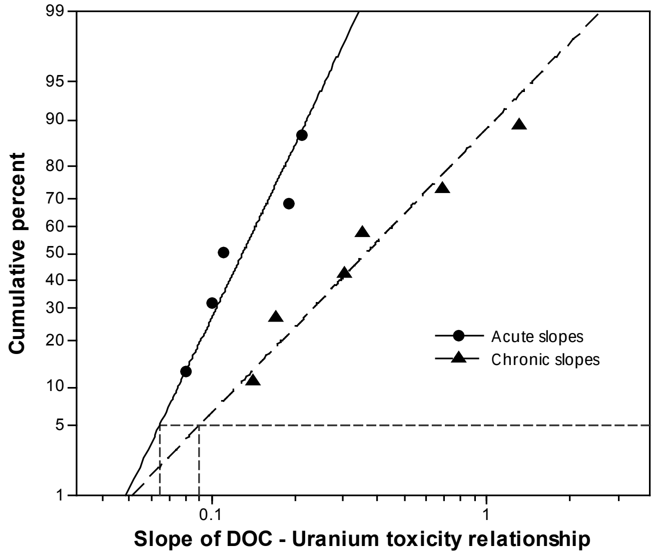

Figure 3.3.2 Log-normal cumulative probability distributions of the slopes of the relationships for uranium toxicity versus dissolved organic carbon (based on normalised IC/LC50 values for acute and chronic exposures. The short dashed lines show the intersection of the 5th percentile with the models (acute slope 5th percentile = 0.064; chronic slope 5th percentile = 0.090).

The slope factors were 0.064 for acute toxicity and 0.090 for chronic toxicity. This equates to a 6.4% and 9.0% reduction in acute and chronic U toxicity relative to the toxicity at the base DOC concentration, for every 1 mg/L increase in DOC concentration (over the DOC range 0–30 mg/L).

The chronic slope factor can be used to modify a site-specific U TV to account for changes in DOC concentrations in the receiving environment. Firstly, the relevant site-specific chronic U toxicity values used to derive the TV need to be adjusted to a standard low DOC concentration. In the case of Magela Creek, a DOC concentration of 1 mg/L can be considered an applicable estimate of a low DOC concentration.

Thus, the U toxicity values (eg IC10 or IC50) can be corrected to 1 mg/L DOC using the following equation using the following equation:

$$\text{U tox}_1 = \text{U tox}_i \times (1 + \text{slope}_{chronic}) / (1 + \text{slope}_{chronic} \times \text{DOC}_i)$$

where U tox_1 is the U toxicity value corrected to 1 mg/L DOC, U tox_i is the initial (ie original) toxicity value, DOC_i is the DOC concentration in mg/L at which U tox_i was calculated, and $slope_{chronic}$ is the slope factor for chronic toxicity (0.090). Once the (base) site-specific TV has been re-derived using the corrected toxicity data, it can then be adjusted based on the DOC concentration in the aquatic environment of interest, using the following equation:

$$\text{DOC modified trigger value (DOCMTV)} = TV_1 / (1 + slope_{chronic}) \times (1 + DOC_f \times slope_{chronic})$$

where TV_1 is the TV calculated at 1 mg/L DOC, DOC_f is the aquatic DOC concentration of interest, and $slope_{chronic}$ is the slope factor for chronic toxicity (0.090). As an example, for a U TV_1 of 2 µg/L, the DOCMTV for a surface water with a DOC concentration of 8 mg/L would be 3.2 µg/L (ie 2 / [1 + 0.09] × [1 + 8 × 0.09]).

The above DOC correction method will increase the environmental relevance of the site-specific U TV. However, given the conservative approach of adopting the 5th percentile of the distribution of the slopes as the DOC correction factor, it will not have a large effect on the U TV across the range of DOC concentrations typically measured in Magela Creek (ie ~2–8 mg/L). In contrast, it will have a substantial effect on U TVs that are adopted as post-rehabilitation and closure water quality criteria for billabongs nearer the Ranger mine, where DOC concentrations can reach 20 mg/L.

The next phase of work will involve updating the current site-specific U TV (which provides the basis for the current U compliance regime in Magela Creek) to incorporate (i) additional U toxicity data acquired over the past 10 years, and (ii) the above DOC correction method.

3.4 Analyses of toxicity monitoring and associated water quality data for Magela and Gulungul Creeks

3.4.1 Background and previous findings

Toxicity monitoring evaluates the responses of aquatic animals exposed in situ in Magela and Gulungul Creeks to diluted runoff water from the Ranger minesite. Egg production by the freshwater snail, *Amerianna cumingi*, over a four day deployment period, has been the method used in Magela Creek since 1990–91 and in Gulungul Creek since 2009–10 (see 'In situ toxicity monitoring' in section 2.2.3.2 of this report).

Following the 2010–11 wet season, analyses were undertaken to provide an improved understanding of environmental (viz water quality) conditions affecting the production of snail eggs during the toxicity monitoring tests.[5] This work was necessary to ensure that it is possible to distinguish between natural and mine-induced effects on snail egg numbers between upstream and downstream sites.

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

For toxicity monitoring data from Magela and Gulungul Creeks acquired between the 2006–07 and 2010–11 wet season (where corresponding continuous electrical conductivity (EC, a reliable surrogate of magnesium sulfate concentrations), water temperature and turbidity data are available), a number of significant correlations and interactions were found between mean egg number and both median EC and water temperature, but not turbidity:

1 A positive linear relationship was observed between EC and snail egg number.

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

3 A significant interacting effect of water temperature and EC upon snail egg counts in Magela and Gulungul Creeks was observed. Plots of EC and snail egg number (for Magela and Gulungul sites combined) were prepared using one degree increments in median water temperature. The changing relationship of the snail reproduction response to EC with rising water temperature was noted, with enhanced egg production with increasing EC at lower water temperatures (27–29°C), an increasingly neutral effect at intermediate temperature (~30°C) and an increasingly reduced/negative effect at higher water temperatures (>30°C).

In the last annual report it was also noted that trapping of suspended organic matter in the capsules containing the snails could possibly have produced a stimulatory effect on downstream egg production (Figure 2.17) by virtue of providing a supplementary food source. To address this issue 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. Suspended inorganic (SIM) and organic (SOM) matter were both found to be higher at the upstream sites of both creeks with no strong relationships found between these variables and mean snail egg number measured in each creek. This work was repeated in the 2011–12 wet season.

Toxicity monitoring data from the 2011–12 wet season have been combined with the in situ toxicity monitoring data from previous wet seasons and the combined dataset reanalysed with associated water quality data (including SIM and SOM) to assess previous findings and conclusions.

3.4.2 Analyses following 2011–12 wet season

Correlates of variability in snail egg difference values

For the 2009–10 and 2010–11 wet seasons, greater variability was noted between upstream and downstream sites in the egg counts from Gulungul Creek compared with the same response measured in Magela Creek (see Figure 2.17 of the present report). This higher Gulungul variability corresponded to similar and generally more variable (compared with Magela Creek) water quality in Gulungul Creek, attributed to the greater proportional influence of runoff to Gulungul Creek from catchment sources between the upstream and downstream sites in this relatively small drainage basin.

This water quality-biological variability relationship was examined more closely for Gulungul and Magela Creeks, and with the addition of 2011–12 wet season data. Water quality (temperature, EC, turbidity) differences were calculated from the medians of upstream and downstream values measured at a 10 minute frequency over each of the four-day tests conducted over the three (Gulungul) or six (Magela) wet seasons for which in situ toxicity and continuous (water quality) monitoring data were available. 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 for each wet season. Correlation analysis was conducted between the standard deviation of annual egg difference values and standard deviation of water quality (temperature, EC, turbidity) differences values for the data from both creeks combined.

The only significant water quality correlate of annual egg difference variability was electrical conductivity (EC), as depicted in Figure 3.4.1. Higher variability in upstream-downstream EC differences in both Gulungul and Magela Creeks is associated with significant mine-water discharge events in a particular wet season, most evident in Magela Creek in the 2006–07 wet season and, for the period of toxicity monitoring in Gulungul Creek, in the 2009–10 wet season. Given the significant relationship depicted in Figure 3.4.1, these specific mine-water discharge events are implicated in changes to the paired-site, egg number difference values, even though there may be no significant difference in overall mean snail egg difference values between wet seasons. The nature of the egg production response to EC is discussed in the following section.

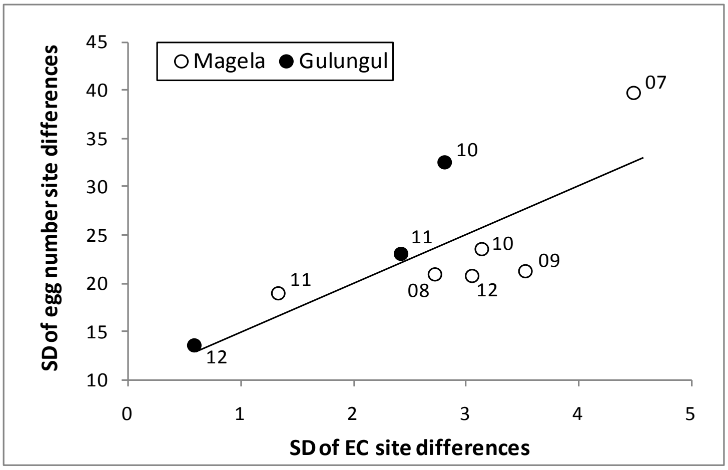

Figure 3.4.1 Regression relationship between standard deviations (SD) of upstream-downstream difference values for snail eggs numbers and electrical conductivity (EC) in both Magela (2006–07 to 2011–12) and Gulungul Creek (2009–10 to 2011–12) wet seasons. Subscript numbers against symbols refer to year (eg 07 = 2006-07 wet season).

Effect of EC and water temperature upon snail egg production

Toxicity monitoring results from Magela and Gulungul Creeks for the 2011–12 wet season were combined with previous toxicity monitoring data to determine the consistency of the recent data with previous findings of (i) water temperature-EC interacting effect upon snail egg number (ie changing relationship of the snail reproduction response to EC with rising water temperature), and (ii) a positive linear relationship between EC and snail egg number.

The water temperature-EC interacting-effect upon snail egg number continued with addition of 2011–12 data. While the plots of EC versus egg number with incremental (1°C) increases in water temperature are not included here, the slope of the trend lines for the egg number-EC relationships are plotted against water temperature increments in Figure 3.4.2. Positive and negative regression slopes indicate enhanced and suppressed effects of EC upon snail egg production, respectively.

Nevertheless, over and above the interacting effect of water temperature and EC upon snail egg counts, for the range of median (four-day) EC values recorded in the creeks (between 7 and 30 µS/cm), a positive non-linear relationship is observed, and has continued, between EC and snail egg numbers (Figure 3.4.3). This suggests a net, albeit small, enhancement to snail egg production with increasing additions of mine-derived solutes to Magela and Gulungul Creeks over the range of median EC values observed.

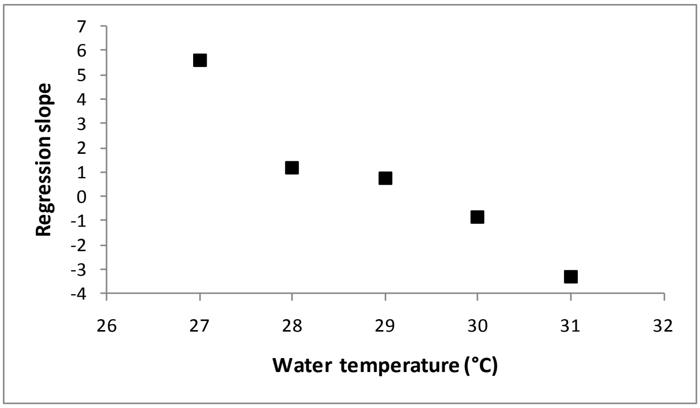

Figure 3.4.2 Relationship between slope of the regression relationships between mean snail egg number and median EC for toxicity monitoring tests conducted in both Magela and Gulungul creeks, 2007 to 2012, and median water temperature

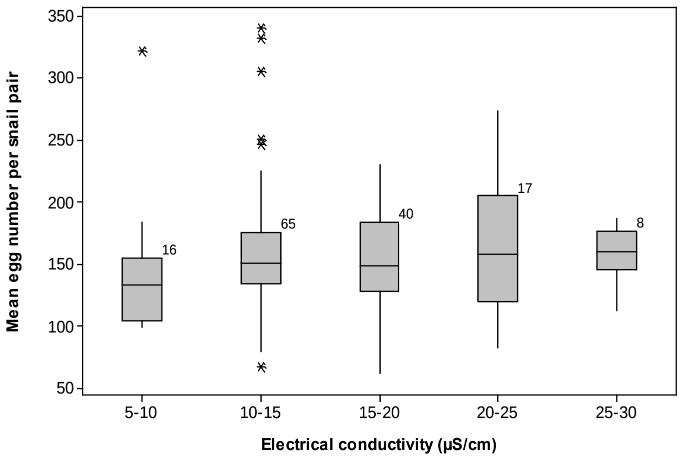

Figure 3.4.3 Box plots of mean snail egg number observed in in situ toxicity monitoring tests in Gulungul and Magela Creeks, 2007–2012, grouped according to ambient electrical conductivity in creek waters. Box plots show median, range, 25th and 75th percentiles. Points at a greater distance from the median than 1.5 times the Inter-Quartile Range are plotted individually as asterisks ('outliers'). Subscript numbers against boxes denote number of toxicity monitoring tests.

Relationships between snail egg response and suspended inorganic and organic matter

Very few significant relationships were found between SOM and SIM and mean snail egg number when considering Magela and Gulungul creeks, and years (2011 and 2012), separately and combined. Most 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 in both years, whereas snail egg numbers were generally lower at the upstream sites (Figure 2.17). Thus, the hypothesis that SOM contributes to higher downstream egg production is not supported by the data. Few significant correlations were found between SOM and SIM and either EC or water temperature when considering Magela and Gulungul Creeks, and years (2011 and 2012), separately and combined.

3.4.3 Conclusions

Reproductive responses of freshwater snails exposed in Magela and Gulungul Creeks in the wet season appear to be stimulated by small increases in EC across the range of median (four-day) values recorded in these receiving waters(7–30 µS/cm, Figure 3.4.3). Median EC values greater than 20 µS/cm are a consequence of mine water discharges, and so inputs of water from the minesite are implicated in at least part of the stimulatory response represented in Figure 3.4.3. In these very low solute streams, it is unsurprising that freshwater organisms would benefit from small additions of ions, including mine-derived magnesium sulfate. (Magnesium is an essential element in biological systems.)

There is some debate in the literature about the ecological significance of stimulatory effects of potential toxicants (especially for those that are essential ions or trace nutrients at low levels) at concentrations below those eliciting negative and adverse toxic effects. However, as an essential ion, and for chronic exposures at such very low concentrations, it is unlikely that Mg is resulting in ecological harm in the receiving waters of Magela Creek downstream of the Ranger mine. In support of this assertion, recessional flow sampling of macroinvertebrate and fish communities in Magela and Gulungul Creeks has provided no evidence that changes to water quality downstream of Ranger as a consequence of mining during the period 1994 to 2012 have altered or adversely affected these communities (see section 2.2.3.2 of this report). Nevertheless, the issue of Mg-related stimulation may warrant further study through literature review and corroborative laboratory studies.

