Ranger Mine Closure Plan
2023

Issued Date: 1 December 2023

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1 INTRODUCTION

Photo: Meg Parry monitoring vegetation growth on Pit 1

The former Ranger uranium mine (Ranger) is located within the Ranger Project Area (RPA) adjacent to the township of Jabiru, approximately 260 kilometres (km) east of Darwin on Mirarr country in the Alligator Rivers Region of the Northern Territory (NT) (Figure 1-1). The RPA occupies approximately 79 square kilometres (km^2) and is surrounded by, but separate from, Kakadu National Park.

The RPA and the former mine are bounded on the north by Magela Creek, east by Corridor Creek, and on the west by Gulungul Creek. Access to the mine is via the Arnhem Highway. The total disturbance footprint of mine activities on the RPA was approximately 1,060 hectares (ha). Figure 1-2 shows the location and extent of the main components of the mine (these are commonly termed closure domains).

Closure and rehabilitation of Ranger is governed by both Commonwealth and NT legislation. The key instrument that governs operations on a day-to-day basis is the Ranger Authorisation 0108-18 (the Authorisation) issued under the Northern Territory *Mining Management Act 2018* (Mining Management Act). The main Commonwealth authority issued under Section 41 of the *Atomic Energy Act 1953* (Atomic Energy Act; Section 41 Authority) provides the key tenure and land access approval required for the mine.

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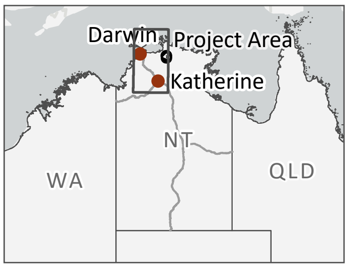
FIGURE 1-1

Location of the Ranger Project Area (RPA)

LEGEND

- Ranger Project Area
- Jabiluka Lease
- Kakadu National Park World Heritage Area
- National Park
- Primary Roads
- Town



0 25 50
Kilometres

Scale 1:2,000,000 at A4
GDA 1994 MGA Zone 53

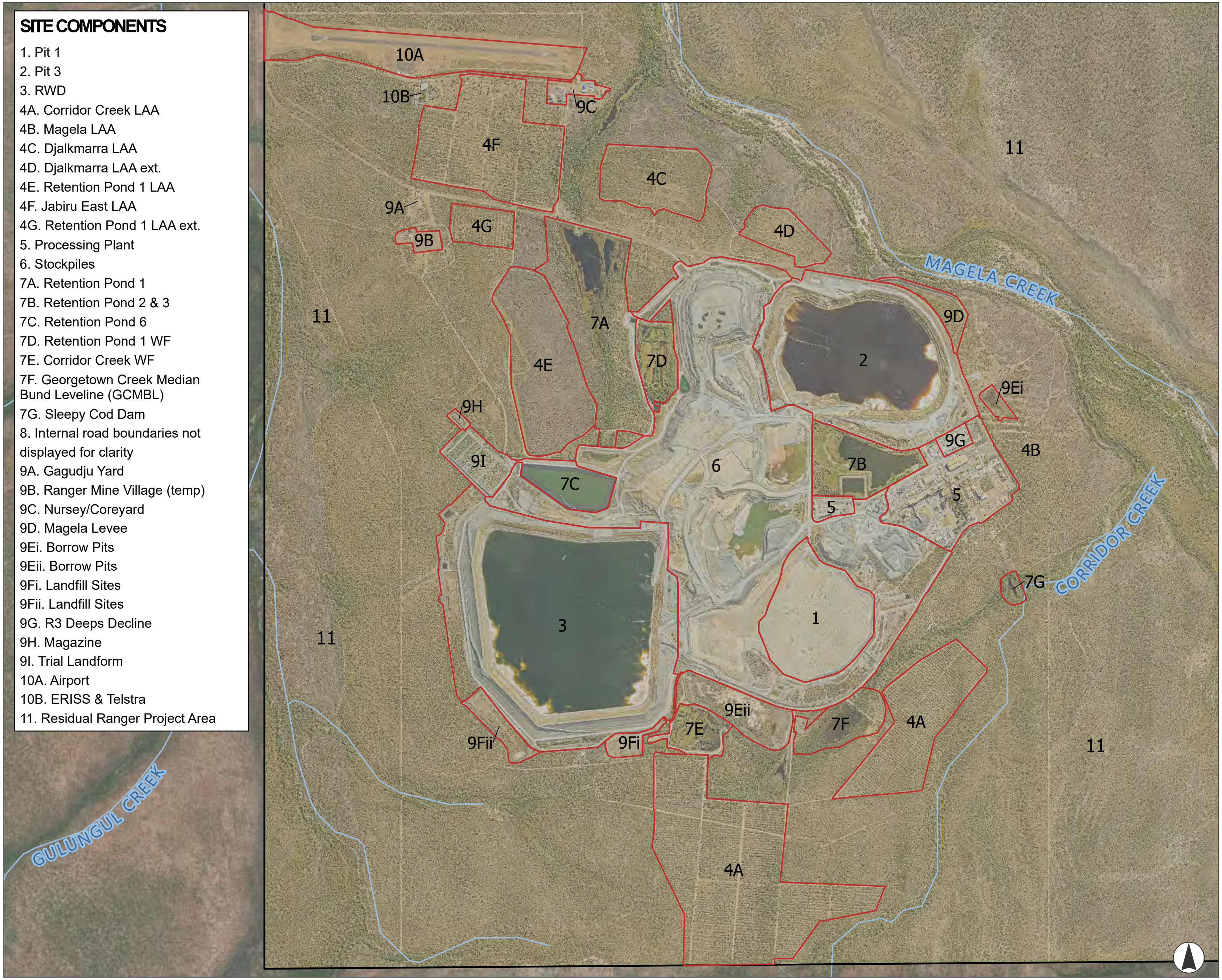
Image Source: ESRI Basemap (2022); **Data source:** NT Government Data (2023)

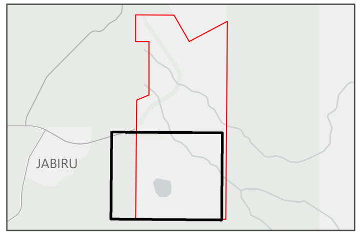
FIGURE 1-2

Ranger – Closure Domains

LEGEND

- Mine closure domain
- Ranger Project Area





0 0.5 1

Kilometres

Scale 1:32,500 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

The Ranger Environmental Requirements (ERs) are attached to the Section 41 Authority and set out environmental objectives that establish the principles by which the Ranger mining operation is to be conducted, closed and rehabilitated, and the standards that are to be achieved. The Mining Management Act also requires the Authorisation to incorporate, by reference, the ERs.

Since closure of the mine, ERA's focus is:

To create a positive legacy and achieve world-class, sustainable rehabilitation of former mine assets.

This Mine Closure Plan (MCP) is prepared by ERA to demonstrate how the proposed closure activities will achieve the ERs and the role of ERA in supporting the post-mining social and economic transition of Jabiru.

The MCP is submitted for approval to both the Commonwealth Minister for Resources and for Northern Australia, and the NT Minister for Mining and Industry. In 2016 the NT Government approved ERA's request to combine the annual Mining Management Plan and the Annual Environment Report to avoid duplication of information. As the Ranger mine has completed the operational phase and is now in the closure phase, the Mine Closure Plan appropriately addresses the requirements of the annual Mining Management Plan for Ranger, as defined in Section 40(2) and 41 of the Mining Management Act. The MCP is submitted as a formal request for assessment as an Annual Environment Report and Mining Management Plan for the approval of the NT Minister for Mining and Industry.

1.1 Operator Details

ERA operated Ranger from its commencement of mining in 1980 for more than 40 years, making it Australia's longest continuously operating uranium mine. During this time ERA provided international customers with a reliable supply of uranium oxide, with the Ranger mine producing more than 132,000 tonnes (t) of uranium oxide to meet global demand for fuelling nuclear power plants. ERA's product was supplied to power utilities in Asia, Europe and North America in accordance with strict international and Australian safeguards.

In accordance with the Section 41 Authority, all mining operations and uranium processing ceased on 8 January 2021. The current priority of ERA is the comprehensive rehabilitation of the RPA to a standard where it can be incorporated into the surrounding Kakadu National Park if Traditional Owners and the Commonwealth Government wish.

Rio Tinto owns 86.3 per cent (%) of ERA shares with the balance of the shares publicly held and traded on the Australian Securities Exchange. Information about ERA and a business overview can be found at www.energyres.com.au.

Contact details for the Ranger Rehabilitation Project Director (i.e. the responsible position) and the Manager of Health, Safety and Environment are provided in Table 1-1. ERA maintains an organisational structure sufficient to carry out the closure and rehabilitation of the RPA.

Table 1-1: Ranger operator details

Name of Operator	Energy Resources of Australia Limited
Name of Mining Site	Ranger Mine
Address	Locked Bag 1
	Jabiru NT 0886
ABN	71 008 550 865
ACN	008 550 865
Address for service documents	GPO Box 0801 Darwin NT 0801
Principal Place of Business	Level 8, 24 Mitchell Street Darwin NT 0800
Phone	08 8924 3500
Fax	08 8924 3555
Email	info@era.riotinto.com
Ranger Rehabilitation Project Director	Bernard Toakley
Manager of Health, Safety and Environment	Joshua Curran
Commodity	Uranium
Product	Uranium Oxide (U_3O_8)

1.2 Title Details

Figure 1-3 provides a regional context to the location of the RPA. The land portions within the RPA are predominantly NT portions 2376 and 1662, with small areas comprising NT portions 2539, 2281, 1685, 1657, 1686 and 1656 (Figure 1-4).

Aboriginal freehold title exists across the land of the RPA. The longitude/latitude boundaries of the RPA are defined in Schedule 2 of the *Aboriginal Land Rights (Northern Territory) Act 1976* (Cth). Aboriginal freehold titles granted under the Aboriginal Land Rights Act are held by the Kakadu Aboriginal Land Trust. The Atomic Energy Act provides ownership of uranium in the NT to the Commonwealth. ERA's approval to operate Ranger under the NT Mining Management Act and the Commonwealth Atomic Energy Act provide it a right of occupation for the RPA. Table 1-2 summarises the holder details associated with Ranger.

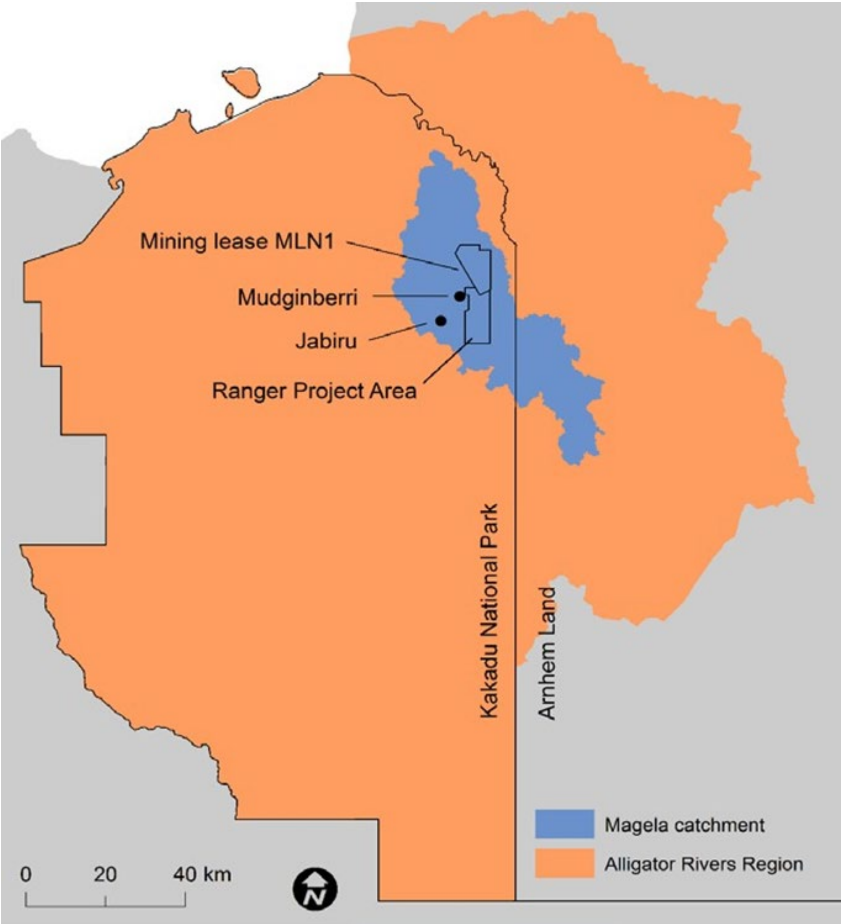


Figure 1-3: Regional location of the RPA

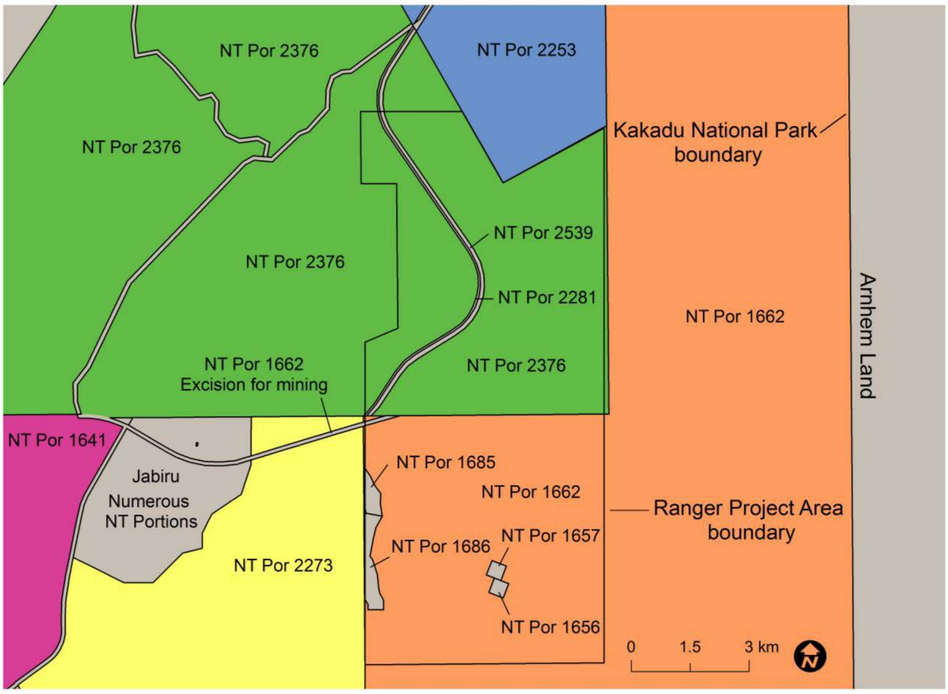


Figure 1-4: Land portions within and surrounding the RPA

Table 1-2: Ranger mine title holder details

Name of Mining Site	Ranger Mine
Mineral Title	Ranger Project Area (RPA)
Mining interests	Uranium mining
Administration act	*Atomic Energy Act 1953* (Cth)
Authorisation number	0108-18
Operator to whom Authorisation was granted	Energy Resources of Australia Ltd