3.5 Ecotoxicological assessment of distillate product from a pilot-scale brine concentrator

Steadily increasing process water inventory at the Ranger mine has become a significant operational issue for Energy Resources of Australia Ltd (ERA). Following an assessment of potential technology options, ERA concluded that brine concentration was the most viable technology to reduce the inventory. A brine concentrator produces large volumes of a purified water product (distillate) and a waste stream containing the salts present in the process water (brine concentrate). The distillate will be released into the environment via a yet to be determined method, while the brine concentrate will be returned to the tailings storage facility (TSF). Rio Tinto–Technology and Innovation (RT-TI, Bundoora, Victoria) was engaged by ERA to conduct trials on a pilot-scale brine concentrator plant. Two key aims of RT-TI trial were to (i) demonstrate that the distillate does not pose risks to operator health or the environment, and (ii) provide data to assist with designing water management and disposal systems. To assist with addressing the aquatic environment protection aspect, SSD undertook a comprehensive toxicity testing program of the pilot plant distillate. The aims of the toxicity test work were to: (i) detect and quantify any residual toxicity of the distillate and, (ii) in the event effects were observed, to identify the toxic constituent(s) of the distillate.

Initial toxicity screening of the distillate was conducted with a limited range of dilutions of the distillate using three aquatic species that had previously displayed sensitivity to treated process water permeate from the Ranger Treatment Water Plant. Specifically, a unicellular algae (*Chlorella* sp; 72-h cell division rate), a hydroid (*Hydra viridissima*; 96-h population growth rate) and a cladoceran (*Moinodaphnia macleayi*; 3-brood reproduction) were exposed to Magela Creek water (MCW) control and three dilutions of the distillate (0, 25, 50 and 100% distillate). Further testing was conducted on a second batch of distillate using the same concentration range and two additional species, a duckweed (*Lemna aequinoctialis*; 96-h growth rate) and a fish (*Mogurnda mogurnda*; 96-h larval survival). The toxicity of the second batch of distillate was also assessed using *Chlorella* sp, *H. viridissima* and *M. macleayi*, although only at 0 (MCW) and 100% distillate, in order to assess the inter-batch reproducibility of the test methods.

In order to identify the toxic constituents of the distillate, a range of Toxicity Identification Evaluation (TIE) tests were conducted using the sole sensitive species, *H. viridissima*. The TIE tests involved assessing the relative toxicity of distillate samples produced by specific physical and chemical manipulations to change its composition or the speciation of specific constituents of potential concern. The results enable conclusions about potential primary toxicants. Six TIE tests were conducted to identify the cause of adverse effects on *H. viridissima*.

The distillation process reduced all major ions, ammonia and metals to near detection limits. The toxicity tests results showed that the distillate was of low toxicity to four of the five organisms tested (Table 3.5.1). However, the population growth rate of *H. viridissima* was reduced by ~50% and 100% following exposure to undiluted (ie 100%) distillate samples from the first and second batch, respectively.

Ammonia and manganese (Mn) were measured at concentrations previously reported to be toxic to *H. viridissima*, while an unknown organic component was measured at low but detectable concentrations. Initial TIE testing focused on assessing whether these three constituents were causing or contributing to the toxicity of the distillate. However, initial TIE results suggested none of these constituents were causing or contributing to the observed negative effect on *H. viridissima*. Specifically, pH manipulation (raising pH) and stripping to remove the small amount of ammonia that was present indicated that ammonia was not causing the effect. Whilst the pH manipulation suggested Mn may be contributing to the effect, the addition of ethylenediaminetetraacetic acid, (EDTA, a chelating agent for Mn,) did not reduced the toxicity of the distillate, which indicated that this was unlikely.

Removal of the organic component also did not change the toxicity of the distillate, discounting organics as a cause of toxicity.

TABLE 3.5.1 TOXICITY OF THE PILOT BRINE CONCENTRATOR DISTILLATE

Species	Endpoint	IC_{10} or LC_5 [a] (95% confidence limits)	Percentage effect relative to the control (± CV% [b]) following exposure to 100% distillate	
			1st batch	2nd batch
Chlorella sp (unicellular alga)	72-h cell division rate	79 (NC) [c]	11 ± 2	0 ± 0
Lemna aequinoctialis (duckweed)	96-h growth rate	>100 (NC) [d]	NT[e]	0 ± 0
Hydra viridissima (green hydra)	96-h population growth rate	30 (NC – 77)	53 ± 5	100 ± 0
Moinodaphnia macleayi (cladoceran)	3 brood (6 day) reproduction	72 (50–100)	13 ± 6	6 ± 13
Mogurnda mogurnda (fish)	96-h survival	NC [d]	NT	7 ± 25

[a] Inhibitory Concentrations (IC) are expressed as percentage of distillate that causes a 10% effect (IC10) or, in the case of *M. mogurnda*, a 5% effect (LC_5); [b] Percent Coefficient of Variation ; [c] NC = Not calculable; [d] derived from test conducted on the 2nd batch of distillate; [e] NT = Not tested.

In light of the above negative findings, the issue of major ion deficiency was specifically investigated as a potential cause of the effect on *H. viridissima*. Firstly, Ca addition was investigated due to its importance for nematocyst function and other physiological processes in *H. viridissima*. The addition of 0.2 and 0.5 mg L^{-1} Ca to the distillate resulted in a 61% and 66% recovery relative to the Synthetic Soft Water (SSW) control, suggesting Ca deficiency as a reason for the effect of distillate on *H. viridissima*. An additional test was conducted that involved the addition of sodium (Na), potassium (K) and Ca at concentrations that were 0, 50 and 100% that of SSW (SSW contains 0.5, 1.0 and 0.4 mg L^{-1} of calcium, sodium and potassium, respectively). The results showed a 100% and 96% recovery of *H. viridissima* population growth rates with the addition of 50 and 100% major ions, respectively. This strongly indicated that the majority of the adverse effect from the distillate on *H. viridissima* was due to major ion deficiency issue rather than a chemical toxicity (Table 3.5.2).

Despite the substantive removal of toxic effect by replacement of major cations, the concentrations of Mn in the distillate (130–230 µg L^{-1}) were investigated further as they were higher than the IC_{10} of 60 µg L^{-1} previously reported for *H. viridissima* in circumneutral pH (6.0–7.0) soft water. Additionally, the lack of major ions in the distillate had the potential to exacerbate Mn toxicity. Therefore, the effects of Mn in the presence of reduced concentrations of major ions were examined using modifed SSW (ie pH ~6.0 with 0, 50 and 100% Na, K and Ca concentrations). Manganese concentrations of 250 µg L^{-1} caused a 10–20% reduction in growth rate, independent of the major ion concentrations. Consequently, in addition to the recognised issue with deficiencies of major ions in the distillate, a potential for Mn toxicity was also identified.

TABLE 3.5.2 RESULTS OF MAJOR ION ADDITION TOXICITY IDENTIFICATION EVALUATION TESTS USING *HYDRA VIRIDISSIMA*

TIE test	Treatment	Control growth rate (mean day^{-1} ±SE)	Distillate growth rate (mean day^{-1} ±SE)	Distillate compared to control (mean % ± SE)
Calcium addition	0.0 mg L^{-1} Ca added	0.14 ± 0.00	0.00 ± 0.00	0.0
	0.2 mg L^{-1} Ca added	0.27 ± 0.01	0.16 ± 0.00	61 ± 2
	0.5 mg L^{-1} Ca added	0.28 ± 0.00	0.18 ± 0.01	66 ± 5
Major ion addition	0.0 mg L^{-1} Ca, Na and K added	0.04 ± 0.06	0.13 ± 0.01	353 ± 23 [a]
	0.2, 0.5 and 0.2 mg L^{-1} Ca, Na and K added	0.29 ± 0.02	0.29 ± 0.01	100 ± 4
	0.5, 1.0 and 0.4 mg L^{-1} Ca, Na and K added	0.34 ± 0.01	0.32 ± 0.02	96 ± 5

[a] Growth rate in the distillate was three times higher compared to SSW with no major ions, but was still significantly lower than distillate with major ions added.

In conclusion, although the brine concentrator distillate was of hugely improved quality compared with the feed process water, it may still have the potential to impact some species inhabiting the receiving environment if it was the dominant component. The most likely negative effect relates to deficiency of essential major ions. However, the lack of major ions may also exacerbate the toxicity of other components present at low levels. The results of the tests reported here are for distillate produced from an off site pilot plant. ERA has indicated that it is likely the distillate from the full-scale plant will contain less trace components than the pilot plant since it will have much lower carryover of spray droplets with the condensate.

The following key recommendations have been made in relation to management of the distillate and further assessment of its properties:

1 Supplementation of the distillate with major ions (Ca, Na and K) may be required prior to its discharge to the off-site aquatic environment;

2 Further site-specific data are needed to adequately assess the environmental risk of Mn in the distillate;

3 The distillate product from the full-scale plant will need to be assessed for toxicity and, if necessary, a TIE conducted to determine the cause(s) of any measured effects.

3.6 Developing water quality closure criteria for Ranger billabongs using macroinvertebrate community data

3.6.1 Background

Georgetown Billabong (GTB) is a natural waterbody located immediately downstream of Ranger minesite (Map 2) that discharges into Magela Creek. It has historically received low levels of minesite solutes (mainly magnesium sulfate ($MgSO_4$) and also uranium (U)) since the inception of mining. Slightly elevated U in the sediments of GTB sampled in 1978, (compared with sediments of adjacent reference waterbodies) also indicates that erosion from the surface expression of ore body number 1 located in the Georgetown Creek catchment has contributed U to the billabong historically and prior to mining.[6] Figure 3.6.1 shows the historical seasonal electrical conductivity(EC) record in GTB. Electrical conductivity is a surrogate for the concentration of $MgSO_4$, the main mine-derived solute. As last reported in the Supervising Scientist's Annual Report for 2006–07, GTB is being used as a case study to develop surface water quality closure criteria, in this case for the solutes EC, $MgSO_4$ and U, for natural waterbodies within the mining lease.[7]

The approach to deriving water quality criteria from biological response data in local waterbodies is consistent with the framework outlined in the Australian and New Zealand Water Quality Guidelines (2000). Specifically, if the post-closure ecological condition in Georgetown Billabong is to be consistent with similar undisturbed (reference) billabong environments of Kakadu National Park (KNP), then the range of measured water quality data from the billabong over time that supports such an ecological condition – as measured by macroinvertebrate communities in this instance – may be used to derive the criteria.

Macroinvertebrate sampling in 1995, 1996 and 2006 among aquatic plants growing along the edges of waterbodies (so-termed 'littoral macrophytes', and representing water column habitat) supported the conclusion that biological conditions (viz relative abundances of different macroinvertebrate families) in GTB were consistent with those of reference waterbodies sampled elsewhere in the region. These results indicated that the corresponding water quality in GTB for the three sampling years was compatible with the maintenance of the aquatic

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6 Humphrey C, Turner K & Jones D 2009. Developing water quality closure criteria for Ranger billabongs using macroinvertebrate community data. In ***eriss*** *research summary 2007–2008*. eds Jones DR & Webb A, Supervising Scientist Report 200, Supervising Scientist, Darwin NT, 130–135.

7 The derivation of closure criteria for turbidity in surface waters and uranium in sediments is being addressed by separate ***eriss*** research projects not reported here.

ecosystem values of KNP. Derived water quality closure criteria for electrical conductivity (for $MgSO_4$), magnesium and uranium were subsequently reported (values not shown here), based on water quality and macroinvertebrate data acquired in 1995, 1996 and 2006.

Since 2006, the main criterion that has been applied to trigger the need for further assessment of biological condition of these waterbodies is if water quality in GTB deteriorates beyond the quality observed in past sampling years (1995, 1996 and 2006). Such an occurrence provides an opportunity to adaptively adjust the previously-derived criteria.

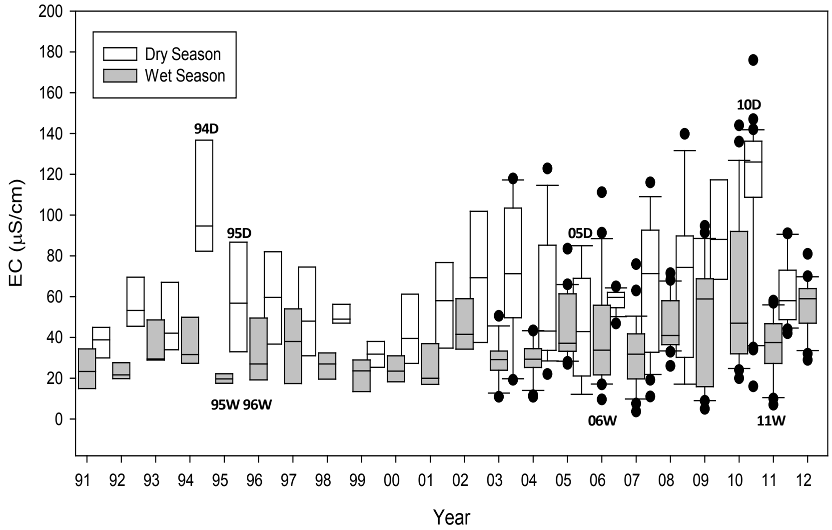

Figure 3.6.1 Summary box plots of weekly electrical conductivity (EC) values measured in GTB between 1991 and 2012. Box plots show median, range, 25th and 75th percentiles and outliers (points). Periods relevant to macroinvertebrate sampling are indicated by year and season (wet (W) or dry (D)). Data from Energy Resources of Australia. Wet season – January to May. Dry season – June to December.

In the late 2010 dry season, water quality in GTB deteriorated to the worst that it has been in the past decade (Figure 3.6.1). Accordingly, the biota in the 13 waterbodies that were sampled previously were re-sampled during the wet-dry recessional flow transition period in May 2011 (ie end of the 2010–11 wet season). In addition to macroinvertebrates, phytoplankton and zooplankton communities were included this time in the sampling program to assess the relative sensitivities of these other important biological assemblages to water quality. Phytoplankton and zooplankton community results are only briefly reported here, given the low level of within-waterbody replication that was possible and the paucity of similar sampling in the past to provide a time series reference.

3.6.2 Sampling

Macroinvertebrate communities have been sampled four times between 1995 and 2011 with sampling conducted in up to 14 waterbodies during the wet-dry season transition period between April and May. Waterbodies have been classified as either mine water exposed, or reference that are not exposed to Ranger mine waters or influenced by natural expressions of uraniferous material. The exposed sites include the originally-natural Djalkmara (removed in the 2006 dry season) by development of the open pit accessing the Ranger 3 orebody), Coonjimba, Georgetown and Gulungul Billabongs and the constructed minesite waterbodies Ranger Retention Pond 1 (RP1) and Retention Pond 2 (RP2). Reference sites include Baralil, Corndorl, Wirnmuyurr, Malabanjbanjdju, Anbangbang, Buba and Sandy Billabongs and Jabiru Lake. See Maps 2 and 3 for locations of these waterbodies.

In each waterbody, samples were collected from five locations and at each of these, separate samples were taken from littoral macrophyte and littoral sediment (benthic) habitats (thus 10 samples per waterbody). In 1995 and 1996, benthic and macrophyte samples were composited before sample processing while for 2006 and 2011, samples from each of these two zones were collected and processed separately. In 2011 (only), duplicate plankton samples were collected from each waterbody for phytoplankton and zooplankton analysis (species-level community structure). Water and sediment samples were collected at the same time as the biological samples were taken from each of the five waterbody locations sampled in 2006 and 2011, and from just one of the waterbody locations sampled in 1995 and 1996.

3.6.3 Results

Water quality

The concentrations of mine-water-derived U in GTB have been generally low and importantly, in the antecedent periods (ie wet and/or dry season months prior to sampling) for 1995, 1996, 2006 and 2011, were at least an order of magnitude below the relevant trigger value (TV) for protection of local aquatic organisms (published SSD results). [8]

Plots of the median of (generally) weekly EC values (direct correlate of $MgSO_4$) measured in GTB since 1991 are shown in Figure 3.6.1 for the wet season (January to May inclusive) and dry season (June to December) time periods.