1.3 Purpose of this MCP

This MCP has been prepared as part of ERA's obligations under the Ranger Authorisation (Annex B: Submission and Assessment of the Mine Closure Plan). This MCP is prepared by ERA to demonstrate how the proposed closure activities will achieve the ERs and the role of ERA in supporting the post-mining social and economic transition of Jabiru.

This MCP is the result of the past 40 years of extensive scientific research, engineering design and stakeholder consultation. It is noted that the structure of the MCP has been modified considerably from previous iterations to provide a document that is easier to read and transparently conveys the current progress towards achieving each of the ERs.

Chapter 5 describes the consistent approach that has been adopted to articulate progress towards achieving each ER, and the activities that are yet to be completed to achieve each ER. The relevant information pertaining to each of the six Ranger themes, are included in:

- Landform – Chapter 6;
- Water and Sediment – Chapter 7;
- Soils – Chapter 8;
- Ecosystems – Chapter 9;
- Radiation – Chapter 10; and
- Cultural – Chapter 11.

ERA were exempt from providing a 2021 and 2022 MCP. As such, this 2023 MCP includes updates from 1 July 2020.

The MCP would typically provide information current to the end of June of each given year (i.e. for this 2023 MCP, up until 30 June 2023). However, the exemption of the 2022 MCP was granted in consideration of ERA's expected completion of the 2022 Feasibility Study by September 2023, and that the relevant findings of that study would be incorporated into this 2023 MCP. This MCP provides the most up to date information from the 2022 Feasibility Study.

The 2020 MCP and a draft of the 2022 MCP was subject to stakeholder review and detailed feedback was provided and has been considered in the preparation of this document. It is noted that further studies are ongoing, and that the outcomes of these studies will be presented in future annual updates of the MCP.

1.4 Implications of Feasibility Study Reforecast

In May 2022, ERA commenced a feasibility study update in connection with a lower technical risk rehabilitation methodology (primarily relating to the subaerial capping of Pit 3) and to further refine the RPA rehabilitation execution scope, risks, cost and schedule. ERA has received outcomes and data from the 2022 Feasibility Study and those matters are currently under review. A number of significant findings emerged from the 2022 Feasibility Study requiring further analysis and studies that will likely proceed into 2024.

This 2023 MCP provides an indicative sequence of major closure activities and estimates of future milestones. It is noted that the timeframes are subject to the outcomes of further studies to investigate alternative solutions for:

- minimising the inflows of water to the process water storages;
- lower cost alternatives for the treatment of mildly contaminated process water;
- improving the water treatment capacity and reducing the operating costs of the water treatment systems;
- optimising the movement of bulk materials into Pit 3; and
- a value engineering study.

1.5 Scope of this MCP

The MCP covers the RPA, specifically referring to the following areas and assets (refer Figure 1-2):

- Ranger ore processing infrastructure, former mine pit voids, Ranger Water Dam (RWD) formerly known as the Tailings Storage Facility (TSF), the exploration decline and all associated utilities within the operational area of Ranger.
- Land application areas (LAAs), wetland filters and other infrastructure associated with Ranger.
- Jabiru Airport and associated infrastructure and utilities: noting that discussions are progressing between ERA, Traditional Owner representatives and relevant government agencies regarding the potential future use of the airport. These discussions will include rehabilitation obligations.

The following areas and assets are not considered in this MCP:

- the town of Jabiru (with the exception of ERA's role in supporting the post-mining social and economic transition of Jabiru); and
- the infrastructure located on the RPA immediately south of the Jabiru Airport, occupied by the Environmental Research Institute of the Supervising Scientist (ERISS) and Telstra.

ERA has defined the closure and rehabilitation activities in the phases outlined in Table 1-3. Table 1-3 must be read subject to the qualifications provided in Chapter 13.

Table 1-3: Timelines of the operations and closure phases of Ranger

Phase	Timeline	Closure Related Activities
Operations	1980 to 8 January 2021	Mining from two open pits was undertaken and the operational phase ceased on 8 January 2021 as per the requirement of the Ranger Authorisation. Operational and closure related research and monitoring activities occurred during this period.
Closure	Period between 8 January 2021 and the completion of final landform and rehabilitation	Decommissioning, demolition, waste disposal into Pit 3 and RP2, bulk material movement to achieve final landform, progressive rehabilitation and ongoing monitoring.
Monitoring and maintenance	Currently estimated to be 25 years after Closure Phase	Completion criteria monitoring (and maintenance rehabilitation works as required).
Relinquishment	Issue of close-out-certificate(s), relinquishment of RPA	Progressive close-out certificates may be obtained for specific areas rather than a single relinquishment for the entire RPA (see Chapter 2, Section 2.1.2).

2 STATUTORY, CULTURAL AND CLIMATIC CONTEXT

Photo: Partridge Pigeon (*Geophaps smithii smithii*) [Vulnerable] observed on the Trial Landform

2.1 Statutory Context

Rehabilitation and closure of Ranger are governed by both Commonwealth and NT legislation. ERA maintains a compliance register that identifies the legislative Acts and regulatory obligations relevant to the closure and rehabilitation of Ranger. Twelve Acts and 292 obligations are of relevance. This chapter does not list each of these, rather it provides a summary of the key instruments under Commonwealth and NT legislation.

2.1.1 Shared regulatory responsibility and the Ranger Authorisation

The Commonwealth and NT governments share regulatory responsibility for uranium mining in the NT via the Memorandum of Understanding (MoU) in relation to the Working Arrangements for the Regulation of Uranium Mining in the NT (the Working Arrangements). The purpose of the Working Arrangements is to establish procedures for consultation between the Commonwealth of Australia and the Northern Territory of Australia (the two parties to the Working Arrangements) in the performance of their legislative functions with ‘maximum efficiency and minimum duplication’. The Working Arrangements also establish the functions of the Ranger Minesite Technical Committee (MTC).

2.1.2 Australian Government (Commonwealth) legislation

Atomic Energy Act 1953

The primary Commonwealth legislative instrument for Ranger is the *Atomic Energy Act 1953* (Atomic Energy Act). The ERs are conditions of the Section 41 Authority issued under the Atomic Energy Act and prescribe environmental protection conditions that Ranger must comply with. The ERs include environmental objectives, which establish the principles by which the Ranger operation is to be operated, closed and rehabilitated. The ERs are also included in the Ranger Authorisation as Annex A.

The *Atomic Energy Amendment (Mine Rehabilitation and Closure) Act 2022* was passed in November 2022, amending the Atomic Energy Act. The amendments to the Act allow the Minister to vary or confer a new Authority for the express purposes of authorising rehabilitation, remediation and monitoring operations at Ranger beyond the previously legislated deadline of 8 January 2026. The amendment also outlines a process for the progressive relinquishment (close-out) of parts of the RPA. ERA continues to work with the Commonwealth Government, Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) (on behalf of the Mirarr Traditional Owners), to negotiate the revised Section 41 Authority for the RPA. ERA intends to apply for a new Authority on or before May 2024.

ERA has identified opportunities for relinquishing parts of the RPA ahead of the mine disturbed footprint (e.g. an area of approximately 3,000 ha to the north of Magela Creek that was subject to minimal exploration disturbance). Engagement with the GAC to date has indicated support for the progressive close-out of areas of the RPA.

Environment Protection (Alligator Rivers Region) Act 1978

The Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* establishes the functions and responsibilities of the Office of the Supervising Scientist (OSS) and the Environmental Research Institute of the Supervising Scientist (ERISS), as well as establishing the Alligator Rivers Region Advisory Committee (ARRAC) and the Alligator Rivers Region Technical Committee (ARRTC).

Chapter 3 provides details of these stakeholder groups. It is noted that the OSS is appointed to protect the Alligator Rivers Region environment from the effects of uranium mining. The OSS conducts research programs into the environmental effects of uranium mining in the region, develops standards and practices for environmental protection, undertakes environmental monitoring, and provides advice to the Commonwealth minister, NT minister and/or the Supervising Authority of the Ranger Authorisation. Where information from the OSS is included in this MCP it is acknowledged and referenced appropriately.

Aboriginal Land Rights (Northern Territory) Act 1976

Title to the RPA was granted to the Kakadu Aboriginal Land Trust in 1978, in accordance with the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976*. Prior to the Commonwealth minister approving the Ranger mine, the Commonwealth government entered into the Section 44 Agreement with the NLC under the Aboriginal Land Rights Act. The post-mining land use of the RPA will be ‘Aboriginal land’, which means an Aboriginal Land Trust subject to the Aboriginal Land Rights Act.

Nuclear Non-Proliferation (Safeguards) Act 1987

ERA has obligations with regards to the possession and disposal of nuclear material under the Commonwealth *Nuclear Non-Proliferation (Safeguards) Act 1987*. Of relevance:

- ERA is the holder of a Permit to Possess Nuclear Material (PN004), which currently relates to the retained waste containing uranium that is present within the on-site calciner.
- ERA is the holder of a Permit to Decommission Facility (DF003), which relates to the plant, structures and buildings previously used for the mining, processing, production, storage and transport of uranium ore concentrates.
- ERA is yet to obtain a permit that allows the removal and disposal of the calciner from its currently approved location. That is, an additional permit is required from the Australian Safeguards and Non-Proliferation Office before the calciner can be removed from its current location and disposed into Pit 3. ERA will apply for this permit at the appropriate time and will not relocate the calciner into Pit 3 until this permit is obtained.

Environment Protection and Biodiversity Conservation Act 1999

The rehabilitation of Ranger is not subject to assessment or approval under Part 3 of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). As outlined in Section 43(a) of the EPBC Act, certain actions that started prior to 16 July 2000 are exempt from the assessment and approval provisions of the EPBC Act. Mining at Ranger commenced in 1980. The Ranger ERs were revised in 1999 and include rehabilitation requirements, which remain applicable. The overall objective for rehabilitation and closure has been based on the rehabilitation goals outlined in the ERs and Ranger Authorisation.

The new Section 41CW of the Atomic Energy Act, amended by the Bill passed in November 2022, further clarifies that actions authorised by the historic Section 41 Authority are exempt from Part 3 of the EPBC Act provided that the action is taken in accordance with any condition or restriction to which the Authority is subject to, or any requirement that has been imposed.

2.1.3 Northern Territory Government legislation

Mining Management Act 2001

The primary NT legislative instrument for Ranger is the Mining Management Act, which is administered by the Department of Industry, Tourism and Trade (DITT). The Ranger Authorisation is issued to ERA under the Mining Management Act.

In accordance with clause D.1 of the Ranger Authorisation, ERA is required to submit annually a *Mining Management Plan* for the approval of the relevant Commonwealth and NT ministers, with the advice from the OSS. More recently (from 2022), the Ranger MCP has been the single document provided by ERA to satisfy the requirements of the *Mining Management Plan*.

It is noted that the NT Government is introducing a range of regulatory reforms. In September 2019, the first stage of reforms was enacted with the passing of the *Environment Protection Act 2019* (EP Act). At the time of writing, the Environment Protection Legislation Amendment (Mining) Bill 2023 had been introduced into NT Parliament. This Bill proposes to transfer the responsibility for the environmental regulation of mining from the Mining Management Act to the EP Act, which is administered by the Department of Environment, Parks and Water Security (DEPWS). If the Bill is passed, the Mining Management Act would be repealed.

Northern Territory Aboriginal Sacred Sites Act 1989

All sacred sites in the NT are protected by the *Northern Territory Aboriginal Sacred Sites Act 1989* (NTASSA). The Aboriginal Areas Protection Authority is an independent statutory authority established under the NTASSA, responsible for overseeing the protection of Aboriginal sacred sites in the NT.