The antecedent wet season median EC values were low in 1995, 1996 and 2006 compared with the local EC TV of 42 µS/cm (based on an equivalent Mg TV of ~3 mg/L) for the protection of aquatic ecosystems (published SSD results). However, in 2011 and in the several wet season months prior to sampling, median EC values in GTB (Figure 3.6.1) approached the EC trigger value (weekly median of 2.5 mg/L Mg).

Antecedent dry season EC is typically much higher than wet season values in GTB due to evapo-concentration of solutes that occurs during this period. During the wet season, solutes in surface runoff from the minesite (via Corridor Creek, see Map 2) are diluted by surface water contributions from the rest of the GTB catchment, as well as backflow from Magela Creek. Prior to 1982, EC naturally reached median dry season values of 43 µS/cm but at this time Na, K, Cl and alkalinity were the main contributors to total solute concentration and not Mg (median Mg value only 0.6 mg/L, ERA data) and sulfate. Dry season EC values in 1994 and 2010 (prior to 1995 and 2011 wet-dry transition season samplings, respectively) were

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[8] Hogan A, van Dam RA, Markich SJ & Camilleri C 2005. Chronic toxicity of uranium to a tropical green alga (*Chlorella* sp.) in natural waters and the influence of dissolved organic carbon. *Aquatic Toxicology* 75, 343–353.

the highest (median dry season values: 1994, EC of 95 µS/cm and Mg 2.9 mg/L; 2010, EC of 128 µS/cm and Mg 8.8 mg/L) for the four years in which macroinvertebrate sampling occurred.

Macroinvertebrate communities

Macroinvertebrate community structure data (taxa and their abundances) from replicate sites of the different waterbodies have been summarised and analysed using community summaries and multivariate statistical techniques. Community summaries reported here are based on taxa (usually family) number and total abundance. One of the multivariate techniques – multi-dimensional scaling ordination (MDS) – depicts the community structure of samples graphically, in a reduced (typically two or three) dimensional space. The closer samples (in this case replicate sites) are together in ordination space, the more similar is their community structure. Possible mine-related effects upon community structure would be inferred if mine-water-exposed sites were separated from those of reference sites, while interspersion of replicates of the different exposure types would imply no significant difference in community structure. Statistical tests of the separation of different community groups (in this case, different mine-exposure categories) in multivariate ordination space were quantified using Analysis of Similarity (ANOSIM) – effectively an analogue of the univariate ANOVA.

Apart from Ranger RP2, the mean taxa number and mean total abundance for macroinvertebrates sampled from littoral macrophyte habitat did not vary markedly amongst the waterbodies in 1995, 1996 and 2006 (Figure 3.6.2).

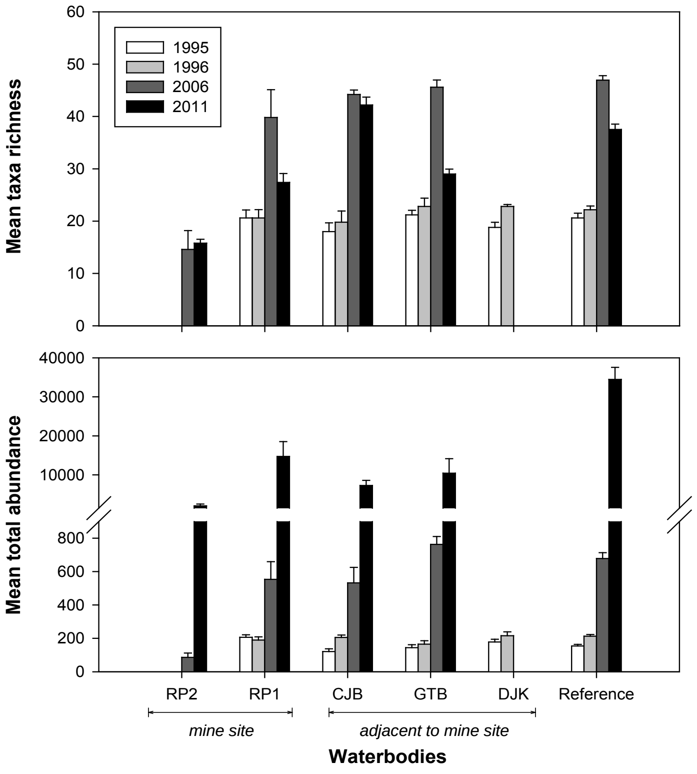

Figure 3.6.2 Histograms of mean (±SE) taxa richness (= number) and macroinvertebrate abundance amongst waterbodies on or near the Ranger uranium mine site for the four years of sampling. Site codes are Ranger Retention Pond 2 (RP2) and Retention Pond 1 (RP1), Coonjimba (CJB), Georgetown (GTB) and Djalkmara (DJK) Billabongs. Reference waterbodies are Gulungul, Baralil, Corndorl, Wirnmuyurr, Malabanjbanjdju, Anbangbang, Buba and/or Sandy Billabongs and Jabiru Lake.

For these three years the macroinvertebrate communities from GTB were very similar to those sampled from reference waterbodies. In 2011, however, both mean taxa number and particularly mean total abundance in GTB were lower than values measured for reference waterbodies (Figure 3.6.2).

MDS ordinations, depicting the relationship of macroinvertebrate samples to one another, for each of the four years are shown in Figure 3.6.3. The RP2 data were excluded from the ordination analysis results plotted here as the high degree of separation of the RP2 replicates from those from all other waterbodies would have resulted in scaling compression of the data from other waterbodies. The MDS plots for these other waterbodies showed interspersion of replicate samples from GTB among reference waterbody samples in 1995, 1996 and 2006 but separation of GTB samples from reference waterbody samples in 2011 (Figure 3.6.3). The ANOSIM test statistic was used to compare the observed differences *between* groups – in this case exposure type, GTB, versus reference waterbodies – with the differences among replicates *within* the groups. The degree of separation between groups is denoted by the R-statistic, where R-statistic > 0.75 = groups well separated, R-statistic > 0.5 = groups overlapping but clearly different, and R-statistic < 0.25 = groups barely separable. A significance level of < 5% = significant effect/difference.

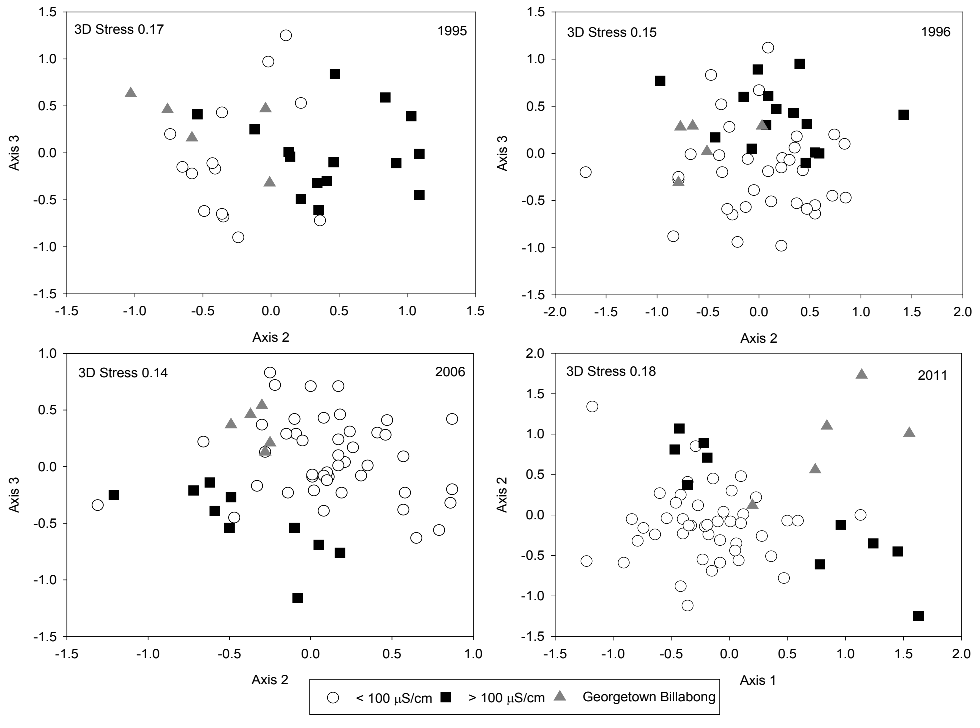

Figure 3.6.3 Ordination plots of macroinvertebrate communities from different sites and habitats in waterbodies on or near the Ranger minesite for four sampling years. Waterbodies are classified according to different degrees of exposure to mine waters indicated by electrical conductivity (EC): high for two waterbodies (RP1 and Coonjimba Billabong) and low for all other waterbodies including Georgetown Billabong.

The ANOSIM results are shown in Table 3.6.1. While GTB samples in 1995 were significantly different from reference waterbody samples, the ANOSIM R statistic is low and near the criterion defined above as 'barely separable'. On this basis, the macroinvertebrate communities of GTB in 1995 are not regarded as different from those in adjacent reference waterbodies in the region. For 2011, however, ANOSIM results indicate that GTB samples are clearly and significantly separated from reference waterbody samples. This result is consistent with the community summary results reported above which show reduced diversity of GTB macroinvertebrate communities compared with reference waterbody communities.

TABLE 3.6.1 ANOSIM SUMMARY STATISTIC RESULTS FOR EACH YEAR COMPARING GTB WITH REFERENCE WATERBODIES (NO MINE INFLUENCE)

Year	R Statistic	Significance Level %
1995	0.296	1.7
1996	-0.064	65.8
2006	0.07	30.8
2011	0.594	0.1

The power of phytoplankton and zooplankton community analyses was lower because only duplicate samples were collected from within each waterbody. In summary, the ordination analyses indicated that GTB phytoplankton and zooplankton communities more closely resembled those from mine-exposed waterbodies (Coonjimba Billabong and Ranger RP1) than those from reference waterbodies. These observations are consistent with those reported above for the 2011 macroinvertebrate communities data.

3.6.4 Conclusions

Macroinvertebrate sampling of waterbodies in 2011, in and around the Ranger mine lease, revealed for the first time, evidence of water quality impacts upon the fauna of GTB, corresponding to a reduction in water quality observed during the preceding dry and wet seasons. The EC and Mg concentrations measured during the entire antecedent dry season, and for several weeks in the latter part of the wet season prior to sampling, were consistent with those for which biological effects may occur based upon trigger values derived from laboratory ecotoxicity studies. As a consequence, only the ('no effects') water quality data from 1995, 1996 and 2006 can be used to derive potential water quality closure criteria for U, Mg and EC. The proposed values are currently under review. It should be noted, however, that further consideration needs to be given as to whether the dry season EC and $MgSO_4$ data from 1994 should be included in the derivation of dry season TVs for those respective solutes, given: (a) their high values relative to reported guideline trigger values (Figure 3.6.1) and (b) the macroinvertebrate data from the end of the wet season in 1995 that showed some slight, but significant separation of GTB replicate samples from reference waterbody samples (Table 3.6.1).

In previous SSD reporting, it has been argued that antecedent wet season water quality, rather than antecedent dry season quality, would likely be of much greater significance to resident biota given (i) the recency of exposure, (ii) the much higher biological diversity present in waterbodies in the wet season months compared with the dry season, and (iii) that the local fauna would likely be more sensitive to inputs of solutes during the wet season given that the natural exposure condition for this period is water quality similar to background receiving waters which are characterised by very low solute concentrations.

However, on closer examination of the collective results to date, the influence of antecedent dry season water quality may be of greater importance for macroinvertebrate communities in billabongs than originally thought, given (i) the correspondence between poor dry season water quality in 1994 and 2010 and significant difference in GTB macroinvertebrate communities from reference communities in subsequent wet-dry season transition periods (1995 and 2011 respectively; albeit a small shift only in 1995); and (ii) the potential for poor dry season water quality to adversely affect taxa such as molluscs and worms which are resident in the billabong throughout the annual wet and dry season cycle.

A similar approach to that described above for Georgetown Billabong is being considered for deriving water quality closure criteria for natural (Coonjimba Billabong) or proposed-to-be-reinstated (Djalkmara Billabong) waterbodies elsewhere on the mining lease.

3.7 Assessing runoff, soil erosion and solute losses from the trial landform

3.7.1 Introduction

In the 2010–11 annual report, the initial results for rainfall and bedload (2009–2010 & 2010–2011 water years) from a long-term project to assess runoff, sediment and solute losses from a trial rehabilitation landform at the Ranger mine were described. ERA constructed the trial landform at the end of 2008 with the objective of testing over the long term proposed landform design and revegetation strategies for the site, such that the most appropriate one can be implemented when the site is decommissioned. SSD is leading the erosion assessment project, and providing most of the staff resources, with a substantial level of field assistance and collaboration also being provided by technical staff from ERA.

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 material (laterite). In addition to two different types of cover materials, two different planting methods were originally going to be assessed: direct seeding and tube stock. Plots 1 and 4 were planted with tube stock in March 2009 with infill planting to replace dead specimens in January 2010. Plots 2 and 3 were direct seeded in July 2009. However, because of poor germination success, these plots were infill planted with tube stock in January 2011. The trial landform surface was ripped on the contour before the erosion plots were constructed. Over the past three years eroded material has been washed into the rip lines but there is still a large amount of potential sediment storage that can occur before the lines are obliterated.

The locations of SSD's four erosion plots (approximately 30 m × 30 m) constructed during the 2009 dry season (see 2009–10 annual report) are shown on Figure 3.7.1. Erosion plots 1 and 2 contain waste rock, and erosion plots 3 and 4, mixed waste rock and laterite. The plots were physically isolated from runoff from the rest of the landform by raised borders.

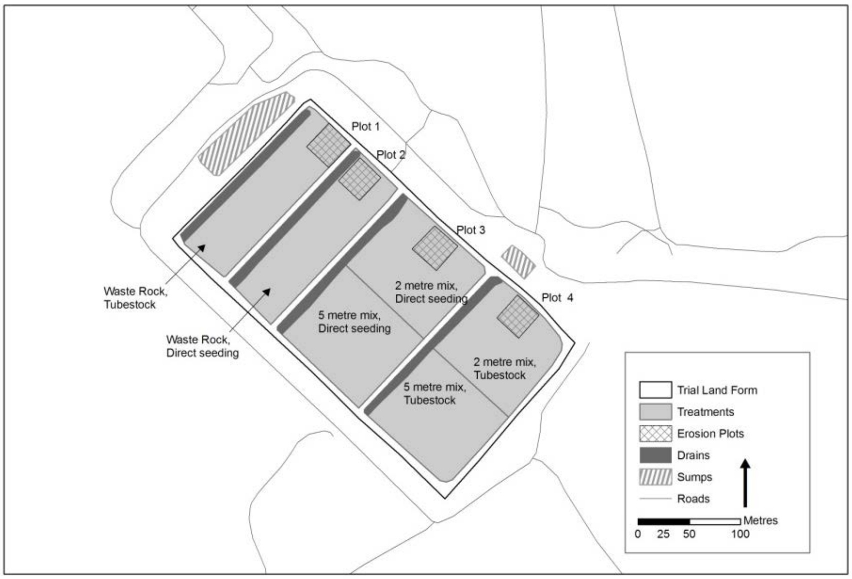

Figure 3.7.1 Layout of the plots on the trial landform

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 tipping bucket rain gauge, a primary shaft encoder with a secondary pressure transducer to measure stage height; a turbidity probe to measure suspended sediment concentration; electrical conductivity probes located at the inlet to the stilling basin and at the entry to the flume to provide a measure of the concentration of dissolved salts in the runoff; an automatic pump sampler to collect event based water samples; a data logger with mobile phone telemetry connection and a rectangular broad-crested weir to accurately determine discharge from the plots.

The latest results from the trial landform project are described below.

3.7.2 Rainfall, runoff and bedload

Overview

Preliminary sediment and solute losses from the four erosion plots were presented for the first year of monitoring (2009–10 water year) in the 2009–10 annual report. A water year extends from the driest month for 12 consecutive months, instead of being represented by a calendar year. Water years are used because 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. A 'water year' has been defined as the period from September in the first year to August in the next. Rainfall for all four plots and runoff from erosion plot 1 is reported in this annual report. Plot 1 is the only one for which runoff has been calculated to date for all three water years, 2009–10, 2010–11 and 2011–12.

Sediment is transported by flowing water as either suspended load or bedload. The results of the bedload measurements will be reported again this year because the suspended sediment and solute data are still being analysed.

Bedload samples were collected at weekly to monthly intervals during the wet season, depending on event magnitude and staff availability or on demand following isolated large rainfall events. The collected samples were transported to the ***eriss*** laboratory in Darwin for processing.

Rainfall and runoff results

The rainfall data for each plot for each water year are contained in Table 3.7.1 and the runoff data for plot 1 are summarised in Table 3.7.2.

TABLE 3.7.1 RAINFALL DATA FOR THE FOUR EROSION PLOTS ON THE TRIAL LANDFORM FOR THE THREE YEARS OF MEASUREMENT

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

TABLE 3.7.2 RAINFALL AND RUNOFF DATA FOR EROSION PLOT 1 ON THE TRIAL LANDFORM FOR THE THREE YEARS OF MEASUREMENT

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

Mean annual rainfall at Jabiru Airport (Station No. 014198) is 1576 mm[9] (Bureau of Meteorology. This BoM station is located 2.3 km from the trial landform and has an incomplete record for the period 1971–2012. Furthermore, the record since 1993 is not quality controlled.[9]

The annual rainfall for the 2011–12 water year on the trial landform was similar to the 2009–10 water year (Table 3.7.1), and both were slightly less than average at Jabiru Airport. On the other hand, the annual rainfall for the 2010–11 water year was much greater than for the other two years (Table 3.7.1), and was comparable with the 95th percentile annual rainfall at Jabiru Airport.[9]

The discharge data from plot 1 over the three years are summarised in Table 3.7.2. The number of discrete runoff events is very large and reflects the rapidly responsive nature of the plots (approximately 30 m by 30 m) to small rainfall events. The number of runoff events that produced discharge over the crest of the weir was less in the first year after construction (2009–10) and was greatest in the wettest year (2010–11). Unusually, annual runoff was less in the 2009–10 water years than in the drier 2011–12 year (Table 3.7.2). This is most likely the result of the infilling with water of the initially empty pore space in the waste rock and laterite from which the trial landform was constructed. Annual runoff was greatest in the wettest year (2010–11) when 13.5% of rainfall was converted to runoff, and was least in 2009–10 when the trial landform was wetting up (Table 3.7.2). As expected for small areas, the runoff coefficient for plots is much less than for larger catchments in the ARR. Areas up to about 1 km^2 behave as if they are drylands in the seasonally wet tropics.

There is a close curvilinear relationship between event rainfall and event runoff over the full range of rainfall for all three years for plot 1. Figure 3.7.2 shows this curvilinear relationship between total event rainfall and runoff for all 152 events on plot 1 for 2011–12. When event rainfall exceeds 30 mm there is proportionately greater runoff than for smaller events (Figure 3.7.2). These smaller events do not totally infill the rip lines with water and so runoff is only produced from a small part of the plot near the down slope border. Event rainfall greater than 30 mm can totally infill the surface storage, hence generating runoff from the whole plot surface.

Bedload results

The annual bedload yields recorded for each plot for each water year are shown in Table 3.7.3. Annual bedload yields have declined greatly since construction (Table 3.7.3). Time since construction has had a much greater effect than cover material type and development of vegetation to date (Table 3.7.3). Major land disturbances, such as construction or landslides, are usually characterised by an initial pulse of high sediment yield followed by a rapid decline in sediment yield. The nature of sediment yield decline following the initial large pulse has been reported as either exponential or logarithmic or linear (Figure 3.7.3).

[9] www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=-47599587&p_stn_num=014198, accessed 11 July 2012

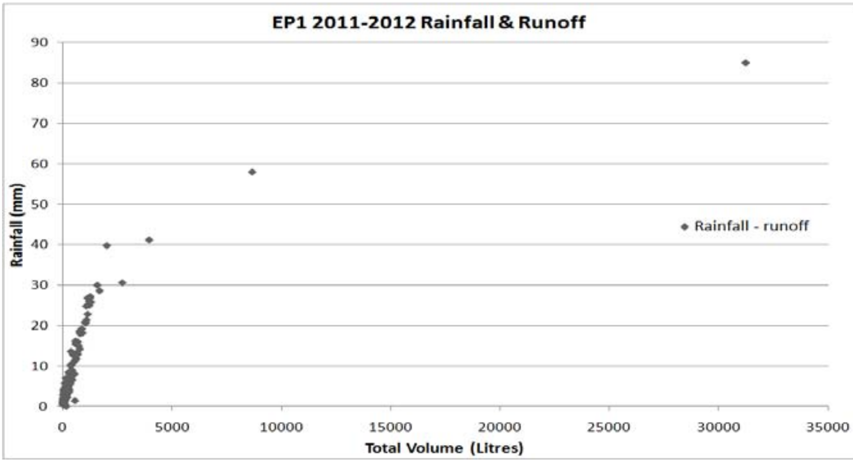

Figure 3.7.2 Relationship between total event rainfall and runoff for plot 1 for every runoff event in the 2011–12 water year

Previous research in the ARR has shown that sediment yields decline progressively over at least the first three years following a major surface disturbance as a result of initial washout of fine sediment and the subsequent formation of a gravel-armoured surface. Clearly, time since construction, rather than rainfall, is the dominant driver of bedload yield because by far the greatest rainfall occurred in the second year (Table 3.7.1) whilst bedload was substantially less than in the first year (Table 3.7.3). Using the average rainfall per rain day as an index of rainfall intensity, the values for the three years were 13.6, 15.2 and 11.8 mm/d for the 2009–10, 2010–11 and 2011–12 water years, respectively. Clearly 2010–11 was not only the wettest year but also had the most intense rainfall.

The highest bedload yields were always generated from Plot 2 (Table 3.7.3). While it is still not clear why this happens, shallow rip lines dominate the lower part of Plot 2, resulting in direct connection of diffuse overland flow transporting sediment with the down slope plot drain.

TABLE 3.7.3 ANNUAL BEDLOAD YIELDS FOR EACH PLOT ON THE TRIAL LANDFORM FOR EACH YEAR OF MEASUREMENT

Water year	Erosion Plot 1 Bedload Yield ($t/km^2.yr$)	Erosion Plot 2 Bedload Yield ($t/km^2.yr$)	Erosion Plot 3 Bedload Yield ($t/km^2.yr$)	Erosion Plot 4 Bedload Yield ($t/km^2.yr$)	Mean Annual Bedload Yield ± Standard Error ($t/km^2.yr$)
2009–10	106	147	111	143	127 ± 12
2010–11	59	113	54	56	71 ± 16
2011–12	34	48	38	15	34 ± 8

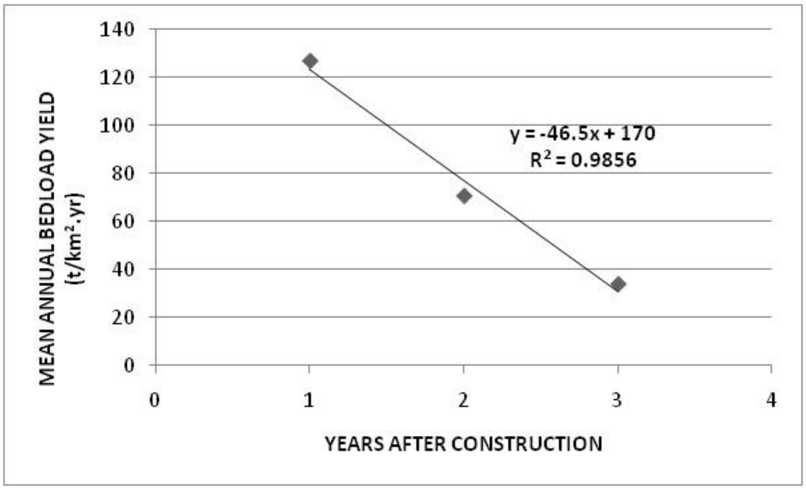

Figure 3.7.3 Linear decrease in mean annual bedload yield with time since construction for the four erosion plots on the trial landform

In the third year since construction a clear signature of the effect of vegetation is starting to be seen in the annual bedload yields. The two plots (1 & 4) originally planted with tube stock now have the greatest shrub densities and, both now show lower bedload yields than the plots (2 & 3) initially planted by (failed) direct seeding followed a year later by infill planting with tube stock. Indeed, plots 1 and 4 also recorded the two lower bedload yields in 2011–12 (Table 3.7.3). Plot 4 has the lowest yield because it has also been invaded by weeds which densely cover about half of the plot.

3.7.3 Future work

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

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

3.8 Radon exhalation from a rehabilitated landform

3.8.1 Introduction

Details of the design of the trial landform are provided in the previous paper that describes the work being done to quantify the rate of erosion. The trial landform also provides a unique setting to investigate seasonal and long-term changes in radon (^{222}Rn) exhalation, soil activity concentration and terrestrial gamma dose rate for the four different treatments, and dependency on cover type, weathering and compaction effects and developing vegetation.

Radon is part of the natural uranium decay chain and is produced by the decay of radium (^{226}Ra) in soil particles. It is a noble gas and some of the radon emanates from the particles, migrates through the soil pore space and eventually exhales from the soil surface. High soil radium activity concentrations and high porosity will lead to larger radon flux densities and vice versa. In addition, particle size and soil moisture have an influence on radon exhalation, with smaller particles favouring radon emanation and high soil moisture generally inhibiting the migration of radon through the soil profile.

Radon decays with a half life of 3.82 days to short-lived isotopes of the metals polonium (^{218}Po, ^{214}Po), lead (^{214}Pb) and bismuth (^{214}Bi). It is these radon decay products in the air, rather than the radon gas, that can deposit in the lungs and deliver a radiation dose upon inhalation. The knowledge of the radon exhalation fluxes from a rehabilitated landform thus is the first step to predict potential inhalation doses received from a constructed landform.

3.8.2 Methods

Radon flux density measurements have been made on the four erosion plots every four months since early 2009. In addition, radon flux density was measured on the original land surface before construction of the trial landform to determine the magnitude of radon exhalation from the substrate underlying the constructed landform (that is, the pre-construction background). A total of 765 measurements of radon flux densities have been made to date.

Brass canisters (15–20 per erosion plot) filled with activated charcoal are placed randomly over the surface of the erosion plots. Radon exhaling from the surface is trapped on the charcoal. After deployment for three days, the brass canisters are collected, sealed and sent to the SSD Darwin laboratories for analysis. Radon trapped on the charcoal decays and the activity of radon decay products collected in each brass cylinder is measured using a sodium iodide (NaI) gamma detector. The measurements coupled with the length of the deployment and measurement periods, enable radon flux densities from the surface of the soils to be determined.

The gamma dose rate has also been measured across the entire trial landform using environmental dose rate meters. A 5 m grid was used for each of the four erosion plots with a 10 m grid being used for the reminder of the landform. A total of 921 measurements were made. The terrestrial component of the gamma dose rate was determined by subtracting the contribution from cosmic radiation to the gamma signal. The terrestrial gamma dose rate can be used as a surrogate for the substrate ^{226}Ra activity concentration as the gamma signal from natural uranium series elements measured at 1m height originates predominantly from ^{214}Pb and ^{214}Bi, which are short lived decay products of ^{226}Ra.

3.8.3 Results and discussion

Terrestrial gamma dose rates

Figure 3.8.1 shows the trial landform, the locations of the erosion plots (EP 1–4) and a contour plot of the terrestrial gamma dose rates measured across the surface in June 2012. This plot has been generated using the ArcGIS (version 9.3.1) Spatial Analyst tool. Erosion plots 1 and 2 were constructed on the waste rock cover, while plots 3 and 4 are located on the waste rock–laterite
mix.

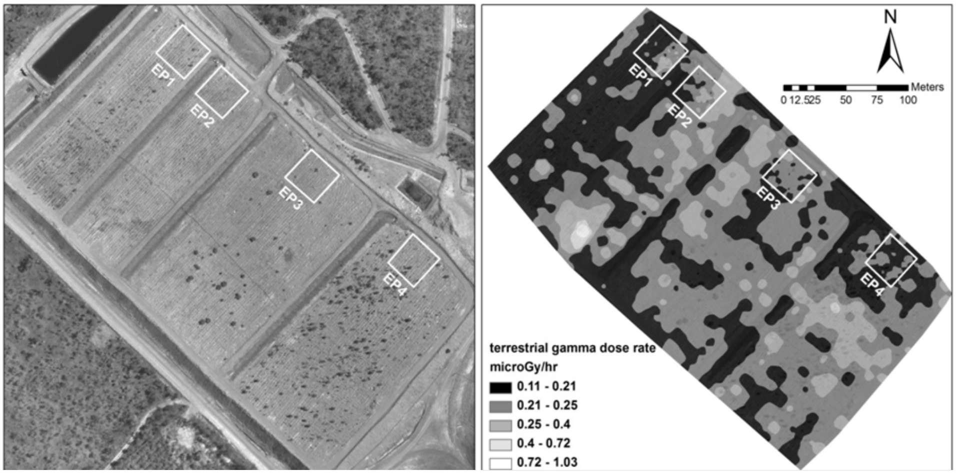

Figure 3.8.1 Aerial photo of the trial landform and contour plot of the terrestrial gamma dose rates measured across the trial landform in June 2012

Apart from a small area on the opposite side of the landform to EP 2 where terrestrial gamma dose rates of about 1 $\mu Gy \cdot hr^{-1}$ were measured, the dose rate is between 0.11–0.46 $\mu Gy \cdot hr^{-1}$, which is about 2–4 times higher than typical terrestrial background dose rates in the region. Average (both arithmetic and geometric) terrestrial gamma dose rate is lowest over erosion plot 4 (0.20 $\mu Gy \cdot hr^{-1}$) and highest over erosion plot 2 (0.24 $\mu Gy \cdot hr^{-1}$).

Radon flux densities

Radon flux densities on the four erosion plots have now been measured over three years starting in May 2009 and covering both wet and dry seasons. Arithmetic (and *geometric*) averages for each plot and measurement campaign, and the associated standard errors, are shown in Table 3.8.1. The spread in the measurements is large due to the small surface area of the charcoal canisters used to collect the exhaled radon relative to the surface area of the erosion plots. Such a variability is not unusual, and it has been shown that the geometric average is a better representation of the average, due to environmental radon flux densities typically being log normally distributed. Radon flux density from the pre-construction unmineralised substrate was measured late in 2008 and was around 70 mBq·m^{-2}·s^{-1}, similar to values determined previously in the region.

TABLE 3.8.1 AVERAGE (ARITHMETIC AND *GEOMETRIC*) RADON FLUX DENSITIES MEASURED ON EROSION PLOTS 1-4, MAY 2009 - JULY 2012

Plot	^{222}Rn flux density [mBq·m^{-2}·s^{-1}] arithmetic (*geometric*) average ± error (95% confidence)									
	May 09	Sep 09	Feb 10	May 10	Sep 10	Jan 11	May 11	Oct 11	Mar 12	Jul 12
EP1	22(*14*) ±11	15(*9*) ±8	7(*4*) ±3	43(*21*) ±25	60(*26*) ±47	100(*27*) ±76	60(*18*) ±63	68(*24*) ±47	47(*18*) ±27	112(*82*) ±40
EP2	42(*27*) ±15	17(*9*) ±10	8(*5*) ±4	45(*28*) ±20	69(*40*) ±34	126(*50*) ±86	67(*38*) ±37	82(*43*) ±43	107(*41*) ±41	165(*121*) ±121
EP3	18(*13*) ±7	14(*9*) ±8	5(*1*) ±2	51(*21*) ±35	102(*78*) ±35	64(*32*) ±50	65(*37*) ±33	63(*49*) ±19	69(*35*) ±38	199(*162*) ±59
EP4	18(*14*) ±7	40(*19*) ±32	6(*3*) ±4	83(*42*) ±51	111(*68*) ±60	89(*25*) ±57	71(*55*) ±22	112(*79*) ±41	40(*20*) ±20	170(*106*) ±97

Figure 3.8.1 shows a plot of the geometric average, or typical value, of the radon flux densities measured over time. The daily rainfall measured on the trial landform is shown for comparison. Annual rainfall averages are given in Table 3.7.1.