An authority certificate is a non-compulsory certificate that may be applied for, to identify and record any sacred sites and any conditions to be observed to protect these sites, during the conduct of works. ERA currently hold an authority certificate for mining activities at Ranger.

2.1.4 Closure Objectives and Closure Criteria

A set of closure objectives have been developed from the rehabilitation and final land use related objectives described in the ERs. They have been developed in consultation with stakeholders over many years. The closure objectives are grouped under the following themes:

- Landform (see Chapter 6);
- Water and sediment (see Chapter 7);
- Soils (see Chapter 8);
- Flora and fauna (ecosystem) (see Chapter 9);
- Radiation (see Chapter 10); and
- Cultural (see Chapter 11).

The closure objectives underpin the closure criteria, which represent direct measurable and quantifiable values, or tiered assessment processes based on site-specific research programs and industry leading practice frameworks, such as the International Commission of Radiological Protection, Inventory Multi-tiered Assessment and Prioritisation and National Environment Protection Measures. The closure criteria will be used as the basis for determining the successful fulfilment of closure objectives. The closure objectives and criteria for each of the above themes are provided in the relevant chapter of this MCP (i.e. Chapter 6 to Chapter 11).

2.2 Cultural Context

The landscape in which the RPA is situated has a rich cultural history. The Traditional Owners, the Mirarr people, have cared for the country since the dreamtime. Recent research conducted at Madjedbebe rock shelter, which is on the Mirarr Estate to the north of the RPA, has found evidence of occupation for at least 65,000 years (Clarkson *et al*., 2015, 2017). The entire area has many tangible cultural heritage places, and an equally rich intangible cultural heritage complex, which links the landscape and peoples with the wider West Arnhem community.

The post mining land use is Aboriginal land. The key attributes of Aboriginal land are (*pers. comm.* O'Sullivan, GAC, March 2023):

- the land has cultural integrity and is part of a cultural landscape;
- the land is in a condition for a variety of potential economic uses that are consistent with its cultural integrity;
- the land is private, not available to public access without Traditional Owner's permission; and
- the land is generally free of contamination and safe for traditional uses including camping, hunting, collecting natural resources and other cultural practices.

2.3 Climatic Context

2.3.1 Climate

The regional climate is dominated by a seasonal wet-dry monsoon cycle with large intra-seasonal variability and tropical cyclone activity. It is characterised by a dry season from May to September and a wet season from November to March, when approximately 95% of the 1,549 millimetre (mm) annual average rainfall occurs (Jabiru Airport) (Figure 2-1). The tropical cyclone season in northern Australia typically extends from November to April, averaging around two cyclones a year, with peak activity from December to March. When cyclones and tropical lows are present, the Alligator Rivers Region can experience high winds and rainfall.

Temperatures exhibit a small daily and annual range and are typically high, with the lowest average maximum monthly temperature in June (31.9 degrees Celsius (°C)) and highest in October (37.7°C). Annual evaporation is approximately 2,594 mm and relative humidity varies from 85% in February to 55% in August.

During the dry season, most of the floodplain and channels of Magela Creek dry out, reducing to a series of isolated backflow billabongs and swampy depressions with the deeper billabongs forming refuges for aquatic fauna. During the wet season, flooding is common and the creeks surrounding the RPA form sheets of water extending beyond their low banks.

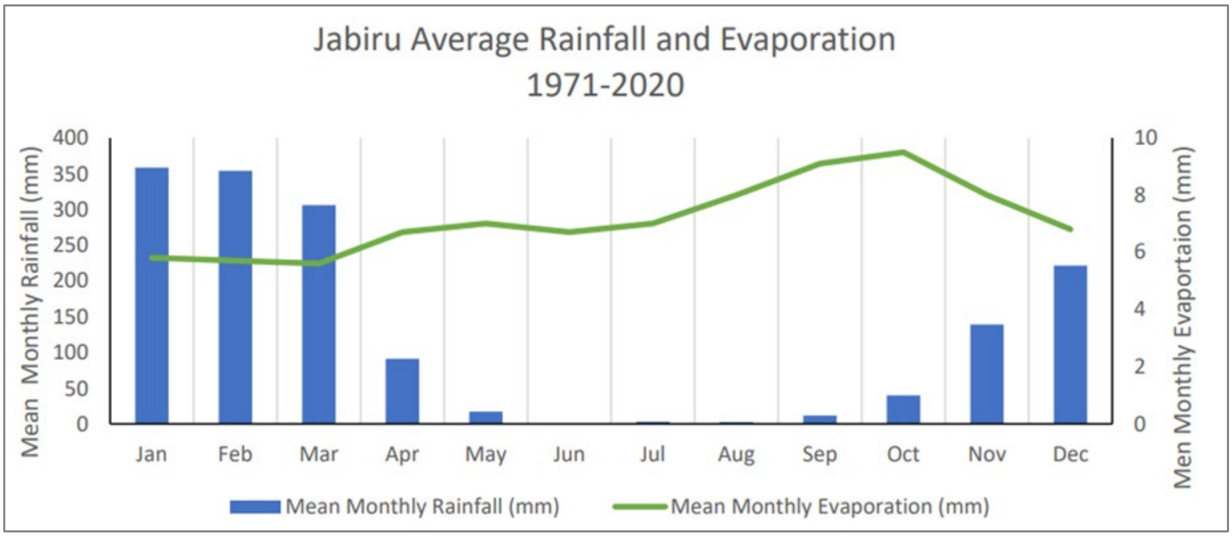


Figure 2-1: Jabiru mean monthly rainfall and evaporation (1971 to 2020)

2.3.2 Climate Change

Climate change is a growing concern for organisations, governments and individuals globally. It is an issue that may affect the performance and desired outcomes of mine closure. The latest available reports from the Intergovernmental Panel on Climate Change (IPCC: IPCC, 2022; hereafter IPCC6) predict the following:

- an increase in percentage of precipitation in monsoon seasons;
- future, heavy precipitation and pluvial flooding in Northern Australia;
- increased fire weather throughout Australia; and
- cyclones – fewer but stronger.

The previous IPCC reports (IPCC5) were published in 2014. Table 2-1 (from BMT 2023d; see Appendix 2.1) compares some of the broader differences between AR5 (used for the IPCC 5th Assessment Reports in 2014) and AR6 (used for the ICPP 6th Assessment Reports in 2021).

Climate change may have a significant effect across the Kakadu region. Most effects are likely to occur beyond 2050, and therefore later than the relatively short period (compared to climate change timeframes) of active on-site management before the site is expected to stabilise. In the longer term, most climate change risks are landscape in nature and would likely affect the entire Kakadu region.

Table 2-1: Comparison of AR5 and AR6 climate findings

Variable	What the variable means	AR5 (2014)	AR6 (2021)	Change between AR5 and AR6
TXx: annual maximum value of tasmax (°C) (intensity)	How hot it can get on a summer day (maximum temp)	4ºC higher	5.4ºC higher	Maximum temperature towards the end of the century is projected to be 1.4ºC higher in AR6
TNn: annual minimum value of tasmin (°C) (intensity)	How hot it can get on a summer day (minimum temp)	3.7ºC higher	4.7ºC higher	Minimum temperature on a hot day towards the end of the century is projected to be 1ºC higher in AR6
10-year ARI for tasmax average over Australia	What would be the intensity of a 1 in 10-year extreme hot day	45ºC	48.8ºC	3.8ºC higher intensity of 1-in-10 year event is predicted in AR6
wsdi (warm spell duration index): annual count of days with at least six consecutive days when tasmax: >90th percentile (duration)	Heatwave days	132.3 days	166.1 days	Number of days with heatwave conditions towards the end of the century is projected to be 33 days more in AR6 compared to AR5
Rx1day: annual maximum value of daily precipitation (mm) (intensity)	How intensely it can rain	5.1 mm	5.1 mm	No change
R10mm: annual count of days when precipitation ≥ 10 mm (days) (frequency)	How often it can rain heavily	0.8 days	0.5 days	Heavy rainfall frequency is slightly less in AR6 compared to AR5 (towards the end of the century)
10-year ARI for precipitation over Australia	What would be the intensity of 10-year ARI rainfall			The 10-year precipitation ARI increases by 15.5%
CDD (maximum length of dry spell): maximum number of consecutive dry days (i.e. with precipitation < 1 mm) (days) (duration)	Dry conditions	12.9 days	13 days	Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century)

3 STAKEHOLDER ENGAGEMENT

Photo: Mural depicting Ngalelek (corella) and Karnamarr (black cockatoo) sitting under manmorlak (Kakadu plum tree) sharing manme (food). Excerpt of murals by Ellie Hannon and Selone Djandjomerr on the Jabiru Kabolkmakmen Office and Jabiru Property Services Office in the Jabiru Plaza

World-class closure and rehabilitation at the former Ranger mine is dependent on a consolidated and strategic approach to community and stakeholder engagement. ERA's approach to stakeholder engagement is focussed on several significant aspects of closure and rehabilitation, such as:

- land tenure and governance;
- planning process and schedule;
- determining post-mining land use, closure objectives and closure criteria;
- technical aspects of closure, including engineering and design criteria for water treatment, mine pit backfilling and landform design;
- selection of closure strategies, technologies and methodologies, along with resource allocation for closure studies and activities;
- compliance with legal requirements and obligations stemming from agreements related to Ranger and Jabiru;

- facilitating information sharing and review processes; and
- managing applications, approvals and verification processes.

ERA regularly engage with stakeholders on various topics related to the company, Jabiru, and local and regional development.

3.1 Stakeholders and Engagement Mechanisms

Figure 3-1 identifies the external stakeholders associated with the closure and rehabilitation of Ranger. Most discussions with stakeholders are coordinated through the forums and committees listed in Table 3-1. These committees oversee and/or contribute to the mine's approval processes, mandatory reporting obligations and the scientific integrity of studies, trials and projects that address Key Knowledge Needs (KKNs). For a more detailed understanding of the regulatory framework, refer to Chapter 2.

Table 3-2 lists the engagement mechanisms and the related engagement activities that ERA undertake to support community and stakeholder consultation.

Consultation with stakeholders is undertaken in accordance with an engagement framework that includes:

- ERA Communities Policy;
- ERA Communities and Social Performance Plan;
- ERA Communication Standard;
- ERA Community and Stakeholder Engagement Plan;
- ERA Community Consultation, Engagement and Communication work instruction; and
- a number of existing engagement forums and tools.

COMMONWEALTH GOVERNMENT

- Department of Climate Change, Energy, the Environment and Water (DCCEEW)
- Department of Industry, Science and Resources (DISR)
- Department of Prime Minister and Cabinet (DPMC)
- Department of Foreign Affairs and Trade (DFAT)
- Department of Agriculture, Fisheries and Forestry (DAFF)
- Office of the Supervising Scientist (OSS)
- Australian Safeguards and Non-Proliferation Office (ASNO)
- Australian Securities and Investment Commission (ASIC)
- Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)
- National Indigenous Australia Agency (NIAA)
- Parks Australia
- Minister for the Environment and Water
- Minister for Resources
- Minister for Industry and Science
- Minister for Northern Australia

SERVICE PROVIDERS

- Jabiru Kabolkmakmen Limited (JKL)
- Jabiru Health Clinic
- Jabiru Area School
- Jabiru Emergency Services
- Jabiru Police Station / Northern Territory Police Force
- Jabiru Foodland
- Charles Darwin University
- Red Lily Health Board
- Jabiru Childcare Centre
- Jabiru Playgroup
- Jabiru Local Emergency Committee
- Power and Water Corporation

INDIGENOUS GROUPS

- Northern Land Council (NLC)
- Gagudju Association
- Djabulukgu Association
- Warnbi Aboriginal Corporation
- Arnhem Land Progress Aboriginal Corporation

MEDIA

- Local media
- NT media
- National media
- International media

BUSINESS INDUSTRY GROUPS

- Chamber of Commerce NT
- NT Housing

TRADITIONAL OWNERS

- Mirarr Traditional Owners
- Gundjeihmi Aboriginal Corporation (GAC)

TOURISM OPERATORS

- Tourism Top End
- Northern Territory Tourism
- Kakadu Air
- Marrawuddi Arts and Culture
- Bowali Visitor Centre
- Jabiru based tour providers
- Jabiru based accommodation providers

INVESTORS AND SHAREHOLDERS

- Rio Tinto Uranium / Rio Tinto Limited
- Minority shareholders

EMPLOYEES AND CONTRACTORS

- Employees
- Suppliers
- Sodexo
- Hawkins and
- Clements
- Best Contracting
- Corestaff
- Exact

LOCAL GOVERNMENT

- Gundjeihmi Aboriginal Corporation Jabiru Town (GACJT)
- West Arnhem Regional Council (WARC)

LOCAL INDIGENOUS BUSINESSES*

- Tracks Indigenous Services
- IMECNT
- Rusca Environmental
- Kakadu Native Plants
- Zancott Knight
- Shine People Solutions
- Black Cat Civil
- Yingwati
- Kaddum Industries
- KML Cleaning Services

NON-GOVERNMENT ORGANISATIONS

- Environment Centre NT (ECNT)
- Environmental Defenders Office NT (EDONT)
- Minerals Council of Australia - NT
- Australian Conservation Foundation (ACF)
- World Wildlife Fund (WWF)

INTERNATIONAL AGENCIES

- International Atomic Energy Agency (IAEA)
- European Parliament standing committees
- World Heritage Committee of UNESCO

LOCAL AND BROADER COMMUNITY

- Jabiru Residents
- Gunbang Community Action Group
- Gunbalanya Residents
- Manaburduma (Town Camp) Residents
- Community Outstations

NORTHERN TERRITORY GOVERNMENT

- Department of Industry, Tourism and Trade (DITT)
- NT Cabinet
- Department of Treasury and Finance
- Department of Education
- Department of Health
- Department of Planning and Local Government
- Department of the Chief Minister (DCM)
- Minister for Mining and Industry
- NT Worksafe

Figure 3-1: Stakeholder Groups relevant to Ranger

*Local in the context of Indigenous businesses refers to Jabiru and Darwin based businesses

Table 3-1: Stakeholder Engagement Committees and Forums

Forum / Committee	Description	Members / Attendees	Frequency
Minesite Technical Committee (MTC)	The MTC provides a forum for stakeholders to discuss and resolve technical environmental management matters (assessments, inspections, audits and rehabilitation activities), and regulatory matters related to the Ranger mine and Jabiluka mineral lease, and considers the views of the Mirarr and Aboriginal people.	Chairperson, DITT, OSS, ERA, GAC and the NLC The Commonwealth DISR is an observer to the MTC	6 per year (approximately every two months)
Alligator Rivers Region Technical Committee (ARRTC)	The ARRTC oversee scientific studies undertaken to protect and restore the environment in the Alligator Rivers Region from effects of uranium mining. The ARRTC sign-off on scientific projects via KKNs. These projects are undertaken by ERA and/or OSS and articulate the relevant knowledge and tools required to ensure protection of the environment from the potential impacts of mining and closing Ranger.	An independent chairperson, OSS, independent scientific members, NLC, representatives for DITT, Uranium Equities Limited (current holder of the Nabarlek lease), and Parks Australia	Bi-annual
Alligator Rivers Region Advisory Committee (ARRAC)	The ARRAC is a public, non-technical statutory committee intended to facilitate communication between government, industry and community stakeholders on matters relating to the effects of uranium mining on the environment in the Alligator Rivers Region.	An independent chairperson, representatives from several NT and Commonwealth Government departments, Office of the Administrator of the NT, NGOs, GAC, NLC, OSS, ERA, and other mining companies that operate in the region	Bi-annual
Ranger Closure Consultative Forum (RCCF)	RCCF was established to provide updates to stakeholders on Ranger closure activities; give stakeholders confidence that the proposed Ranger closure strategy will achieve the environmental requirements; provide information on upcoming approvals to allow stakeholders to appropriately resource; gain feedback from stakeholders on studies and applications to ensure outcomes are met and provide feedback on the close out of KKNs.	ERA, OSS, NLC, GAC, DITT, DISR	Monthly
Relationship Committee	The committee was established to ensure effective information sharing and review processes between ERA and the Traditional Owners and their representatives.	Traditional Owners, GAC, NLC, ERA, and invited observers	Quarterly
Cultural Reconnection Steering Committee	The steering committee was established in 2021 to ensure the views of Traditional Owners are considered during the closure and rehabilitation of Ranger. The committee discusses cultural reconnection with the RPA, including consideration of how cultural knowledge can contribute to rehabilitation outcomes and how the Cultural Closure Criteria will be monitored and assessed over time.	Traditional Owners, GAC, NLC and ERA	4–6 times per year
Working Groups	Several targeted working groups have been formed to address matters related to specific areas of closure and KKNs. At the time of writing, the functioning working groups are Water, Tailings, Landform and Ecosystem Restoration.	ERA, OSS, NLC and various subject matter experts undertaking work in the relevant area	As required

Forum / Committee	Description	Members / Attendees	Frequency
Jabiru MoU Oversight Forum Jabiru Program Steering Committee (JPSC)	The Jabiru MoU Oversight Forum is responsible for making decisions and coordinating projects and activities listed within the four priority work streams – infrastructure, economic development, housing and services and township leasing. The JPSC drive forward initiatives agreed under the Future of Jabiru.	Department of the Chief Minister and Cabinet, GAC, Department of Tourism and Culture, National Indigenous Australia Agency (NIAA), DITT, Department of Environment and Energy, Parks Australia, ERA and WARC	Quarterly Monthly

Table 3-2: Key Stakeholder Engagement Mechanisms

Engagement mechanism	Description	Frequency
Publicly available reports	These include various public reports, including ASX Reports, Annual Report, and Sustainability Report.	Quarterly, Annual
ERA Website	Dedicated project website page to provide project information and updates on work being undertaken on the RPA and within Jabiru township. Updated following the completion of project milestones and key decisions.	Ongoing
Media releases and briefings session	Briefings to regional and national media, providing updates on closure and rehabilitation activities.	As required
Audio-visual material in language	Creation of accessible material in (Bininj) language to provide information and project updates to Traditional Owners and local Aboriginal communities.	As required
Social media	Provide project updates on social media pages, the Jabiru Noticeboard, a page administered by volunteers in Jabiru used to provide information to local community members.	Ongoing
Mine Closure Plan	ERA must submit a Mine Closure Plan (MCP) for the NT and Commonwealth ministers to approve each year. The MCP is the rehabilitation plan referenced in the Environmental Requirements and must demonstrate how the rehabilitation and closure activities will meet the ERs.	Annual
Informal meetings	One-on-one impromptu discussions and informal conversations, either face-to-face or via email or phone.	As required
Site visits	Scheduled site visits for the community and tourists to Kakadu including more focussed and targeted site visits for key stakeholder groups (i.e. project activities and studies).	As required for closure activities
Routine Periodical Inspections (RPI)	RPIs provide a forum for MTC members to attend site and undertake physical inspections of specific areas of focus. This is chaired by the Supervising Scientist.	Monthly
Best Practicable Technology (BPT) workshops	A best practicable technology (BPT) assessment is required under Ranger's ERs to accompany each proposal for consideration by the MTC. The MTC uses the BPT as a basis to make recommendations to ministers for approval.	As required
Industry conferences	Attendance and contributions to presentations, key-note speeches, panel discussions, to share knowledge and learnings about Ranger	Ongoing
Ministerial briefings	Briefings provided to both Commonwealth and Northern Territory ministers and senior advisors on ERA operations, including on-site rehabilitation and Jabiru township.	As required
Community briefings/meetings	Briefing/meetings for community residents tailored to meet the information needs and interest of the stakeholders.	Quarterly
Kakadu Board of Management Meetings	ERA provide operational updates, including mine rehabilitations status. The Forum also provides an opportunity for ERA to consult with the broader Indigenous population.	Bi-annually

3.2 Engagement with Traditional Owners

ERA is committed to engaging with the Traditional Owners and local Indigenous groups. In January 2013, a suite of agreements covering the RPA were signed by the Mirarr Traditional Owners, ERA, the NLC and the Commonwealth Government. One of these agreements was the Mining Agreement, which established the Relationship Committee to facilitate efficient information sharing and review processes between ERA and the Mirarr and their representatives. The Mirarr Traditional Owners are represented by the GAC at the various forums and committees (refer Table 3-1).

ERA also engages directly with Mirarr Traditional Owners through the Cultural Reconnection Steering Committee to ensure the views of Traditional Owners are considered during the project and integrated into the design and execution strategy. The committee meet on the RPA and help facilitate cultural reconnection with the RPA, including consideration of how cultural knowledge can contribute to rehabilitation outcomes and how the cultural closure criteria will be monitored and assessed over time. Matters including water management, cultural heritage and environmental protection, revegetation and landform design, employment and training, housing and town planning, and involvement in decision-making processes, have been topics discussed and negotiated during Cultural Reconnection Steering Committee visits.

ERA aims to create a physical, ecological and cultural landscape that meets the expectations of the Mirarr Traditional Owners by fostering greater cultural awareness and recognition of connection to, and knowledge of, Country throughout the closure and rehabilitation process.

3.3 Current Engagement Context

ERA has undergone a significant transition from an operations focus to a closure and rehabilitation focus. During this time, stakeholder engagement has revolved around this change, and included engagement topics and issues such as:

- Adoption by ERA of its new company purpose and vision statement – to create a positive legacy and achieve world-class, sustainable rehabilitation of former mine assets.
- Restructure of the company and integrated delivery model with environmental and social consultancy Umwelt in approvals, engineering company Bechtel to build project capability (in the form of an Integrated Project Management Team), and Kakadu Native Plant Supplies to undertake revegetation activities for the duration of the rehabilitation project.
- Amendments to the Atomic Energy Act allowing ERA to apply to extend its existing Ranger Authorisation (including the S41 Authority that contains the ERs) beyond the 8 January 2026 deadline, so that the RPA can continue to be rehabilitated until the rehabilitation process is complete. The amendment also provides a clear pathway for partial and full relinquishment.
- 2022 Feasibility Study to further refine the execution scope, risks, costs and schedule of the mine closure and rehabilitation.
- The Ranger MCP and ERA's withdrawal of the 2022 Ranger MCP in June 2023 following feedback from stakeholders that the MCP is to be aligned with the outcomes of the 2022 Feasibility Study.

- Applications to progress closure activities, including:
    - The Pit 3 Capping, Wate Disposal and Bulk Material Movement application (resubmitted in September 2023), with a supporting impact and risk assessment that addresses the OSS and NLC feedback received on the initial application (submitted in April 2022).
    - Brine Squeezer upgrade, including approval to operate for process water treatment.
    - Brine Concentrator Distillate release criteria modification.

Additionally, stakeholders are provided regular updates on site activities, monitoring programs, progress of studies, closure planning, outcomes of working groups, management plans, and health, safety and environmental incidents.

3.4 Stakeholder Engagement Planning

Going forward, ERA are committed to a consolidated and strategic approach to stakeholder engagement. Over the next 12 months, relevant topics ERA will engage with key stakeholders on include:

- Pit 3 installation of geotextile and the initial capping;
- future major approvals – Ranger Water Dam Deconstruction and Final Landform;
- renegotiations on agreements following the amendments to the Atomic Energy Act;
- local and Indigenous participation in rehabilitation and monitoring;
- the future of the Jabiru Airport;
- Jabiru housing and town infrastructure works;
- workforce accommodation;
- execution activities, schedule and progressive rehabilitation;
- processes and options for partial relinquishment of the RPA;
- BPT assessments; and
- projects, studies and assessments that inform KKNs.

Additionally, ERA are investing in engagement and consultation to further build trust and certainty amongst stakeholders. Changes and enhancements that ERA are implementing include:

- consolidating record keeping across stakeholder interactions and forums into a stakeholder management system;
- embedding stakeholder engagement into the project execution schedule;
- building internal capacity and capability, and local and regional participation;
- adopting a culturally appropriate engagement approach, utilising storytelling and translation methods; and
- increasing consultation and touchpoints with the broader community to gain a deeper understanding of the concerns and perceptions raised via various engagement channels.

3.5 Social Impact and Opportunities Assessment

In 2023, ERA commissioned Umwelt to undertake a Social Impact and Opportunities Assessment (SIOA), including an updated Social and Economic Baseline Study. The scope of the SIOA was to understand the range of existing and predicted social and economic impacts and opportunities associated with the cessation of mining and the closure and rehabilitation of Ranger. SIOA's are common best practice in the industry to support projects to identify impacts and opportunities of activities on host communities and set out clear mitigations to be monitored over the closure and post-closure phases.

3.5.1 Context of the Assessment

In 2018, the NT Government and the Mirarr Traditional Owners agreed to keep the Jabiru township in-situ as part of the Mirarr vision to transition to a post-mining future. This was in the context of the pending closure of the mine and the expiry of the Jabiru township head lease in 2021. This decision reset ERA's original requirements to remove all assets and return the land to its original state. This was the assumption considered in the previous Social Impact Assessment in 2018.

As part of the decision for the future of Jabiru, the Mirarr set a new vision for Jabiru to be a world leading ecologically sustainable, economically and socially vibrant community where traditional Aboriginal culture, all people and the natural environment flourish. This vision is captured in the Jabiru Masterplan which guides all works in Jabiru and is overseen by the Gundjeihmi Aboriginal Corporation Jabiru Town.

In support of this vision, the Commonwealth of Australia, ERA, the NT Government and GAC signed the Memorandum of Understanding (MoU) on the Future of Jabiru Township in 2019. The MoU sets out the shared intentions and commitments of the parties to work together to support the Jabiru township transition. In 2021, the town lease for Jabiru was formally transferred to the Mirarr Traditional Owners. Since mine operations ended in 2021, ERA's role in the community has shifted, with ERA now supporting the Mirarr's vision for Jabiru.

As a result of this context, ERA recognises that the SIOA process is key to inform decision-making and plans for Ranger. Through the SIOA, ERA has drafted a set of goals and objectives related to its current role in the region's transition (Table 3-3).

Table 3-3: ERA's draft social transition framework

Goal	Objectives	Success Measures
ERA supports the objectives set by the Mirarr for the future of Jabiru, and ERA has a role to play in delivering the following objectives:	• Deliver on commitments made as part of the Future of Jabiru process. • Provide opportunities for economic development through the delivery of the closure and rehabilitation of Ranger. • ERA's discretionary effort aligns with the vision of the Mirarr.	1. ERA meets commitments regarding housing rectification and other infrastructure work as agreed and to the agreed standards. 2. ERA will engage with stakeholders on a sustainable future for the Jabiru Airport. 3. ERA believes in the development of safe and sustainable Indigenous-owned enterprises and intends to use these service providers and businesses throughout closure and rehabilitation. 4. ERA will actively support the Future of Jabiru governance structures that support the town's successful transition.