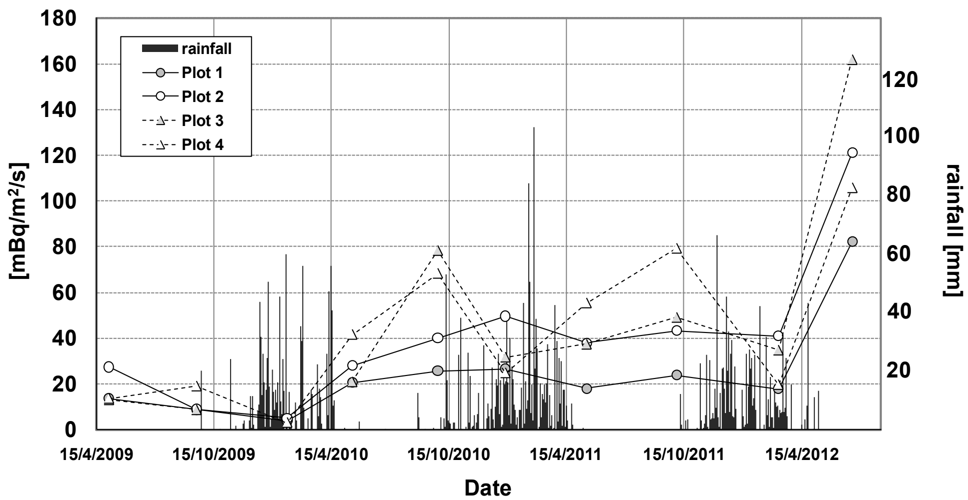

Figure 3.8.1 Time series geometric averages of the radon flux densities measured on erosion plots 1–4 on the landform with daily rainfall overlaid for comparison

Measured radon flux densities were low in 2009, shortly after construction of the landform. The main substrate used for construction of the landform is waste rock, consisting of a chlorite-rich schist that weathers rapidly to smaller gravel and clay size fractions. The higher surface area to volume ratio of weathered rock favours radon emanation, leading to the higher values observed after the first wet season. In addition, radon exhalation from a soil surface is proportional to the gradient of the radon concentration in the interstitial soil space. Typical diffusion lengths for radon are 1.5 m up to 3 m, with diffusion coefficients between 10^{-8} to 10^{-5} $m^2 \cdot s^{-1}$. This gradient needed time, after initial construction of the landform, to develop through the substrate profile until steady state conditions were achieved. Consequently, the initially measured radon flux densities were lower, as the radon originated predominantly from the top most layers, consisting of relatively coarse schistose material.

Following the initial measurements in 2009, radon flux densities on erosion plots 3 and 4 show the expected seasonal trend, with higher values during the dry and lower values during the wet seasons. In contrast, erosion plots 1 and 2 show relatively little seasonal variation and dry season values on these two plots are similar to those measured during the wet season. However, in July 2012 average values were higher compared with the previous sets of data for these two plots.

Differences between waste rock only and the waste rock–laterite mix, both in average radon flux densities as well as its seasonal variation, can be explained by the different properties of the substrate materials. As indicated by the terrestrial gamma dose rate measurements, the average soil radium activity concentration is similar across the four erosion plots. However, erosion plots 3 and 4 have approximately 30 v/v % of fine grained laterite mixed with the waste rock. Soils collected from the waste rock–laterite mix surface have a smaller average grain size, with an average percentage of silts and clays (< 63 µm) of 11% compared with 7% for waste rock only. In addition, the percentage gravel (> 2 mm) is higher for waste rock only (67%) compared with the waste rock–laterite mix (61%). This favours radon exhalation from the waste rock–laterite mix and results in higher radon flux densities during the dry season compared with the waste rock only treatment.

During the wet season, moisture is retained more effectively in the waste rock–laterite mix and radon flux densities decrease. Pooling of water is routinely observed on erosion plots 3 and 4 during the wet season meaning that in some areas the soil is saturated with water. This leads to a decrease in radon exhalation. In contrast, no pooling has been observed on erosion plots 1 and 2. Water infiltrates quickly into the waste rock cover after a rain event and consequently, the difference between wet season and dry season radon flux densities is small. This may change with time, with smaller grain weathering products slowly infilling cracks and voids on the waste rock only cover, perhaps leading to a seasonal variability similar to that currently observed on erosion plots 3 and 4.

3.8.4 Conclusions and future work

Although average soil radioactivity is not markedly different across the four erosion plots, there is a difference in average radon flux densities for the two different surface treatments. In the dry season, typical average radon flux densities from the surface of the waste rock – laterite treatment are higher than radon flux densities from waste rock only, and decrease markedly in the wet. In contrast, there was no obvious seasonal trend observed for radon exhalation fluxes from waste rock only. Ongoing seasonal radon flux density measurements are required to determine whether there will be further long-term changes. This is particularly important to ascertain for the waste rock only treatment, as this is the preferred option for rehabilitation at Ranger.

Soil samples (n=68) down to 10 cm depth were collected in July 2012 from underneath the locations where the radon exhalation measurements were made. These samples will be measured for their ^{226}Ra activity concentration via gamma spectrometry to obtain a quantitative relationship between radon flux densities and ^{226}Ra activity concentration for the two treatments, and the findings will be presented in the next annual report. The results will aid in modelling radon exhalation from various cover types and predicting radon fluxes from the site after rehabilitation.

3.9 Vegetation mapping of the Magela floodplain using high resolution satellite data

3.9.1 Introduction

The significance of the wetlands of the Magela Creek floodplain and their biodiversity has been recognised through their listing by the Ramsar Convention on Wetlands. Since vegetation within the wetland is spatially and temporally variable, a robust methodology for mapping wetland vegetation at scales that can detect this variability is required. Mapping of the vegetation through time can assist with determining the driver(s) of this variability and identify if the change is naturally induced, or the result of human activities (eg burning, mining activities) and/or other stressors (eg feral animals, weeds). Multispectral high spatial resolution (pixels < 5 m) satellite imagery, such as WorldView-2, provides data of sufficient resolution for spatially and spectrally detailed analysis of such landscapes. However, the increased spatial heterogeneity associated with the finer resolution of the data requires data aggregation to assist with classification. The project described here uses GEographic Object-Based Image Analysis (GEOBIA) to classify the Magela floodplain vegetation.

GEOBIA involves the partitioning of remotely sensed images into meaningful image-objects. This involves assessing object characteristics through spatial, spectral and temporal scales. The process generates GIS-ready information to obtain new geo-intelligence (ie geospatial content in context, in this case floodplain communities). Object-based methods have been shown to cope better with the increase in spatial heterogeneity associated with high resolution multi-spectral satellite imagery, compared with traditional pixel-based (based on spectra) classification techniques. One of the main advantages of the GEOBIA approach is the ability to use contextual information to assist with image classification.

Apart from an unpublished map produced by ***eriss*** in 2004 there has been no updated Magela floodplain vegetation community map produced for over 20 years.

3.9.2 Methods

The systematic remote sensing captures that were started in May 2010 continued through 2011 and 2012. Project work in 2011–2012 focused on producing a high resolution map of vegetation for the Magela Creek floodplain, downstream from the Ranger uranium mine, and processing of World-View 2 (WV2) image captures and associated ground surveys through that period.

The multispectral sensors onboard the WV2 satellite collect data in 8 spectral bands (Table 3.9.1) with a spatial resolution of 2 m. The raw data collected by the sensors were geometrically corrected to map projection and radiometrically calibrated to ground reflectance. The methods reported here focus on image classification since the image pre-processing methods used for the May 2010 World-View 2 imagery were reported in the last annual report.

TABLE 3.9.1. WORLDVIEW-2 SPECTRAL BAND SPECIFICATIONS

Spectral band	Wavelength centre (nm)	Wavelength min – max (nm)
Coastal	427	400–450
Blue	478	450–510
Green	546	510–580
Yellow	608	585–625
Red	659	630–690
Red Edge	724	705–745
Near Infrared 1	831	770–895
Near Infrared 2	908	860–1040

The first steps of the classification process created masks (in the form of objects) to extract the regions of non-image pixels and non-target land covers (eg the township and mine site) and eliminate these regions from the remaining processing. The next step involved extracting the floodplain from the surrounding terrestrial savannah landscape. To be able to successfully delineate the floodplain boundary using a semi-automated approach, a threshold segmentation set at 6 m and below was applied to the 30 m digital elevation model (DEM) derived from the Shuttle RADAR Topography Mission. An automated delineation would have not been possible based purely on spectral information due to similarities in the spectral response from some floodplain and non-floodplain vegetation communities (eg *Melaleuca* and *Eucalyptus* open woodlands). Once the floodplain boundary was delineated, objects for the open water class were extracted by segmenting the floodplain based on a threshold of the Near Infrared 1 band of the imagery (NIR1). Pixels within the floodplain with a NIR1 value less than 100 were assigned to open water objects. Similarly, cloud objects were extracted based on a ratio using the Near Infrared 2 (NIR2), Red Edge and Blue bands. Pixels below the threshold value of -850 for this ratio were assigned to the cloud class.

Objects representing floodplain vegetation community classes were created using a series of rules based upon a number of spectral indices (Table 3.9.2). A series of iterations involving segmentation, classification and reshaping were undertaken to create the class objects. The steps typically involved segmentation where objects were iteratively partitioned into smaller objects until an object threshold was met (based either on size or an index or ratio value). Class rules were applied using a step-wise method and adjacent objects of the same class merged to form larger objects. If objects were still spectrally variable (containing measurable heterogeneous pixel cover) they were considered to contain two or more classes and subsequently re-segmented with new rules applied to separate the classes. Otherwise spurious objects deemed too small (generally <5 pixels), and completely enclosed by a larger object of a different class, were dissolved into (that is, deemed to be part of) the larger object. Processes were iterated until satisfactory class separability was achieved.

TABLE 3.9.2 SPECTRAL INDICIES USED WITHIN SEGMENTATION AND CLASSIFICATION ALGORITHMS

Index	Equation	What the index is sensitive to
NDVI2	NIR2-Red/NIR2+Red	NDVI is strongly related to photosynthetic material. The index enabled discrimination between actively photosynthesising vegetation, senescent vegetation such as *Oryza,* and open water.
FDI2	NIR2-(Red Edge + Blue)	The index enables the separation of photosynthetic vegetation from bare soil and non-PS vegetation. In particular it separates woody canopy from understorey and ground cover.
NREB	NIR2+Red Edge-Blue	This index distinguished non-PS vegetation that is highly reflective; in this case communities dominated by *Nelumbo*, *Leersia*, and *Salvinia.*
EVI*	G x (NIR2-Red) / (NIR2+(C1xRed)+(C2xBlue)+L)	EVI is strongly correlated to evapotranspiration.

* G=2.5, C1=6, C2=7.5 and L=1

The thematic accuracy of version 1 of the floodplain vegetation map consisted of the validation or 'ground truthing' of the map against the two available reference data sets: an aerial survey collecting 100 reference sites across the floodplain, undertaken 29 May 2010, and an airboat survey collecting 28 reference sites, undertaken 17–20 May 2010. The validation involved site-specific analysis of the classes in the map and the classes determined at the locations within the reference data. This comparison was conducted using a confusion matrix. From the matrix, User's and Producer's accuracies were calculated for each class along with the overall classification accuracy.

The Producer's accuracy was calculated by dividing the number of correctly identified sample units for a given class by the total number of sample units for a given class according to the reference data. The User's accuracy was calculated by dividing the number of correctly identified sample units for a given class by the total number of sample units for given class based on the classification. The overall classification accuracy is given by dividing the total number of correctly identified sample units for all classes by the total number of sample units for all classes.

3.9.3 Results

The final vegetation community map that was produced consisted of 13 vegetation classes labelled based on the dominant *Genera* for the community: *Eleocharis*, *Hymenachne*, *Hymenachne*/Para Grass, *Leersia*, Mangrove, *Melaleuca* open forest, *Melaleuca* woodland, *Nelumbo*, *Oryza*, Para grass, *Pseudoraphis*, *Pseudoraphis/Hymenachne* and *Salvinia*. These class types are consistent with the classes identified and mapped previously in 1989 and 2004. Also displayed within the map are classes for open water, cloud and cloud shadow. Based on the reference data, the overall accuracy of the map was over 72%. User's and Producer's accuracies are displayed in Table 3.9.3.

TABLE 3.9.3 PRODUCER'S AND USER'S ACCURACIES FOR THE CLASSES OF MAGELA CREEK FLOODPLAIN VEGETATION

Class name	Producer's accuracy	User's accuracy
Hymenachne	76.9%	57.1%
Melaleuca woodland	63.6%	58.3%
Eleocharis	46.9%	83.3%
Oryza	85.7%	77.4%
Para grass	80.0%	80.0%
Pseudoraphis	77.8%	87.5%
Pseudoraphis/*Hymenachne*	100%	56.5%
Salvinia	62.5%	83.3%
Melaleuca open forest	60.0%	60.0%
Nelumbo	80.0%	80.0%
Leersia	50.0%	100%
Hymenachne/ Para grass	75.0%	100%
Mangrove	100%	57.1%
Water	66.7%	100%
Cloud shadow	100%	100%
Cloud	100%	100%

The results indicate the vegetation classification process developed for this work easily distinguished between the spectrally and structurally distinct vegetation communities within the floodplain. The major source of confusion was between the *Eleocharis* and *Hymenachne* classes. The use of multiple indices and ratios were able to differentiate between classes that otherwise appeared spectrally (that is, optically) similar. Likewise, several contextual rules were able to be developed using structural (physical morphology features within the objects), differences to differentiate between spectrally similar classes.

3.9.4 Conclusions and future work

This project provides a good example of the application of the GEOBIA technique to mapping floodplain vegetation using high spatial resolution imagery. The rule-set implemented a number of well-known spectral indices and sensor band specific ratios to: (1) segment and classify major landscape units (MLUs) and mask out non-floodplain land covers, and (2) extract objects representative of the vegetation communities within the floodplain from the MLUs. The results indicate the rule set was able to distinguish the majority of floodplain classes. The availability of a digital elevation model with sufficient resolution and the use of contextual physical features, such as size and relationships to neighbouring objects, assisted in identifying and removing spurious objects and in facilitating the separation of objects of different cover type but with otherwise similar spectral characteristics.

This method will now be applied to mapping the floodplain vegetation using the images acquired in May 2011 and in June 2012. The time series of maps will enable the annual variation between communities to be tracked, and facilitate identification of the key contributors to the changes that are occurring. By applying relative measures as opposed to absolute (that is, reducing the reliance on exact values for individual wavelength bands), it is anticipated the rule set will be transferrable from one year to the next (with minor threshold adjustments associated with radiometric differences such as sun and view angle differences). Further work will involve adjustment of class rules to improve the thematic accuracy of the map; and identifying and delineating structural classes for the *Eucalyptus* dominated savannah matrix surrounding the floodplain.