Goal	Objectives	Success Measures
		5. ERA will support the creation of opportunities in the form of employment, training, and/or livelihood opportunities for Indigenous people and local people from the region in the rehabilitation and post-closure stages of the project.

3.5.2 Process of the Assessment

The social locality considered for the SIOA extended across the Alligator Rivers Region, with Darwin also considered as a regional services centre. The impact and opportunities assessment considered a range of themes in accordance with internationally recognised Social Impact Assessment guidance and standards, including way of life, community, accessibility, health and wellbeing, culture, decision-making systems, livelihoods and surroundings.

In updating the social and economic baseline, both primary and secondary data were referenced to identify and understand communities and key stakeholders likely to be affected, both positively and negatively, by the mine's closure and rehabilitation activities. High level stakeholder engagement was undertaken to inform each component of the SIOA, with 34 stakeholders consulted, ranging from community service delivery organisations to individual community members, with their inputs, views and ideas incorporated into the assessment.

It is acknowledged that not everyone was able to participate in the consultation process at the time of undertaking the SIOA. In 2024, ERA plans to invite ongoing consultation with the Mirarr Traditional Owners, GAC, and further community and stakeholder feedback, to inform the design of mitigation measures through the range of management plans being developed.

3.5.3 Findings of the Assessment

The SIOA identified a range of pre-existing impacts as a result of the cessation of mine operations in 2021. Prior to this, the town was already experiencing socio-economic impacts such as a decline in tourism numbers; an ongoing out-migration of the residential population; restrictions in relation to housing access; and enduring community concerns about their futures and a desire for greater clarity and involvement regarding what is planned for both Jabiru and activities on the RPA.

The closure of the mine has exacerbated some of these issues, particularly related to the outflux of workers and their families, which has caused changes to Jabiru's composition, character and social ties; a reduction in local economic activity affecting businesses and services; and changes to the capacity and provision of social infrastructure, community services and housing.

The SIOA also identified a number of direct impacts relating to the closure and rehabilitation activities, including the potential for influxes of transient workers for the rehabilitation project activities and the need to provide temporary accommodation for them without contributing to the already-constrained housing supply. It is understood that the successful delivery of ERA's existing housing commitments would contribute additional housing and accommodation to the pool to allow new workers and their families to move to Jabiru in support of the town's transition. Alongside this, the increase in rehabilitation project work would create potential for short- and medium-term economic opportunities locally, throughout the NT and nationally.

The SIOA also identified a range of possible cultural and community health and wellbeing impacts upon the Mirarr people and other Indigenous groups in the region, to be further understood and validated through consultation as a next step in mitigation planning. Similarly, through the progressive return of the land to Traditional Owners, the SIOA highlights the potential for the restorative healing of Country and renewed cultural reconnection for the Mirarr Traditional Owners, which could contribute to improved community wellbeing. The effects of the cessation of royalties also needs to be further understood in collaboration with the Mirarr and GAC.

Existing mitigations in place to address the impacts identified in the SIOA, include:

- Progress made in improvements to social infrastructure and services such as the new health clinic and power station delivered by the NT Government.
- Continued involvement, and where possible, support for the Jabiru Masterplan activities by MoU parties, including ERA.
- ERA's ongoing refurbishment of housing to ensure suitable accommodation to attract future residents/workers for the town.
- ERA's investment to improve stakeholder and community engagement so that local stakeholders are better informed on rehabilitation activities and future planning.
- Continuation of the ERA Community Partnership Fund to align with community need.
- Development of longer-term partnerships with regional organisations.
- Delivery of a range of management plans to increase the level of Indigenous leadership, decision-making and participation in the rehabilitation efforts and the ongoing monitoring and maintenance.

The SIOA also identified a range of new mitigations and management activities, which include:

- Develop workforce and contractor transition plans that align with the priorities of the Jabiru Masterplan vision.
- Continue to prioritise processes that incorporate Mirarr knowledge and participation throughout rehabilitation planning and closure activities.
- Work in partnership with GAC to design a model to deliver post-closure requirements.

3.5.4 Next steps

ERA acknowledges that SIOA is an iterative process and that collaboration with the Mirarr Traditional Owners and other key stakeholders is essential to agree on the impacts and to formulate plans to address or enhance them. As part of this next stage, ERA will seek to work collaboratively with GAC, the Mirarr people, and key stakeholders to validate the outcomes of the SIOA. This includes receiving input into and feedback on the impacts and proposed management measures, and to develop appropriate plans to mitigate, enhance or otherwise address the social impacts and opportunities of the mine closure and rehabilitation project moving forward. Following completion of the mitigation design and planning process, further outcomes of the SIOA will be made available.

4 DESCRIPTION OF CLOSURE ACTIVITIES

Photo: Pit 1 at final landform on right, RP2 in centre and Pit 3 behind RP2 (2022)

This chapter provides an overview of the activities that have been completed at the time of writing this MCP (see also Appendix 4.1 for a chronology of completed activities), and those yet to be completed. Figure 4-1 provides an indicative timeline of the main activities, noting that timeframes are subject to the outcomes of further studies being undertaken on water management and bulk material movement.

Figure 4-2 shows the location and spatial extent of the areas within which these activities will occur. These areas are termed closure domains. While closure domains are helpful to identify areas requiring similar rehabilitation needs, the activities required to complete closure and rehabilitation often extend beyond a single closure domain. As such, this chapter describes the project by closure activities, which encompasses capping and backfilling the mined-out pits, water management, demolition and disposal of on-site infrastructure and contaminated material, the deconstruction of the Ranger Water Dam (RWD) and the creation of the final landform as well as other tasks that do not fit neatly into a specific domain. Table 4-1 identifies the disturbed areas of each closure domain and the area that has been rehabilitated to date, noting that the bulk of the rehabilitation can only occur after a Final Landform application has been submitted and approved, thus enabling the creation of the final landform.

Within the description of the closure activities, the status of completion for each closure activity is provided and whether or not approval to undertake the activity is being sought via the MCP or a standalone approval application.

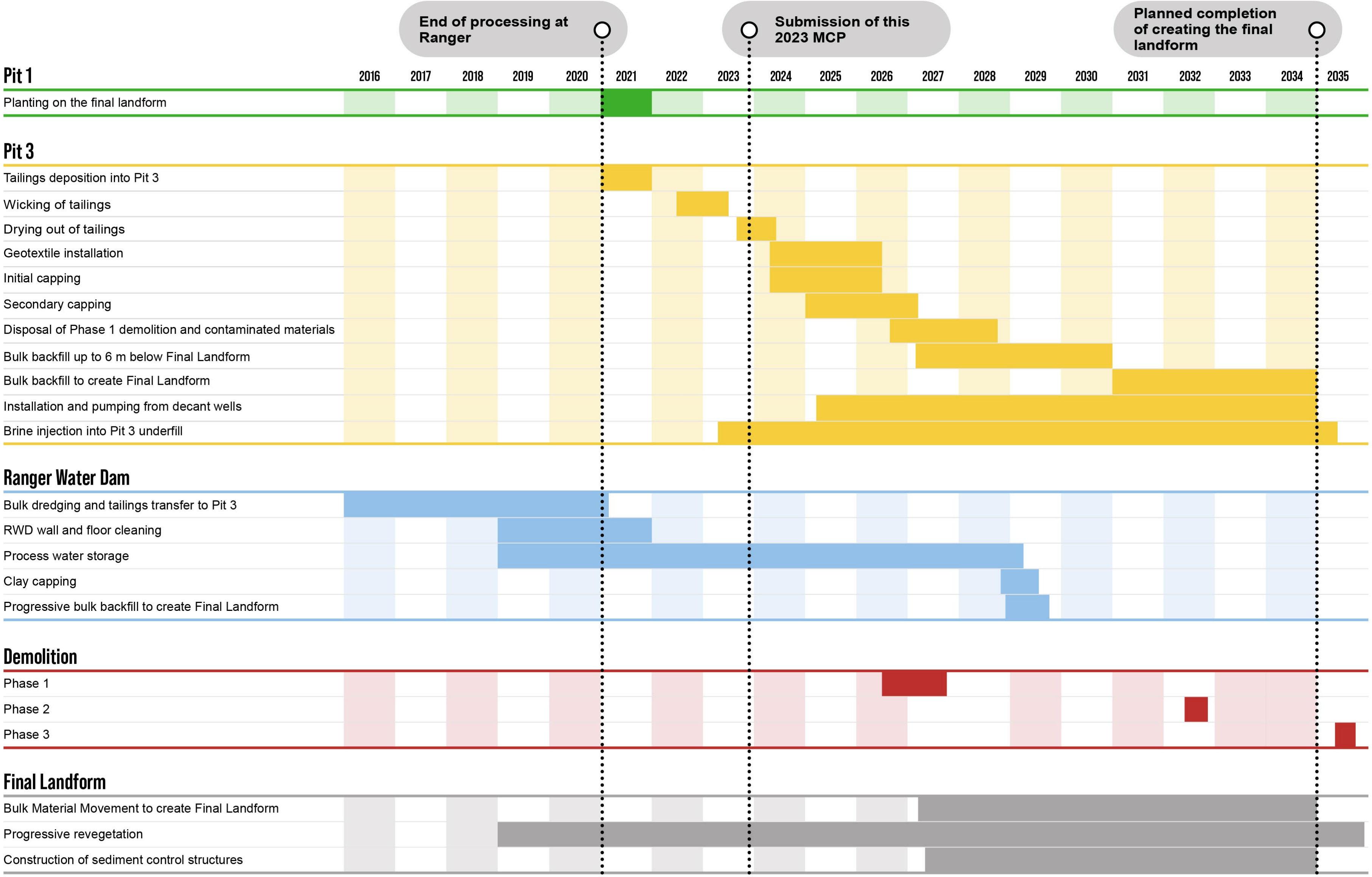


Figure 4-1: Indicative timeline of planned activities

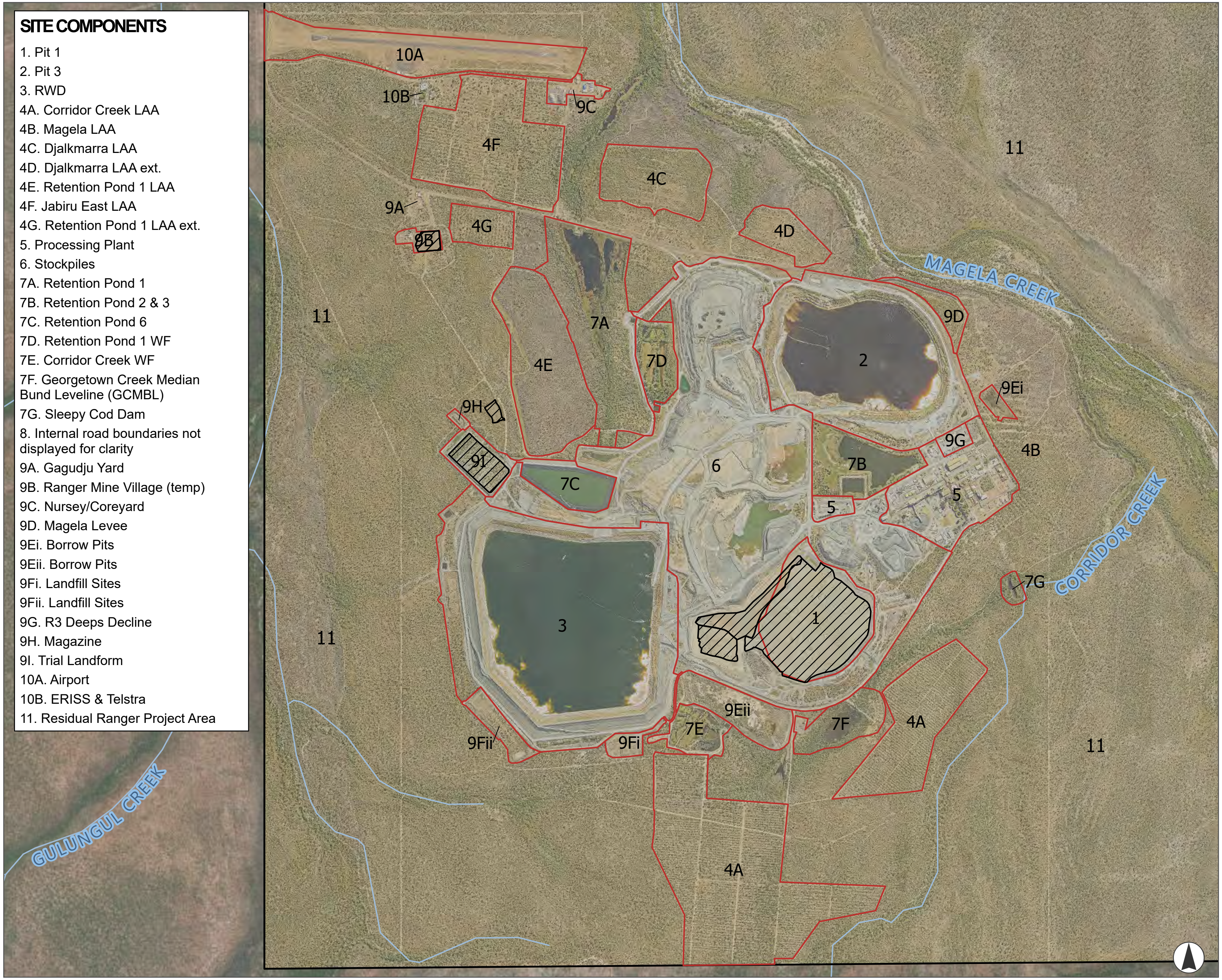
Energy Resources Of Australia

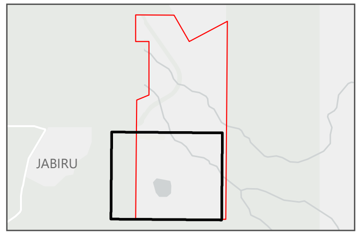
FIGURE 4-2

Ranger – Closure Domains

LEGEND

- Site Component
- Progressive rehabilitation
- Ranger Project Area





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GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