3.10 LiDAR capture for the Alligator Rivers Region

3.10.1 Background

The Australian Government Department of Climate Change and Energy Efficiency (DCCEE) released a report titled ‘Kakadu: Vulnerability to climate change impacts’ in June 2011. The South Alligator River catchment was used as a case study to examine the potential impacts of climate change and in particular sea level rise, on Kakadu National Park’s World Heritage and Ramsar listed wetlands. The report concluded that the freshwater wetlands of the region are vulnerable to climate change impacts, and that sea level rise will increase saltwater intrusion events, thereby threatening the current status of the wetlands. It was identified that the most fundamental information gap is a Digital Elevation Model (DEM) of suitable resolution for this low relief area since: ‘without this tool it is virtually impossible for Park managers to undertake a detailed assessment of the most important Park assets (values), determine which may be at the highest risk of climate change and which may need to be protected or conserved with any degree of certainty'.

In order to address this fundamental information gap, SEWPaC and DCCEE commissioned a LiDAR (Light Detection and Ranging) data capture for the Alligator Rivers Region (ARR) floodplains, through Geoscience Australia's Optical, Geospatial, Radar, and Elevation Supplies and Services Panel (OGRE). ***eriss*** provided advice for the development of the technical specifications for the project and liaised with the DCCEE coordinator on behalf of SEWPaC and the National Environmental Research Program, Northern Australia Hub (NERP NAH). In addition to the lowland ARR floodplain areas (including the Magela Creek floodplain) that were covered by the primary remit of the acquisition, ***eriss*** requested that LiDAR data also be acquired for the Nabarlek (decommissioned U mine) catchment, Myra Camp (U exploration camp in Arnhem Land located in the Tin Camp Creek catchment) and a targeted area of escarpment in the East Alligator area to assist with the uranium mining assessment and research activities of the Division.

3.10.2 Data acquisition

The total area (Figure 3.10.1) for data capture was approximately 4000 km^2. Data acquisition commenced on the 22 October and was completed on 16 November 2011, with 100% of the specified area captured. The data capture was carried out as late as possible in the 2011 dry season and immediately prior to the start of the 2011–12 wet session rainfall, so that the minimum amount of inundation was present at the time of capture.

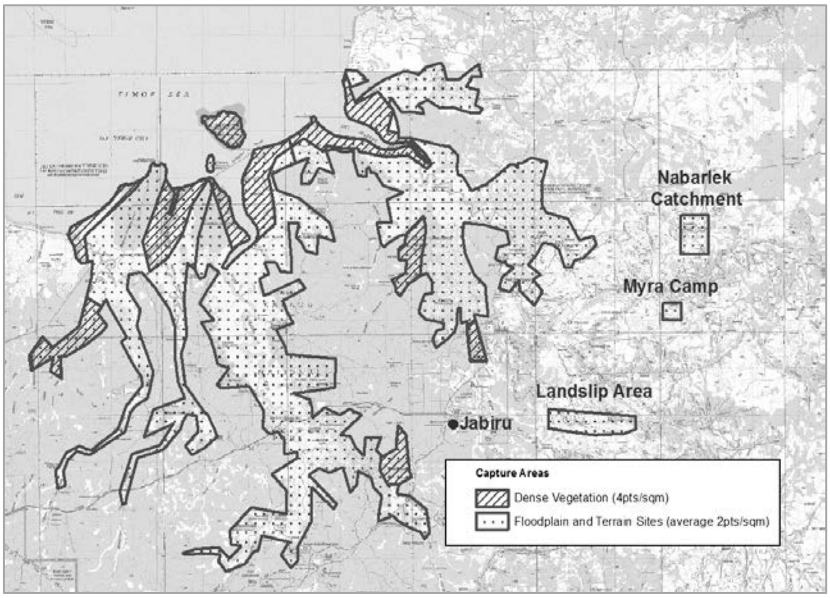

Figure 3.10.1 Alligator River Region data capture area showing those areas where data was required to be captured at a higher sampling rate (ie 4 pts/m^2)

The ground control survey (carried out by the contractor's land survey crew) commenced on 7 November and was completed on 18 November 2011. In order to get ground returns in densely vegetated areas (mangroves and *Melaleuca*), the sampling intensity that was specified was 4pts/m^2, compared with an average of 2pts/m^2 for the less densely vegetated areas on the floodplain and for areas with greater topographic relief (Nabarlek site within the Cooper Creek catchment, Myra Camp and the East Alligator River landslips area). The East Alligator landslips occurred in March 2007 during the wettest wet season on record for Jabiru (refer to Chapter 3 in the 2007–2008 annual report).

3.10.3 Data products and preliminary data

The products to be supplied from this project are shown in Table 3.10.1. The source data are currently being quality assured/quality checked by Geoscience Australia before release. However some preliminary data have been supplied for initial checking. Figures 3.10.2 and 3.10.3 show high resolution topographic images of land surfaces derived from the Digital Elevation Model (DEM) for the East Alligator River landslip area.

TABLE 3.10.1 TOPOGRAPHIC LiDAR PRODUCT SUMMARY

Data product	Format	Resolution
Unclassified LiDAR points	LAS	Av 2pts/m^2
Classified LiDAR points	LAS	Av 2pts/m^2
LiDAR intensity (tiles and mosaic)	ECW (mos.) & Geotiff (tiles)	1 m
Surface model (DSM)	Grid	1 m
Elevation model (DEM)	Grid	1 m
Canopy elevation model (CEM)	Grid	2 m
Canopy foliage model (CFM)	Grid	2 m
Contours	Vector	0.5 m

3.10.4 Future work

The floodplain LiDAR data will be used by NERP NAH researchers in developing hydrodynamic models and assessing the impacts of sea level rise in the Alligator Rivers Region. In terms of SSD specific project work the following projects will utilise the LiDAR data:

- Cooper Creek catchment – the LiDAR derived DEM provides sufficient vertical resolution for the application of geomorphic Landscape Evolution Models to predict the long term erosion potential for this catchment which includes the decommissioned and largely rehabilitated Nabarlek U mine.

- Myra Exploration Camp and Tin Camp Creek catchment – the data will be used in a long-term erosion modelling and monitoring project being undertaken in collaboration between ***eriss*** and the University of Newcastle.
- East Alligator landslips – the LiDAR data will be used to assist with a geotechnical research project (collaboration with the University of Western Australia) on factors controlling occurrence of landslips in high rainfall tropical areas.

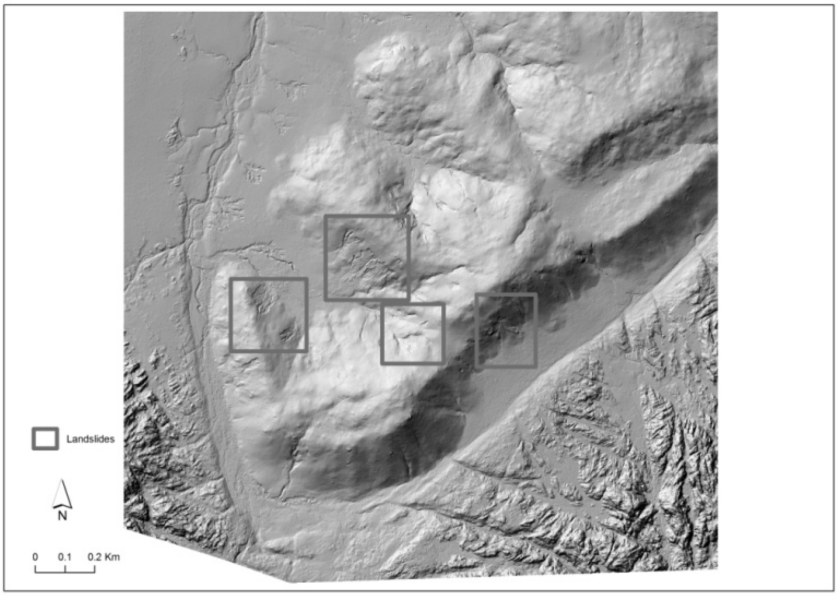

Figure 3.10.2 Hillshade image for the East Alligator landslip area with the landslips highlighted

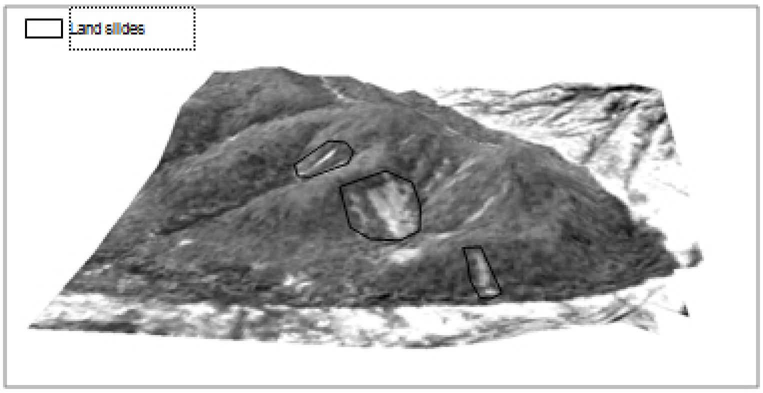

Figure 3.10.3 ALOS AVNIR-2 satellite image (2008) draped over the DEM for the East Alligator landslip area. The areas containing the landslips (lighter shade) have been highlighted.

4 STATUTORY COMMITTEES

4.1 Introduction

During 2011–12, 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*. Members of ARRAC are appointed by the Australian Government Minister for Sustainability, Environment, Water, Population and Communities.

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

- NT Department of Resources
- NT Department of Natural Resources, Environment, the Arts and Sport
- NT Department of Health
- 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
- Afmeco Mining and Exploration 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, stakeholder members provide an update report on their activities during the reporting period. SSD also provides a detailed report to each ARRAC meeting covering the outcomes of audit and assessment activities and the results from SSD environmental monitoring programs.

ARRAC met twice during 2011–12: in Jabiru in September 2011 and in Darwin in April 2012. 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; and
- 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.

Fig 4.1 Members and observers at the 37th meeting of ARRAC

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 appropriately targeted and of the highest possible standard. ARRTC also reviews the quality and adequacy of the science used for the regulatory assessment and approval of uranium mining related applications and proposals in the Alligator Rivers Region.

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

- an independent Chair;
- the Supervising Scientist;
- a number of independent scientific members (including the Chair) with specific expertise nominated by Science and Technology Australia – formerly the Federation of Australian Scientific and Technological Societies (FASTS);
- a member representing Environmental Non-government Organisation interests; and
- a number of members representing other relevant stakeholders including 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.

New members appointed to ARRTC during 2011-12 included the independent scientific member with expertise in groundwater (Ms Jane Coram), the Energy Resources of Australia Ltd stakeholder member (Dr Greg Sinclair) and the Uranium Equities Limited stakeholder member (Ms Melissa Taylor). Dr Simon Barry, current independent scientific member with expertise in ecological risk assessment, was appointed as Chair of ARRTC in March 2012, replacing the acting Chair, Dr Jenny Stauber.

ARRTC held two meetings in 2011–12: in November 2011 and April 2012. Key issues considered by ARRTC at these meetings included:

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

At its meeting in April 2012, ARRTC endorsed the proposed ***eriss*** and ERA scientific research programs for 2012–13. ARRTC also reviewed the status of the current KKNs and agreed to progressing the development of a new risk based framework and associated KKNs covering the rehabilitation, stabilisation and post-mining phases at Ranger.

Fig 4.2 Scientific and stakeholder members at the 28th meeting of ARRTC

The ARRTC 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 participated in community engagement activities such as festivals, open days and school visits within local communities in Kakadu National Park and the Alligator Rivers Region. These activities assist in strengthening SSD's relationships with local indigenous stakeholders, research organisations, non-governmental environmental groups and the general public.

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

Activities undertaken in the reporting period include community liaison and information, scientific education activities, reviews and workshops, and conference organisation and presentations. Liaison with traditional owners and other indigenous stakeholders continued to be a priority.

The 2011–12 program of community engagement activities in the ARR included display booths at the Mahbilil Festival and World Wetlands Day in Jabiru, school talks and participation in a careers expo, interactive informal information sessions on country with local traditional owners, a series of presentations to Kakadu district rangers and hosting visits 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 the Division's scientific data and reports, such as the results of the SSD environmental monitoring program.

5.2.1 Indigenous employment and education and stakeholder consultation

SSD is committed to providing employment and training to local indigenous people. During 2011–12, SSD was once again a host employer for Group Training Northern Territory trainees studying through Charles Darwin University. This year two indigenous trainees have joined the Jabiru Field Station under this scheme.

Our first indigenous trainee commenced in 2009 as a school-based apprentice completing the qualification of Conservation and Land Management (CaLM) certificate II. He became a full-time SSD employee and is in the final stages of completing his CaLM certificate III. He and the JFS CLO were invited to speak about the value of education at the Clontarf academy school rewards breakfast and about their work at SSD.

Our most recent trainee from the community of Patonga in Kakadu National Park started a school-based apprenticeship this year. He is also studying for a CaLM certificate II, and has helped with pop-netting projects and grounds maintenance.

Employment of Indigenous people for activities such as field research projects provides SSD staff the opportunity to work alongside landowners on their country, sharing knowledge and gaining greater insight into traditional cultural values. It is also provides an opportunity for indigenous people to gain valuable technical skills and a greater understanding of how SSD does its work. Regular meetings between SSD's Jabiru-based Community Liaison Officer (CLO) and the Gundjeihmi Aboriginal Corporation (GAC) are held to facilitate this interaction. Matters addressed in these meetings include employment, day labour payment details and updating of GAC's employment register. The CLO delivers specially tailored inductions sessions addressing the role of the Division, workplace health and safety, and emergency procedures to facilitate employment with SSD. During 2011–12, Mirarr people worked 66 days on research and monitoring projects, including popnetting, bush tucker collection, field equipment maintenance and maintenance of Jabiru Field Station grounds and facilities.

Figure 5.1 Gundjeihmi Aboriginal Corporation staff assisting with popnetting

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

The CLO regularly liaises with the broader ARR stakeholder group, including Energy Resources of Australia Ltd (ERA) community relations staff, Parks Operations and Tourism Branch staff, local Indigenous corporations, the Northern Land Council, to ensure there is a continuous supply of information on current and proposed SSD activities. Liaison also occurs with local people to explain SSD projects and seek permission to carry out research on indigenous land, and with Park Operations and Tourism to advise when and where SSD will be carrying out activities within Kakadu National Park (see 5.2.2 below).

5.2.2 Research protocols for Kakadu National Park

Details of proposed 2012–13 SSD research and monitoring activities within Kakadu National Park were submitted to Parks Australia and the Northern Land Council in April 2012 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.

The ***eriss*** Innovation Group was established in August 2011. The purpose of the group is to encourage creative thinking and to explore and test novel ideas to support scientific research and next generation leadership in ***eriss***, SSD and the Department. The group is open to any staff interested in contributing and is predominantly composed of research scientists from ***eriss*** and executive level staff from OSS.

IiP (Investor in People) activities undertaken during 2001–12 are described in Chapter 6.

SSD continues to make extensive use of the Intranet. More than half of SSD staff have received intranet author 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).

SSD's internal newsletter *Newsbrief* is produced fortnightly and is available on the Intranet. It provides information on current SSD 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.

5.2.4 Communication with technical stakeholders and the general public

Two meetings of the Alligator Rivers Region Advisory Committee (ARRAC) and two meetings of the Alligator Rivers Region Technical Committee (ARRTC) were held during the period. The organisation of these meetings were coordinated by the SSD committee secretariat. 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 (GAC) and the Northern Land Council (NLC) are both members of ARRAC, whilst the NLC is a member of ARRTC. Detailed information on ARRAC and ARRTC are provided in Chapter 4 of this report.

As detailed in the last Annual Report a focus for liaison activities continues to be informing Kakadu National Park Rangers about the work that SSD has been doing, and about work that is planned to occur in their specific regions. This communicates at a local level the material contained in the Research Protocols document (see 5.2.2 above).

Figure 5.2 Mahbilil display 2011

SSD hosted a booth at the Mahbilil Festival held in September 2011 in Jabiru. The festival is held in late August to September when the afternoon breezes increase and large numbers of magpie geese gather across the wetlands to lay their eggs. Mahbilil is the Gundjeihmi name of a myth related to the afternoon breeze that occurs in Gurrung (the local calendar name for that time of year). The SSD displays focussed on water and air monitoring, spatial science and mapping and research being conducted on the trial landform rehabilitation landform at Ranger.

Locals and visitors alike browsed the displays, dabbled in the macroinvertebrate trays, and discussed with our staff science topics related to our role. It is important that SSD continues to have a presence at the Mahbilil event to respond to general community concerns that might not otherwise be raised.

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

Figure 5.3 (above) Junior Rangers hard at work at Jabiru Field Station

Figure 5.4 (left) SSD's display for World Wetlands Day in Jabiru Plaza

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

SSD hosted a stall at a Schools Careers Expo in September 2011 in the Jabiru Town Hall. This was a good opportunity to promote SSD's scientific activities, showcase the Division as a future employer and provide reassurance about environmental issues.

All of the above activities served to enhance awareness and understanding of the work and role of SSD and to raise its profile within the local and wider community.

5.2.5 Australia Day awards

Melanie Trenfield received a Department of Sustainability, Environment, Water, Population and Communities Australia Day Award this year. Melanie's award was in recognition of her extensive research undertaken over four years which has substantially advanced scientific knowledge about how organic carbon reduces the toxicity of uranium in freshwater environments.

5.3 National and international environmental protection activities

5.3.1 National initiatives for radiation protection of the environment

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

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

Dr Bollhöfer is the expert scientific member of the steering committee for the joint ARPANSA and DRET project to determine concentration ratios for radionuclides in non-human biota inhabiting Australian uranium mining environments. The steering committee was established in November 2011 to provide guidance and strategic directions for the project and to facilitate the collection of data from published and unpublished sources. The outcomes from this national project will aid in assessing environmental impacts from ionising radiation on fauna and flora in the Australian uranium mining context.

5.3.2 Revision of National Water Quality Guidelines

Currently under revision are the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000), constituting Guideline 4 of the National Water Quality Management Strategy. These guidelines represent a key source document in Australia and New Zealand for managing natural water quality and protecting aquatic ecosystems. SSD continued to support the Guideline 4 revision through the technical coordinator roles of ***eriss*** research scientists, Dr Rick van Dam and Dr Chris Humphrey, and the hosting of the revision project coordinator, Ms Kate Dixon. During 2011–12, the program of revision works and associated budget were approved, and the necessary governance arrangements to procure and manage the revision activities were established. ***eriss*** will continue to work with DSEWPaC's Water Reform Division during 2012–13 to progress the revision activities.

5.3.3 Basslink

SSD staff Dr Chris Humphrey and Dr Mike Saynor, as Australian Government representatives on the Gordon River Scientific Reference Committee (GRSRC), provided comment on the 2010–11 Gordon River Basslink Monitoring Annual Report which evaluated the monitoring program after the fifth year of Basslink operations. In July 2011, Dr Saynor participated in a geomorphology sub-group meeting of the GRSRC to discuss bank seepage trials and aerial photography requirements for the Gordon River. The GRSRC will receive and review in late 2012 the 6-year review report, the last report required under the current license conditions. At this stage, Hydro Tasmania's intent and requirements for monitoring, as well as the Committee's role, beyond that specified in the current licence conditions, are not known.

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 2011–2012, project work was completed by Dr Renée Bartolo from ***eriss*** for the Ecological Program in collaboration with a team of researchers led by the University of Western Australia. The project 'Assessing the likely impacts of development on aquatic ecological assets in northern Australia' builds on the ecological risk assessments previously undertaken by ***eriss*** staff for the Tropical Rivers Inventory and Assessment project (TRIAP).

More information about NAWFA and the program's products can be found at www.environment.gov.au/water/policy-programs/northern-australia.

5.3.5 National Environmental Research Program (NERP)

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

A number of the research themes and projects within the NERP Northern Hub are focused in Kakadu National Park. ***eriss*** staff are collaborating on projects in the 'Aquatic Biodiversity Conservation' and 'Biodiversity Monitoring and Reporting' themes. One of the major activities ***eriss*** has supported to date is the acquisition, in October 2011, of LiDAR data for the floodplains of the Alligator Rivers Region. This is a fundamental dataset for a number of projects within the hub. A vegetation map of the Magela floodplain derived from high resolution satellite data has also been provided to a number of projects. See Chapter 3 for more information about the vegetation map and the LIDAR acquisition projects.

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 (KRAC). Members of the committee are appointed by the Parks Board of Management to advise the Board and the Director of National Parks on strategic research issues and priorities required to support the socio-cultural and biophysical management objectives for the Park. One meeting (16–18 May 2012) of the committee was held during the period. The key items addressed at the meeting were:

1. Perceptions from traditional owners about the role of research and, in particular, what constitutes a good research project, and how they might play a more formal role in determining the research agenda.
2. The role of KRAC in inputting to the development of the research strategy for the next Kakadu Plan of Management that will span 10 years from 2014 to 2024.

In relation to item 2 above the views of committee were sought on what might be the most appropriate model to use for evaluating the success of this next plan of management.

5.3.7 EPBC compliance audits

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

5.3.8 Rum Jungle Technical Working Group

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

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

The group comprises representatives from the NT Department of Resources (DoR), NT Department of Natural Resources, Environment, the Arts and Sport, Australian Government Department of Resources, Energy and Tourism, the Northern Land Council and the Supervising Scientist Division. Mr Alan Hughes (Supervising Scientist) and Dr David Jones (Director ***eriss***) are the current SSD representatives.

An allocation of $7 M of special purpose funds was made in the 2009 Federal Budget to progress assessment of the site over a period of four years. The program of work is being managed by DoR under the terms of a 'National Partnership Agreement (NPA) between DoR and the Australian Government Department of Resources Energy and Tourism. The ultimate objective of the work is to develop a costed rehabilitation plan consistent with contemporary best practice. The RJTWG provides technical advice and oversight of the projects commissioned to address the terms of the National Partnership Agreement (NPA). Background material and project updates have been published by 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.

During 2011–12, SSD attended four meetings of the RJTWG, reviewed and provided comment on many consultancy reports related to characterising the current status of the site, and assisted with contributing to the development of scopes of works for projects to address remaining knowledge gaps.

SSD also submitted the final report for a major project, undertaken under contract to DoR, as part of the NPA, to assess the radiological status of the Rum Jungle South Lake Reserve. This public recreation reserve lies on the footprint of the historic Rum Jungle Creek South uranium mine. The assessment considered the most important pathways through which the public could potentially be exposed to radiation using data from environmental surveys conducted during 2010–11. It was found that for the current recreational uses of the site there is presently no unacceptable radiation risk to the public. The results were reported by DoR, assisted by staff from SSD, to the Coomalie Community Government Council which is responsible for the site.

5.3.9 Advice to SEWPaC's Independent Expert Science Committee on Coal Seam Gas and Large Coal Mines

The Australian Government plays a role in regulating coal seam gas proposals which could have a significant impact on matters protected by the *Environment Protection and Biodiversity Conservation Act 1999*. This includes Matters of National Environmental Significance (MNES), actions involving the Commonwealth and actions taken on, or impacting on, Commonwealth land. To help inform the Government's role, in early 2012 the Department established an Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining.

The Committee gathers and provides to the Department expert scientific advice on relevant issues. ***eriss*** research scientists, Dr Rick van Dam and Dr Andrew Harford, are providing specialist ecotoxicological advice to the Committee in relation to work required to assess the potential for hydraulic fracturing chemicals and fluids from proposed coal seam gas operations to impact on relevant Matters of National Environmental Significance. This role is expected to continue in 2012–13.

5.3.10 Other contributions

Dr David Jones spent three months on secondment between January and April 2012 as Science Advisor to the Office of Water Science within the Water Group in Canberra. He assisted the office through its start up phase to establish a key knowledge needs framework, to scope knowledge acquisition projects, and to identify and commission the research needed to address the cumulative environmental impacts on water resources of coal seam gas and large coal mining developments.

Supervising Scientist Mr Alan Hughes is a member of the Mt Todd Minesite Rehabilitation Reference Group that has been established by DoR. 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 also 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 was not involved in any panel review cases during the reporting period.

During 2011–12, Mr Hughes was also appointed as a member of the Northern Australia Ministerial Forum Expert Advisory Panel.

Dr Renée Bartolo continued as a Director of the Surveying and Spatial Sciences Institute Board. The board oversees the strategic direction of the association that represents spatial professionals across Australia and New Zealand. The board continued to meet once a month during the year.

5.4 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. These in house productions include 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. 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.

A full list of papers and reports published during 2011–12 is provided in Appendix 2. Papers presented at national and international conferences are listed in Appendix 3.

In February 2012, DSEWPaC began the process of redeveloping the department's website, including SSD's website, to ensure that it meets its intended communication purposes of increase community understanding of the Department's programs, policies and the legislation it administers; assisting our stakeholders understand and meet their statutory obligations and request information from us or provide comments, and facilitate online lodgement of applications and submissions.

A project manager for SSD and web content managers for both ***eriss*** and ***oss*** were appointed to manage the initial handover of information to the department's Web Development and Redevelopment Team. An audit of SSD's existing web pages and content was carried out by the SSD web team. Significant work continues on the research section of the SSD website.

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

Conference	Place/date (no. papers)
NT Spatial 2012 Conference	Darwin NT, March 2012 (4)
ARPS 2011, 36th Conference of the Australasian Radiation Protection Society	Melbourne, October 2011 (1)
AusIMM International Uranium Conference	Adelaide SA, June 2012 (1)
AELERT Conference	Darwin NT, October 2011 (2)
Aquatic Macroinvertebrates Taxonomic Workshop	January/February 2012, La Trobe University, Wodonga, Vic
GEOBIA 2012: the 4th International Conference on Geographic Object-Based Image Analysis	May 2012, Rio de Janeiro, Brazil (1)
7th IAHR Symposium on River, Coastal and Estuarine Morphodynamics	September 2011, Tsinghua University, Beijing, China (1)
Mine Closure 2011: Sixth International Conference on Mine Closure	Lake Louise, Canada, September 2011 (1)
6th Australian Stream Management Conference: Managing for Extremes	February 2012, Canberra (1)
9th International Conference on Methods and Applications of Radioanalytical Chemistry (MARC IX)	March 2012, Kailua-Kona, Hawaii (1 paper & 1 poster)
33rd Annual Canadian Nuclear Science Conference	June 2012, Saskatoon, Saskatchewan, Canada (1)
International Conference on Environmental Quality Standards for the Protection of Aquatic Ecosystems (EQSPAE)	Hong Kong, Dec 2011 (1)
Water in Mining Conference	Brisbane, June 2012 (1)
IQPC Water Management in Mining 2011	Brisbane July 2011 (1)

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.

The NT Spatial 2012 Northern Exposure: 'Science and Applications' Conference was held in Darwin 21–23 March and was hosted by the Surveying and Spatial Sciences Institute, NT Region. Dr Renée Bartolo from SSD was on the organising committee for the conference and coordinated the inaugural NT Spatial Excellence Awards, which was held in conjunction with the conference. SSD had an exhibition booth at the conference (Figure 5.5) and presented four papers in the program.

Figure 5.5 The Spatial Sciences and Data Integration group at the SSD booth, NT Spatial 2012 exhibition. Back row from left: Andrew Esparon, John Lowry, Dr Tim Whiteside. Front row from left: Dave Walden, Dr Renée Bartolo and Krissy Kai-Nielsen.

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, 2011–12

Activity	Visitor/organisation	Date
Soil hydraulic measurements on landslides on Oenpelli Dolerite in Arnhem Land with a PhD student (collaboration with Physico-Chemical Processes group project on the significance of landslides as a sediment source in the ARR)	Dr Andy Fourie, University of Western Australia	13–16 August 2011
Assessing geomorphic stability of the Ranger capped Pit 1 landform using the CAESAR landform evolution model	Professor Tom Coulthard, University of Hull	25 June – 6 July 2012

Support/advice re assessment of conceptual rehabilitated landform using SIBERIA landform evolution model	Associate Professor Greg Hancock, The University of Newcastle NSW	2–6 July 2011
Erosion monitoring/modelling activities (Tin Camp Creek)		9–17 August 2011

In 2011–12, ***eriss*** staff supervised one post-graduate research project:

- Identifying the cause of aquatic toxicity associated with a saline mine water (Honours, Curtin University Western Australia; H2A awarded)

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.

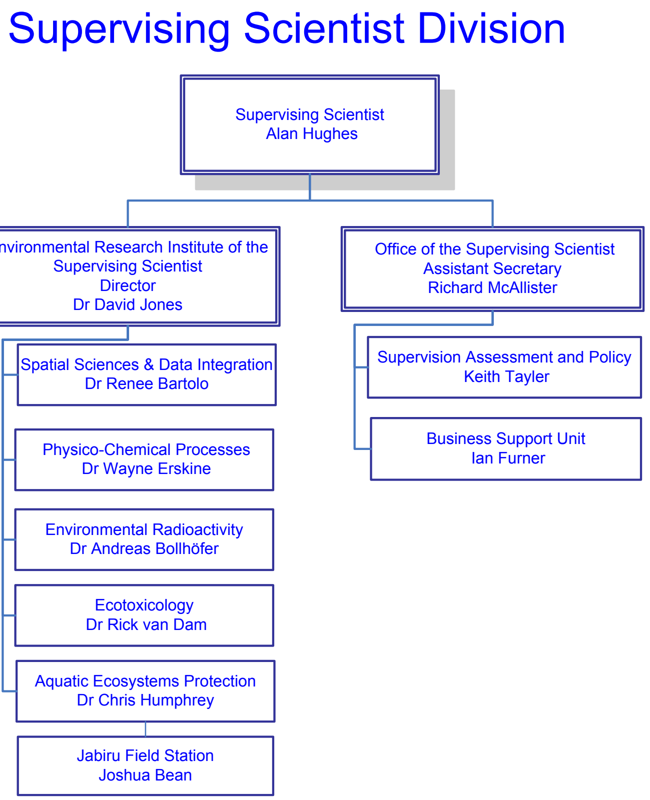

Figure 6.1 Organisational structure of the Supervising Scientist Division (as at 30 June 2012)

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.

Average staffing numbers for 2010–2011 and 2011–2012 are given in Table 6.1.

TABLE 6.1 STAFFING NUMBERS (1) AND LOCATIONS

	2010–2011	2011–2012
Darwin	43	43
Jabiru	8	7
Total	51	50

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

6.1.3 Workforce management

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

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

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

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

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

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

During 2011–12, the health and wellbeing program offered staff access to health screenings, vaccinations for influenza, hepatitis and tetanus, team pedometer challenges and internal health and wellbeing seminars on mental health awareness, stress management, road safety and skin cancer awareness. SSD has also supported Cancer Council fund raising events to raise awareness on cancer associated health risks. Display boards providing staff with information on health and wellbeing issues in the workplace are updated regularly and have been well received by staff.

6.2 Occupational Health and Safety

SSD continued to maintain a strong commitment to Occupational Health and Safety (OHS) during 2011–2012 with the new harmonisation legislation introduced on 1 January 2012. Although the legislation now refers to Work Health and Safety (WHS), SSD has continued to refer to OHS in conjunction with WHS to enable staff to become familiar with, and relate to, the new terminology. SSD has managed the transition to the new legislation by reviewing all OHS policies and procedures as well having all staff undertake online training. All Division, Branch and Section meetings have OHS as the number one item on the agenda, including a 'safety share' that encourages staff to share their OHS experiences both at work and elsewhere.

SSD achieved a 'zero harm' rating for another year with no workplace compensation claims submitted since February 2010.