Table 4-1: Land disturbance and rehabilitation by domains (see Figure 4-2)

Domain Number	Domain description	Area	Area rehabilitated
1	Pit 1	41.4	39
2	Pit 3	107.12	-
3	Ranger Water Dam (formerly the Tailings Storage Facility)	185.18	-
4	Land Application Areas		
4A	Corridor Creek LAA	13.50	-
4B	Magela LAA	45.56	-
4C	Djalkmarra LAA	12.50	-
4D	Djalkmarra LAA extension	5.80	-
4E	Retention Pond 1 LAA	36.0	-
4F	Retention Pond 1 LAA extension	0.9	-
4G	Jabiru East LAA	43.0	-
5	Processing plant, administration buildings and Water Treatment Plants	39.86	-
6	Stockpiles	268.65	10.8[1]
7	Water Management Areas		
7A	Retention Pond 1	53.89	-
7B	Retention Pond 2 and 3	21.80	-
7C	Retention Pond 6	12.85	-
7D	Retention Pond 1 wetland filter	11.43	-
7E	Corridor Creek wetland filter	9.48	-
7F	Georgetown Creek Median Bund Leveline (GCMBL)	13.84	-
7G	Sleepy Cod Dam	2.33	-
8	Linear Infrastructure (tracks, service corridors)	40.79	-
9	Miscellaneous		
9A	Gagudju Yard	1.80	-
9B	Ranger Mine Village (temp)	3.04	3.04
9C	Nursery/Coreyard	4.05	-
9D	Magela Levee	2.82	-
9Ei	Borrow Pits	2.32	1.39
9Eii	Borrow Pits	16.40	-
9Fi	Landfill Sites	3.62	-
9Fii	Landfill Sites	6.79	-
9G	Ranger 3 Deep Decline	2.63	-
9H	Magazine	0.95	-
9I	Trial Landform	10.60	6.38
10 A & B	Airport and ERISS	44.08	-

Domain Number	Domain description	Area	Area rehabilitated
11	Residual RPA	TBC[2]	2.93[3]
TOTAL		**1,064.98**	**63.54**

[1] this includes 4 ha for Stage 13.1 and 6.8 ha for Stage 52.
[2] minor disturbance for access tracks and exploration activities has occurred but has not yet been quantified.
[3] this includes 6 drill pads.

4.1 Pit 1

Construction of Pit 1 began in 1979. Mining of the orebody commenced in 1980 and approximately 18 million tonnes (Mt) of ore was extracted between May 1980 and December 1994. The mined-out pit (Plate 4-1), generally circular in plan view, had a surface area of 41.1 ha, an approximate diameter of 750 metres (m) at the widest point and a lowest elevation of -150 metres reference level (mRL) (about 170 m below the ground level).

Plate 4-1: Pit 1 nearing the completion of mining (1992)

4.1.1 Installation of the Underdrain and Deposition of Tailings

Following the completion of mining, closure activities in Pit 1 commenced. Figure 4-3 provides a diagram that illustrates some of the key elevations. It was recognised that due to the inverted cone shape of Pit 1, rapid filling of the lower benches during tailings deposition would occur, which would provide little opportunity for beaching and air drying of the tailings. To enhance the consolidation of the tailings, a shallow underdrain about 10 m thick was installed, covering an area of around 10,000 m^2.

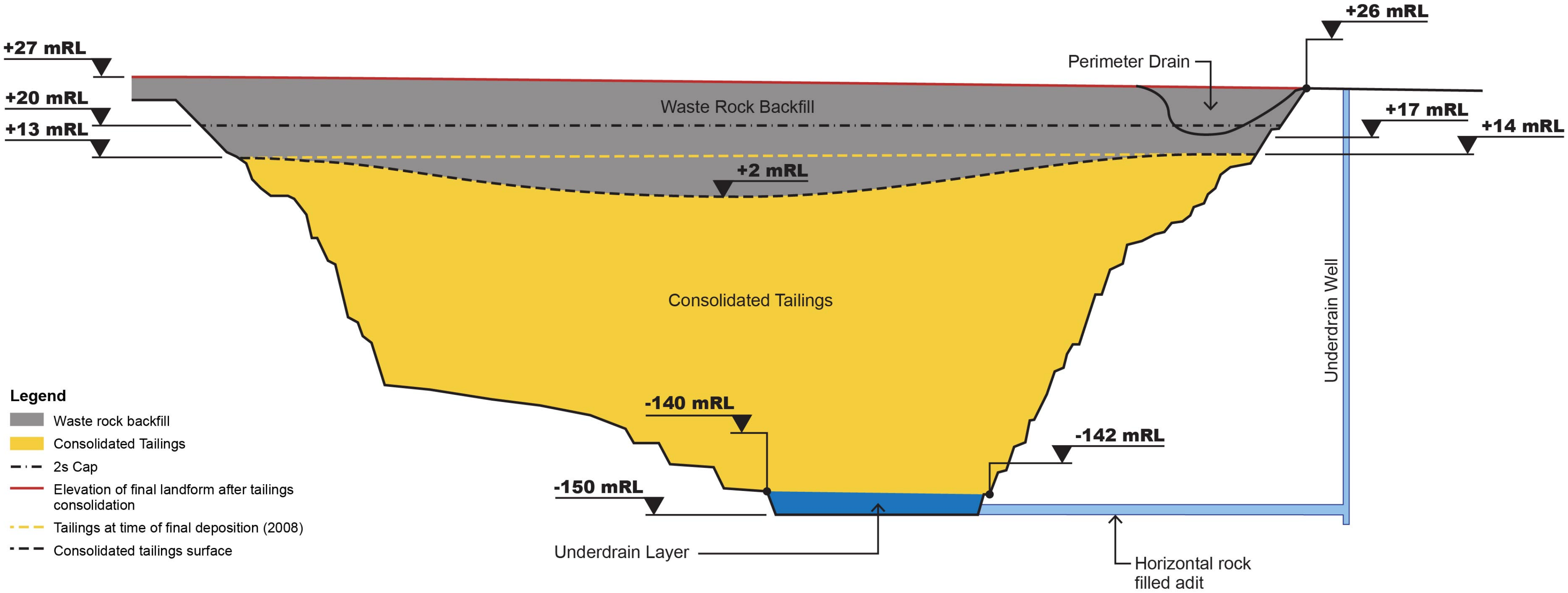


Figure 4-3: Schematic of Pit 1 with key elevations (not to scale)

A horizontal adit was installed to connect the base of the pit to a vertical dewatering bore that pumped process water to the Tailings Storage Facility. The adit was subsequently backfilled with loose rock to allow for drainage from the underdrain system to the pumping bore. These measures provided a hydraulic gradient towards the base of the deposited tailings, promoting consolidation.

Between 1996 and December 2008, approximately 18.9 M m^3 (25.6 Mt) of tailings were deposited in Pit 1. Construction of a seepage-limiting barrier on the southeast section of the pit effectively sealed permeable sections of the pit wall which, following an approval through the MTC, allowed for an increase in the interim level of unconsolidated tailings. At the same time the pit was used to store process water.

Consolidation of the tailings is measured using settlement monitoring plates fitted with standpipes (Plate 4-2), and it proceeded as predicted, reaching approximately 98 to 99% consolidation at the time of the last survey (Fitton, 2021). The settlement monitoring plates were monitored monthly, with the data processed for ongoing validation of consolidation models. This validation was also used to support the validity of other models, such as the consolidation model for Pit 3 (ERA, 2020a).

Plate 4-2: Settlement monitoring plate, with standpipe, at time of installation

With consolidation practically complete in July 2021, the standpipes were cut to just below the level of the landform, capped and buried. This process was completed to allow other rehabilitation activities to commence unimpeded. The location and height of the pipes were surveyed, so the monitoring system can be reinstated should the need arise.

4.1.2 Wicking

Prefabricated vertical drains or wicks (Plate 4-3) consist of a series of perforated pipes that are vertically installed into the tailings to increase the rate of tailings consolidation. Faster consolidation increases both the rate of tailings strength with time, and the rate that the contaminated water that expresses from the tailings (termed pit tailings flux; PTF) can be removed.

A total of 7,554 wicks were installed from May to September 2012 to facilitate consolidation of the upper 40 m of tailings in Pit 1.

Plate 4-3: Tailings surface showing tops of vertical wick drains installed in Pit 1

4.1.3 Geotextile Placement and Initial Capping

After the installation of wick drains and dewatering the pit, a geotextile layer was placed on the exposed tailings surface. An initial waste rock cover was also installed to promote the expression of PTF from the tailings.

Following the completion of the initial capping layer, a laterite layer was placed over the northern half of the pit and a system of training walls was installed prior to the wet season to intercept stormwater and minimise infiltration into the process water catchment.

4.1.4 Backfill

The backfill design aimed to maximise the volume of mineralised (low grade 2s) material placed into Pit 1 whilst ensuring that it remained below the desired height of +20 mRL after settlement due to tailings consolidation (refer Figure 4-3). Surveys demonstrated that the level of 2s is below the +20 mRL, achieving the desired design parameters (Fitton, 2018).

Ensuring that mineralised material was placed below the +20 mRL was important because in Pit 1 this represents the conservative minimum elevation of the simulated long-term average water table, also known as the vadose zone. Placing the 2s material at a level below the vadose zone minimises potential leaching from the mineralised waste rock into groundwater. For this reason, in Pit 1 the +20 mRL level is referred to as the conservative average long-term water level or the 2s cap.

The backfilling was completed in two distinct phases, with the final landform layer of un-mineralised (grade 1s) material being constructed in 2019 and completed in 2020.

Bulk backfilling of Pit 1 involved the movement of approximately 10 Mt of stockpiled material into the pit in two distinct phases:

- 2017–2018: placement of (~4 Mt) mineralised (low 2's) and un-mineralised (1's) waste rock up to the conservative long-term average water level; and
- 2019–2020: placement of (~6 Mt) un-mineralised (1's) material and contouring to form the surface of the final landform.

4.1.5 Tailings Consolidation and Removal of Pit Tailings Flux

Water from various sources contributes to the water balance of Pit 1 (Figure 4-4). Rainfall is collected on the immediate surface of Pit 1 and indirectly via overland flow from nearby catchments that report to the pit. The bottom of the pit is filled with tailings. The pore spaces between the tailings solids contain process water, and as the tailings consolidate under the weight of the waste rock, that process water (PTF) is squeezed upwards.

One decant well was installed during initial capping to collect and extract PTF. This temporary decant well was then replaced with two decant wells during the early phases of bulk backfill. As the tailings in Pit 1 approached the completion of consolidation, the flow rate of expressed process water declined. The two decants currently operate on an as-required basis.

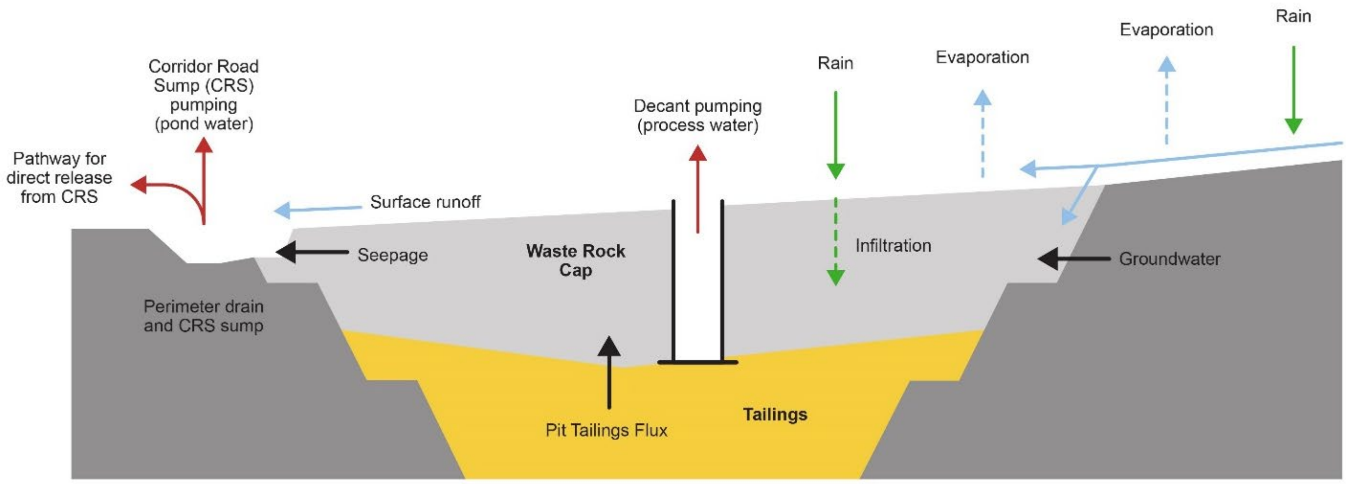


Figure 4-4: Pit 1 water balance schematic

4.1.6 Creation of Final Landform

The surface of Pit 1 was lightly scarified to provide a surface that was easily traversed on foot (Plate 4-4). Once the surface preparation was completed, it was walked and visually inspected by the Traditional Owners during a Cultural Reconnection Steering Committee visit.