The Occupational Health and Safety Committee (OHSC) met regularly and was responsible for reviewing and updating a number of guidelines including road travel, field work, clothing and protective equipment, identification and rectification of workplace hazards, transporting chemicals, OHS management plan, chemical management plan and emergency evacuation plans as well as updating the OHSC terms of reference to align with the new governance requirements of the Department.

All senior managers (accompanied by a Health and Safety Representative [HSR]) have been rostered to conduct OHS site inspections (which occur every three months) to ensure they take an active role in OHS and to enhance their understanding of workplace hazards and the safety concerns of staff. Identified potential hazards not addressed within a specified time at the work group level are subject to a formal escalation process. This has significantly improved the times for resolution of hazards.

SSD has procured and implemented new chemical management software that enables greater control and tracking of the chemicals on site and meets the legislative compliance requirements. An annual chemical audit undertaken to ensure compliance with the Code of Practice on Labelling of Workplace Hazardous Chemicals found minimal actions were required.

In 2011–12, safety education for staff focused on:

- health and wellbeing examinations
- road safety
- skin cancer awareness
- 4WD training for all terrain vehicle operation
- workplace contact officers (WCO)

An internal audit of SSD's OHS management arrangements, undertaken by Price Waterhouse Cooper, found that SSD had a highly effective OHS system with only a few minor improvements to current processes suggested.

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.

6.3 Finance

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

A summary of the actual expenses of the Supervising Scientist against the Department's outputs are provided in Table 6.2.

TABLE 6.2 SUMMARY OF DIRECT PROGRAM EXPENSES

PBS Outcome 5	2010–2011	2011–2012
Program 5.2 – Environmental Regulation *	$8 583 500	$9 224 731
Total*	$8 583 500	$9 224 731

* Excludes departmental corporate overheads of $4 354 758 in 10–11 and $4 942 246 in 11–12.

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 major works were commissioned to install a dehumidification system to rectify long standing problems with air-conditioning and moisture intrusion into the laboratories. The Department also took up the option of extending its lease on the Darwin facility for a further 5 years.

Figure 6.2 Dehumidification unit being lifted into position

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

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

Infrastructure works undertaken by JFS in 2011–12 include: installation of a new fuel store; installation of new monitoring pontoons in Magela Creek; upgrading the laundries at the Westcott Units; replacing the air-conditioning in the library meeting room; constructing drainage at the rear of the JFS facility; asphalting deteriorated driveways; and the installation of a staff planning cabinet in the JFS foyer.

Figure 6.3 Asphalting the JFS driveway

6.5 Information management

Information management activities provided support to staff based in Darwin and the Jabiru Field Station through library services and the co-ordination of records management. In addition to the provision of routine services, library activities have focused on weeding the SSD Library collection and working towards integration of the collection into the Department's catalogue. Records management activities included paper file creation and maintenance, destruction of records in accordance with National Archives procedures, and transfer of selected records to commercial storage.

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 2011–12.

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 2011–12.

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 2011–12 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 final report for the project 'Larval fish for toxicity tests at ***eriss***' (ref no 97016) was submitted to CDU AEC and approved on 2 August 2012. A renewal application for this project (now A12028) was granted in September 2012. Individual permits for ***eriss*** staff conducting research with fish were also granted at this time. This project is due for renewal during August 2014 and the individual permits are valid for two years. Fishes were collected from the field for the project 'Monitoring mining impact using the structure of fish communities in shallow billabongs' (previous ref no A09001, now A12007) and were observed for the project 'Fish community sampling in channel billabongs around Ranger mine using boat visual census'. Approvals for these projects were granted by CDU AEC on 22 February 2012 and will expire on 22 February 2014. Individual permits for ***eriss*** staff conducting research with fish were also granted at this time. The number of fish used in toxicity tests at ***eriss*** was reported in July 2012 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 2011–12.

TABLE 6.3 ANIMAL EXPERIMENTATION ETHICS APPROVALS

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

Appendix 1 ARRTC Key Knowledge Needs: Uranium mining in the Alligator Rivers Region

Overall objective

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

Background

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

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

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

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

Specifically, under the Ranger Environmental Requirements (ERs):

> The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:
>
> (a) maintain the 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

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: The Koongarra Project Area was added to the Kakadu World Heritage Area by the World Heritage Committee on 27 June 2011, and this KKN will need to be revisited pending the possible re-incorporation of the area into Kakadu National Park.

APPENDIX 2 PUBLICATIONS FOR 2011–2012

Published[10]

Bartolo RE, van Dam RA & Bayliss P 2012. Regional ecological risk assessment for Australia's tropical rivers: Application of the Relative Risk Model. *Human and Ecological Risk Assessment* 18 (1), 16–46.

Bayliss P, van Dam R & Bartolo R 2012. Quantitative ecological risk assessment of Magela Creek floodplain on Kakadu National Park: comparing point source risks from Ranger uranium mine to diffuse landscape-scale risks. *Human and Ecological Risk Assessment* 18 (1), 115–151.

Bollhöfer A 2012. Stable lead isotope ratios and metals in freshwater mussels from a uranium mining environment in Australia's wet-dry tropics. *Applied Geochemistry* 27, 171–185.

Bollhöfer A, Brazier J, Humphrey C, Ryan B & Esparon A 2011. A study of radium bioaccumulation in freshwater mussels, *Velesunio angasi*, in the Magela Creek catchment, Northern Territory, Australia. *Journal of Environmental Radioactivity* 102, 964–974.

Chalmers AC, Erskine WD & Erskine F 2012. Partial geomorphic and floristic recovery of an incised channel over the last twenty years on Dairy Arm, Hunter Valley, Australia. In *Riparian Zones: Protection, Restoration and Ecological Benefits*, eds A Kerem & H Har-Even, Nova Science Publishers, New York, 99–128.

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Close PG, Wallace J, Bayliss P, Bartolo R, Burrows D, Pusey BJ, Robinson CJ, McJannet D, Karim F et al 2012. Assessment of the likely impacts of development and climate change on aquatic ecological assets in Northern Australia. A report for the National Water Commission, Australia. Tropical Rivers and Coastal Knowledge (TRaCK) Commonwealth Environmental Research Facility, Charles Darwin University, Darwin. ISBN: 978-1-921576-66-9.

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Dostine PL & Humphrey CL 2012. Macroinvertebrate responses to reduced baseflow in a stream in the monsoonal tropics of northern Australia. Case study. Supporting document in *Guidance on ecological responses and hydrological modelling for low-flow water planning*, Waterlines report 76, March 2012. (nwc.gov.au/publications/waterlines/76)

Erskine WD 2012. Soil colour as a tracer of sediment dispersion from erosion of forest roads in Chichester State Forest, NSW, Australia. *Hydrological Processes*, DOI : 10.1002/hyp.9412.

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Erskine WD, Keene AF, Bush RT, Cheetham M & Chalmers AC 2012. Influence of riparian vegetation on channel widening and subsequent contraction on a sand-bed stream since European settlement: Widden Brook, Australia. *Geomorphology* 147–148: 102–114 doi.org/10.1016/j.geomorph.2011.07.030.

Erskine WD, Saynor MJ, Chalmers AC & Riley SJ 2012. Water, wind, wood and trees: Interactions, spatial variations, temporal dynamics and their potential role in river rehabilitation. *Geographical Research* 50(1), 60–74.

Erskine WD, Saynor MJ, Evans KG & Moliere DR (in press). Application of the Bagnold approach to bedload transport efficiency to a new bedload data set for northern Australia. *International Journal of Sediment Research.*

Erskine WD, Saynor, MJ, Evans KG & Moliere DR 2011. Bedload transport efficiency of forested sand-bed streams in the seasonally wet tropics of northern Australia. In *Proceedings of the 7th IAHR Symposium on River, Coastal and Estuarine Morphodynamics.* Eds Shao X, Wang Z & Wang G, Sep 6–8 2011, Tsinghua University, Beijing, China, Tsinghua University Press, Beijing, China, 1–13.

Erskine WD, Saynor MJ, Evans KG & Moliere DR 2011. *Bedload transport, hydrology and river hydraulics in the Ngarradj Creek catchment, Jabiluka, Northern Territory, Australia*. Supervising Scientist Report 199, Supervising Scientist, Darwin NT.

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Fryirs K, Brierley GJ & Erskine WD 2012. Using ergodic reasoning to reconstruct the historical range of variability and evolutionary trajectory of Wollombi Brook, NSW, Australia. *Earth Surface Processes and Landforms* 37, 763–773 DOI: 10.1002/esp.3210.

Garcia E, Dostine P, Humphrey C, Douglas M, Pusey B & Cook B 2011. Aquatic invertebrates. Chapter 5 In *Aquatic biodiversity in northern Australia: patterns, threats and future*. ed Pusey BJ, Charles Darwin University Press, Darwin NT, 51–70.

Harford AJ, Hogan AC, Jones DR & van Dam RA 2011. Ecotoxicological assessment of a polyelectrolyte flocculant. *Water Research* 45(19), 6393–6402.

Howard BJ, Beresford NA, Copplestone D, Telleria D, Proehl G, Fesenko S, Jeffree RA, Yankovich TL, Brown JE, Higley K, Johansen MP, Mulye H, Vandenhove H, Gashchak S, Wood MD, Takata H, Andersson P, Dale P, Ryan J, Bollhöfer A, Doering C, Barnett CL, Wells C 2012. The IAEA handbook on radionuclide transfer to wildlife. *Journal of Environmental Radioactivity*, DOI:10.1016/j.jenvrad.2012.01.027.

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Medley P, Bollhöfer A & Martin P (in press). Variability of procedural blanks leads to greater uncertainty in assessing detection limits for the measurement of polonium-210. *Journal of Radioanalytical and Nuclear Chemistry*.

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Saynor MJ, Erskine WD & Staben G 2012. Hydrogeomorphic effects of the 2007 extreme flood on the East Alligator River, NT: Impacts on ecotourism operations. In *Proceedings of the 6th Australian Stream Management Conference, Managing for Extremes*. eds Grove JR & Rutherfurd ID, 6–8 February 2012, Canberra, River Basin Management Society, Melbourne, 176–188.

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Alligator Rivers Region Advisory Committee 2012. Alligator Rivers Region Advisory Committee 33rd Meeting, 21 April 2010, Darwin, Meeting papers. Internal Report 602, August, Supervising Scientist, Darwin. Unpublished paper.

Alligator Rivers Region Advisory Committee 2012. Alligator Rivers Region Advisory Committee 34th Meeting, 25 August 2010, Darwin, Meeting papers. Internal Report 604, August, Supervising Scientist, Darwin. Unpublished paper.

Baird DJ 2011. A mini-review of ongoing research and monitoring carried out by the Aquatic Ecosystem Protection and Ecotoxiology Programs at ***eriss***. Internal Report 597, August, Supervising Scientist, Darwin. *

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Bollhöfer A, Doering C, Fox G, Pfitzner J & Medley P 2012. Assessment of the radiological exposure pathways at Rum Jungle Creek South (Rum Jungle Lake Reserve) – Batchelor. Consultancy Report prepared for the Northern Territory Government Department of Resources, February 2012.

Cheng K, Harford A & van Dam R 2012. Ecotoxicological testing of receiving waters downstream from Newmont Woodcutters mine site. Commercial-in-Confidence Consultancy Report prepared for Newmont Pty Ltd, June 2012.

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eriss Ecotoxicology Program 2012. Cladoceran Reproduction Test Report (1272D). Toxicity test summary report submitted to Vista Gold Pty Ltd, 29 May 2012, Commercial-in-Confidence.

APPENDIX 3 PRESENTATIONS TO CONFERENCES AND SYMPOSIA, 2011–2012[11]

Bush M 2011. The International Working Forum for the Regulatory Supervision of Legacy Sites: An update. Paper presented at *AELERT Conference*, Darwin Australia 26–28 October 2011.

Bush M 2012. The International Working Forum for the Regulatory Supervision of Legacy Sites. Paper presented at *AusIMM International Uranium Conference*, Adelaide Australia 13–14 June 2012.

Costello C, Trenfield M, Harford A & van Dam R 2012. Dissolved organic carbon; the water flea's remedy against uranium toxicity. Poster presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

Doering C, Ryan B, Bollhöfer A & Esparon A 2011. Bioaccumulation of radioactive uranium-series constituents from the environment (BRUCE): a tool for estimating radionuclide transfer to northern Australian bushfoods and ingestion doses to members of the public. Paper presented at *ARPS 2011*, 36th conference of the Australasian Radiation Protection Society, Melbourne, 16–19 October 2011.

Esparon A 2012. Development of a novel method for continuous monitoring of vegetation regrowth on a rehabilitated minesite using a simple LED spectroradiometer. Paper presented at *NT Spatial 2012 Conference*, Darwin, Northern Territory, 21–23 March 2012.

Harford A, Hogan A, Jones D & van Dam R 2012. Stuck in the goop! Difficulties in assessing the environmental risk of organic flocculants. Paper presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

Hogan A, Trenfield M, Cheng K, Harford A, Costello C & van Dam R 2012. And the winner is: Filtration, for successfully isolating unicellular algae from pulse exposure waters. Poster presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

Humphrey C 2012. Integrated water quality assessments: a national and northern Australian perspective. Paper presented at *Water in Mining Australia conference*, Brisbane, 20–21 June 2012.

Jones D 2011. Understanding sustainable water management in decommissioning and rehabilitation. Paper presented at *IQPC Water Management in Mining 2011*, July 26–27, Brisbane Qld.

Lowry J 2012. Using LiDAR data to derive geomorphic parameters for landform design. Paper presented at *NT Spatial 2012 Conference*, Darwin, Northern Territory, 21–23 March 2012.

11 Presentations to conferences and symposia that have been externally published in 2011–12 are included in Appendix 2.

Medley P 2012. Variability of procedural blanks leads to greater uncertainty in assessing detection limits for the measurement of polonium-210. Paper presented at *Ninth International Conference on Methods and Applications of Radioanalytical Chemistry (MARC IX)*, 25–30 March 2012, Kailua-Kona, Hawaii.

Medley P & Bollhoefer A 2012. Radioanalytical methods for monitoring and research into the impacts of uranium mining in the Alligator Rivers Region. Posterpresented at *Ninth International Conference on Methods and Applications of Radioanalytical Chemistry (MARC IX)*, 25–30 March 2012, Kailua-Kona, Hawaii.

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van Dam R, Harford A, Trenfield M, Markich S, Humphrey C, Hogan A & Stauber J 2012. Updating water quality guidelines for uranium – Standardising measures of toxicity and incorporating the influence of dissolved organic carbon. Paper presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

van Dam RA, Markich SJ, Harford AJ, Trenfield MA, Hogan AC & Stauber JL 2011. Updating water quality guidelines for uranium – Standardising measures of toxicity and incorporating the influence of dissolved organic carbon. *International Conference on Deriving Environmental Quality Standards for the Protection of Aquatic Ecosystems (EQSPAE – 2011)*, 3–7 December 2011, Hong Kong.

Walden D, Boyden J & Bartolo R 2012. Monitoring the wetland weed para grass (*Urochloa mutica*) using remotely sensed data in Kakadu National Park, Northern Territory. Paper presented at *NT Spatial 2012 Conference*, Darwin, Northern Territory, 21–23 March 2012.

Whiteside T, Bartolo R & Staben G 2012 A rule-set driven approach to classifying vegetation from high spatial resolution imagery. Paper presented at *NT Spatial 2012 Conference*, Darwin, Northern Territory, 21–23 March 2012.

Woodworth J, Hack L, van Dam R & Fox D 2012. Teething troubles with consulting in ecotoxicology. Paper presented at *2nd SETAC – Australasia Conference*, 4–6 July 2012, Brisbane Australia.

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Feedback on the Supervising Scientist 2011–12 annual report

We hope we have presented a comprehensive and informative account of the activities of the Supervising Scientist Division during 2011–2012.

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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