Plate 4-4: Scarification of the surface on Pit 1 (October 2020)

The following interim water management structures were installed in 2020 and 2021 to mitigate water and sediment risks:

- a water collecting perimeter drain was installed to capture rainfall runoff (Plate 4-5); and
- the previous sump (Corridor Road Sump: CRS) was extended to a capacity that could accommodate the collected rainfall runoff, and additional pumping and piping infrastructure was installed (Plate 4-6).

These interim water management structures will remain in place until the final landform construction commences in the neighbouring Corridor Creek catchment, at which time final erosion and sediment control features will be installed.

Monitoring of the surface topography, erosion and sediment transport is conducted using high-resolution digital elevation models, drone photography and field observations. Remediation activities to manage erosion (largely on the steeper slopes adjacent to the perimeter drain; Plate 4-7) is undertaken as required.

Plate 4-5: View of the perimeter drain and rock check dams along the southeast edge of Pit 1 (January 2021)

Plate 4-6: Completed Corridor Road Sump upgrade works with pumping infrastructure installed

Plate 4-7: Back-cutting erosion on the steeper slope leading into the temporary perimeter drain (2022)

4.1.7 Revegetation and Habitat Creation

Pit 1 marked ERA's first opportunity to carry out a large-scale revegetation initiative. It provided valuable insights for improving processes related to seed treatment, propagation, planting and plant survival. The approximate 40 ha top surface of Pit 1 was planted over a period of ten months, which included research trials and progressive revegetation as part of the Ecosystem Establishment Strategy. The trial successfully explored propagation methods in different seasonal conditions and experimented with materials for planting, irrigation techniques and methods for successfully establishing vegetation.

The input and collaboration with ERA's long time partners Kakadu Native Plant Supplies (KNPS) was key to the success. Despite challenges such as the absence of topsoil, more than 70 native species were actively introduced, and after two years the average plant survival rate across Pit 1 is ~70% and some plants have reached 7 m in height.

An important element to plant survival on the waste rock is irrigation of the tubestock. A central pivot tower was installed as the main irrigation system for the Pit 1 area. Revegetated areas were initially irrigated using a solid-state sprinkler system before the pivot system became operational. The Pit 1 revegetation trial has shown that irrigating for up to six months is important to promote plant establishment and survival.

To assist with the re-creation of rock habitat areas, ERA worked with, and continues to work with, Traditional Owners as part of the Cultural Reconnection Steering Committee (Brady *et al.,* 2021). Several rocky habitat features were placed on Pit 1 during 2021 (Plate 4-8).

The rock habitat features were designed by local Bininj man, Peter Christophersen (of KNPS), in consultation with the Mirarr and the Cultural Reconnection Steering Committee. They will be placed on pre-determined lines that will link the surrounding ecosystem to the final landform (Figure 4-5) and encourage the return of fauna from the surrounding areas. The selection of plant species for the rocky outcrops was determined through engagement at the Cultural Reconnection Steering Committee to incorporate traditional ecological knowledge and cultural preferences. The committee held discussions of the links between desired flora and fauna and people's connection to each other and to places, story and cultural practice.

After just two years, fauna and natural recruitment of plant species are returning to the area, showing progress in ecosystem restoration.

Plate 4-8: Rocky outcrop habitat feature installed on Pit 1

Figure 4-5: Preliminary plan for rocky outcrop habitat feature lines on the final landform

4.1.8 Planned Future Activities

The remaining activities in Pit 1 are the removal of the interim water management perimeter drain, Corridor Road Sump, decant wells and infrastructure, and the revegetation of these areas. These activities will be included in the FLF application.

4.2 Pit 3

Mining of the Pit 3 orebody commenced in 1997, approximately 94 Mt of ore and waste rock was extracted between July 1997 and November 2012. The mined-out pit was approximately 1,050 m long, 770 m wide and 280 m deep (approximately -265 mRL at its lowest elevation).

In April 2022, a draft of the Pit 3 Capping, Waste Disposal and Bulk Material Movement Application was provided for review to the OSS and the NLC representing the GAC. Feedback was received from the OSS and NLC in June 2022, which recommended that additional studies were undertaken prior to submitting the final Pit 3 application. These additional studies have been undertaken in consultation with OSS and NLC and the final Pit 3 application was submitted to the MTC members in September 2023.

Figure 4-6 provides a schematic diagram that illustrates some of the key elevations within Pit 3, and particularly the elevation of tailings and waste rock at the time of placement and as the tailings consolidates over time.

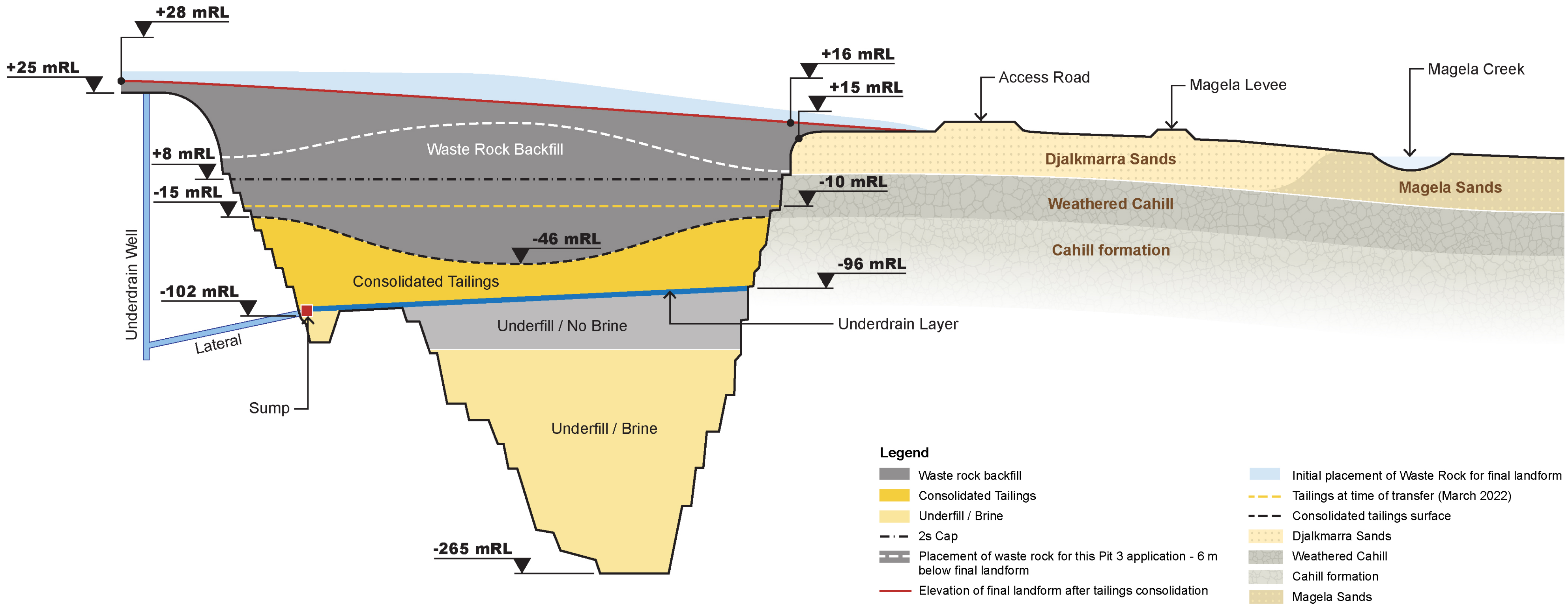


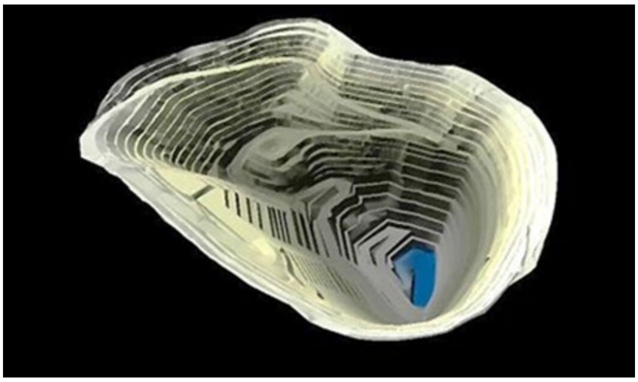
Figure 4-6: Schematic of Pit 3 with key elevations (not to scale)

4.2.1 Construction of the Underfill and Underdrain

As with Pit 1, a waste rock underfill and underdrain was installed at the bottom of Pit 3. The Pit 3 underfill however was significantly larger, being approximately 160 m thick. The installation of the underfill in Pit 3 serves two purposes:

1. it functions as a final repository at a suitable depth for the injection of the brine waste stream (Section 4.2.2); and
2. it established a broad, level surface area for the subsequent deposition of tailings, which maximises the uniformity of tailings consolidation.

Figure 4-7 illustrates the shape and surfaces of Pit 3 at the end of mining and after the construction of the underfill.



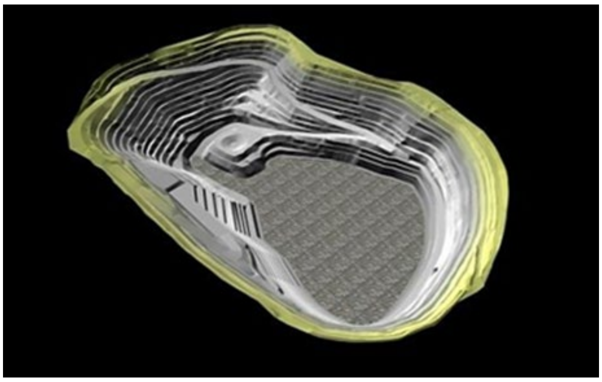


Figure 4-7: Pit 3 in 2021 (left) and after construction of the underfill in 2014 (right)

The underfill was constructed by placing 31.7 Mt of waste rock into the bottom of the pit, raising the height of the floor from -265 mRL up to an average level of -100 mRL (refer Figure 4-6). The waste rock was deliberately and systematically placed in a fan-like pattern radiating outward from a fixed point to maximise material segregation. This method was used so that larger size material would run down the face of the dumped waste rock and fill the bottom of the pit, with finer material increasing towards the top of the underfill.

An engineered drainage system, referred to as the 'underdrain' was constructed on top of the underfill. The constructed underdrain system involved excavating trenches within the underfill to accommodate the drainage system. The purpose of the underdrain is two-fold: firstly, it facilitates the removal of process water released during the consolidation of overlying tailings, and secondly, it enables abstraction via the underdrain bore of water displaced upward from the underfill. The underdrain system features a high-permeability waste rock drainage layer, approximately 2 m thick, that is gently graded towards the west. The gradient ensures water flow is directed towards a designated engineered sump located at a low point along the southwest wall of the pit (refer Figure 4-6). The sump is connected to a horizontal bore that intersects a vertical bore known as the 'Underdrain bore'. Water collected in the sump is pumped to the process water circuit via piping infrastructure.

4.2.2 Pit 3 Underfill Capacity and Brine Injection

The primary method of treating process water is through the Brine Concentrator, which uses mechanical and thermal energy to evaporate water. This produces a clean distilled water (distillate) and a concentrated brine that requires permanent disposal. A BPT assessment that considered various methods for brine disposal was undertaken in 2013 (see Appendix 4.2). Twenty-seven methods were identified, and eight options were assessed in detail. Several options were assessed under each of the three common methods employed to manage brine: brine injection, crystallisation and thermal distillation. Brine injection into a waste rock underfill was chosen as the preferred disposal method at Ranger.

The storage capacity of the underfill has been investigated over many years (Brown, 2013; Coghill, 2016), with additional analysis and verification conducted as part of the 2018 Feasibility Study and the 2022 Feasibility Study. The ability of the underfill to accept brine depends on both the total volume of the Pit 3 underfill and the porous nature of the waste rock within it.

Initially, the void volume of the Pit 3 underfill was determined as approximately 2.5 gigalitres (GL) (Coghill, 2016). For the 2022 Feasibility Study, the capacity of the underfill to accept brine was reassessed and verified by calculating the total volume of the underfill multiplied by the waste rock's (effective) porosity (Waterman, 2023). Two methods were used to verify the Coghill (2016) estimate for waste rock porosity:

- Wang and others (2017) used a global database of 431 samples from different depositional environments to develop a relationship between the coefficient of uniformity and porosity; and
- Lopik and others (2017) used laboratory experiments with a combination of artificial and natural sands to directly measure grain size distribution and porosity.

The brine capacity of the underfill in Pit 3 is calculated by multiplying the total volume of the pit between -265 mRL and -100 mRL by the applied effective porosity (0.182). This is highlighted in Figure 4-8, which demonstrates that at an elevation of -100 mRL, Pit 3 can hold about 2.5 GL of brine. The total volume of brine to be disposed at Ranger is estimated to be 1.9–2.1 GL, which represents 76–84% of the calculated storage capacity.

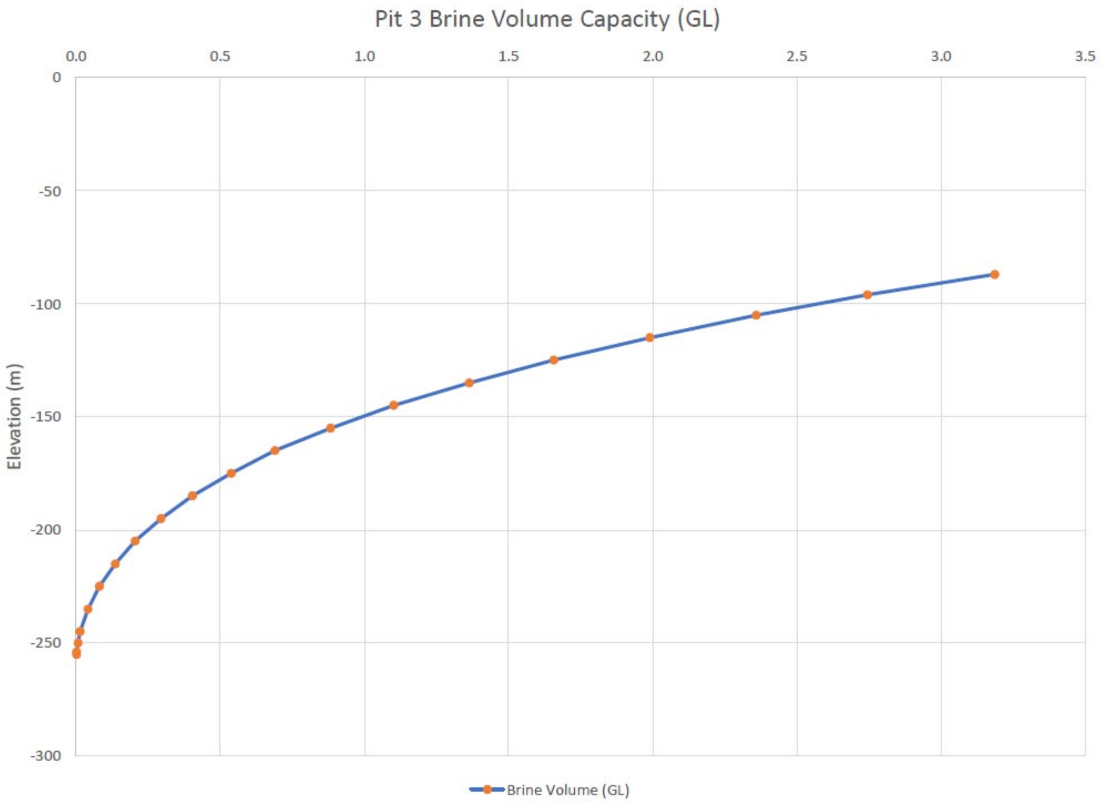


Figure 4-8: Pit 3 underfill brine storage capacity (2.5 GL at -100 mRL)

Following construction of the underfill and underdrain in 2014, five vertical brine injection bores were installed from the surface of the underdrain. Each had a dedicated pipeline connecting back to a valved manifold located on the western ramp of Pit 3. Injection of brine into the underfill began in early 2016, starting with the deepest well. The intent was that when backpressure indicated no further capacity, the well would be abandoned and the process would be repeated at the second deepest well, and so on until all five wells were exhausted.

Scaling in the pipes of two of the injection bores and operational issues with the underdrain bore halted injection activities in late 2016, after injecting 0.28 GL of brine. Remediation work on the underdrain bore and associated infrastructure was completed in the second half of 2020. Investigations during recommissioning revealed that two of the original five in-pit injection bores had irrecoverably failed, two other bores had failed but were recoverable, and one bore remained operational. Injection operations resumed in 2021 but by May 2022, all injection bores had failed, and the in-pit brine injection bores were abandoned.

In November 2022, ERA successfully installed three directionally drilled injection bores located on the perimeter of the pit (Figure 4-9). The intent is that one bore is used at a time. The second bore will be used when a build-up of back-pressure indicates the first bore is to be worked-over and/or that section of the underfill has reached capacity. The third bore is a contingency bore. The first bore became operational on 31 May 2023. At the time of writing (November 2023), the first bore is operational and accepting on average 850 m^3 of brine per day with no back pressure. Approximately 388 megalitres (ML) of brine has been injected into the underfill to date compared to the total volume of 1.9–2.1 GL of brine to be injected (i.e. approximately 20% of the total brine to be injected has been injected).

Figure 4-9: Location of Well Heads of the Directionally Drilled Brine Injection Wells

4.2.3 Tailings Deposition

Tailings deposition into Pit 3 involved pumping mill tailings and dredged tailings from the TSF into the pit. The processing plant (mill) tailings deposited directly into Pit 3 were pumped as a neutralised slurry of approximately 50% solids by weight via an overland high-density polyethylene (HDPE) pipeline. The tailings from the TSF were dredged and transferred to Pit 3 via HDPE pipelines.

Initially, a subaerial deposition method was used, releasing tailings slurry through wall mounted spigots located above the tailings level at the time. This created a sloping beach across the pit floor. Tailings segregation was observed with a significant proportion of the coarser tailings accumulating and forming a beach at the eastern end of the pit and the finer tailings migrating into the decant pond at the western end of the pit, where they settled to form a near horizontal surface below the surface of the water. This segregation resulted in a slope in the tailings surface (approximately 10 m) from east to west.

ERA hosted a stakeholder workshop in January 2018 to discuss Pit 3 tailings deposition. Stakeholders agreed that subaqueous tailings deposition would be unlikely to increase the risk of long-term environmental impact to ground and surface water. A subaqueous discharge trial for dredged tailings occurred from December 2018 to March 2019.

Following the successful trial and completion of additional tailings characterisation studies, an application was submitted to the MTC to modify the method of tailings deposition (from subaerial deposition to subaqueous deposition) and to increase the maximum tailings level to -15 mRL. Approval was received in August 2019, but this approval was specific to the fixed mill deposition spigots only. In August 2020, the final average tailings level was approved to be increased to -10 mRL across the pit based on the low risk to the offsite environment during deposition.

Dredging left a considerable volume of remnant tailings on the floor, inner walls and borrow pits of the TSF. Approximately 1.77 M m^3 of remnant tailings material was dozed into piles to dewater and once sufficiently dried, trucked to and dumped at a tip head constructed on the south-west corner of Pit 3 (Plate 4-9). Due to the soft and uneven nature of the TSF floor, the 1.77 M m^3 included approximately 1.4 M m^3 of tailings, 320,000 m^3 of sub-floor lateritic gravel material and 50,000 m^3 of rock material (from wall cleaning). Transfer of the remnant tailings was completed in December 2021.

For the transfer, a HDPE liner was installed at the tip head and down a section of the pit wall to assist the movement of material (Plate 4-10). Trucks dumped the tailings material onto an area near the pit crest and an excavator or dozer pushed them down the wall. The tailings were discharged at variable moisture contents, ranging from a near slurry to near dry. Water was introduced as needed to aid the transfer process. Despite efforts made to remove the tailings material from benches, some material (a mass of co-mingled tailings and weathered rock referred to as the 'Pit 3 tip head material') remained hung up on the south-west wall of Pit 3 above -10 mRL (Plate 4-10). This material will be removed and placed on the tailings surface.

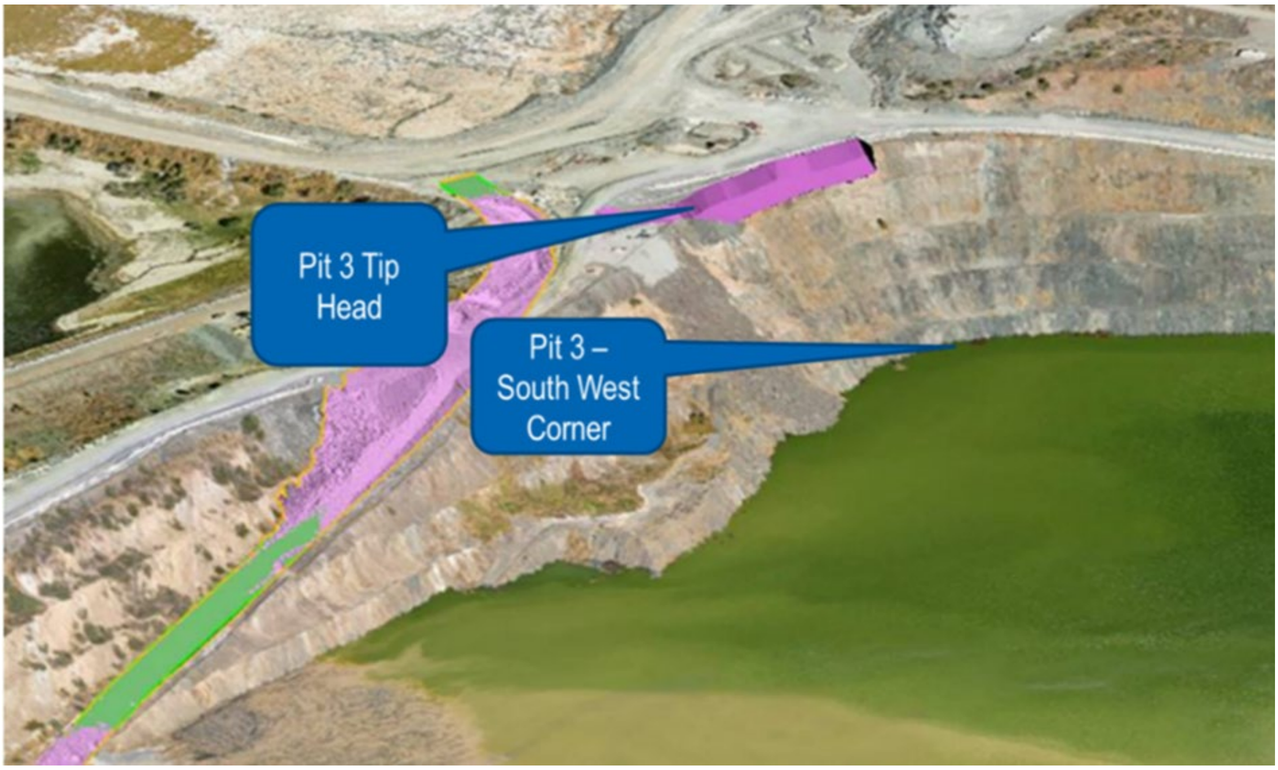


Plate 4-9: View of the Pit 3 wall for proposed tip head (south west view)

Plate 4-10: Tailings currently hung up on the tip head

4.2.4 Tailings Consolidation and Wicking

As with the tailings in Pit 1, consolidation of tailings increases their geotechnical strength, which establishes a safe and stable foundation for capping and backfilling activities. As the tailings consolidate, they release PTF. To prevent this water from potentially seeping into the surrounding environment, the PTF is collected through an underdrain system (described in Section 4.2.2) and decant system (described in Section 4.2.6.2).

Approximately 43,000 prefabricated vertical drains have been installed in Pit 3 to increase the rate of tailings consolidation. To access the low strength tailings, wicks were installed from a floating barge (Plate 4-11). The wicking barge and rigs required the water level in Pit 3 to be managed and held at approximately -14 mRL during construction of the wicking barge and the installation of the wicks. The installation of the wicks was completed on 12 April 2023.

Plate 4-11: Pit 3 wicking barge and rigs

4.2.5 Activities Occurring at Present – Drying Out of Tailings

At the timing of writing, the water expressed from the tailings and any rainfall into Pit 3 is being drained and transferred to the RWD. This draining of the process water will facilitate the drying out (desiccation) of the tailings surface to create the required geotechnical strength, enabling the installation of geotextile and the capping works. The drying out of the tailings has the potential to generate dust, and therefore this activity was the subject of a separate application to the MTC, which included management controls. Approval was granted on 28 June 2023.

The tailings surface within Pit 3 is not uniform, with a higher elevation on the eastern side compared to the western side, except for a narrow perimeter strip around the western side that also has a higher elevation. As a result, the pit floor has been divided into five zones that will dry out at different times during and after dewatering (Figure 4-10).

Tailings in Zones 1 and 2 are being progressively exposed as the water level of the pit drops during dewatering. An amphibious excavator (Plate 4-12) is being used to help accelerate tailings desiccation and create a tailings surface crust that avoids dusting.

An amphirol (Plate 4-13), a screw propelled vehicle able to traverse soft sites, will mechanically assist drying of the pit floor in the non-wicked areas. This machine produces a crust-like surface with a thickness of approximately 1–1.5 m as it overturns the tailings surface, reducing the time taken to gain sufficient geotechnical strength on the surface of the tailings and prevent anhydrous salt formation (anhydrous salt is prone to dusting).

Wick drains have been installed in Zones 3A, 3B and 4 to facilitate dewatering and accelerate consolidation. The tailings surface where wicking has been completed is expected to stay in the near saturated condition for up to two years.

Plate 4-12: Amphibious excavator

Plate 4-13: Amphirol on a red mud dam

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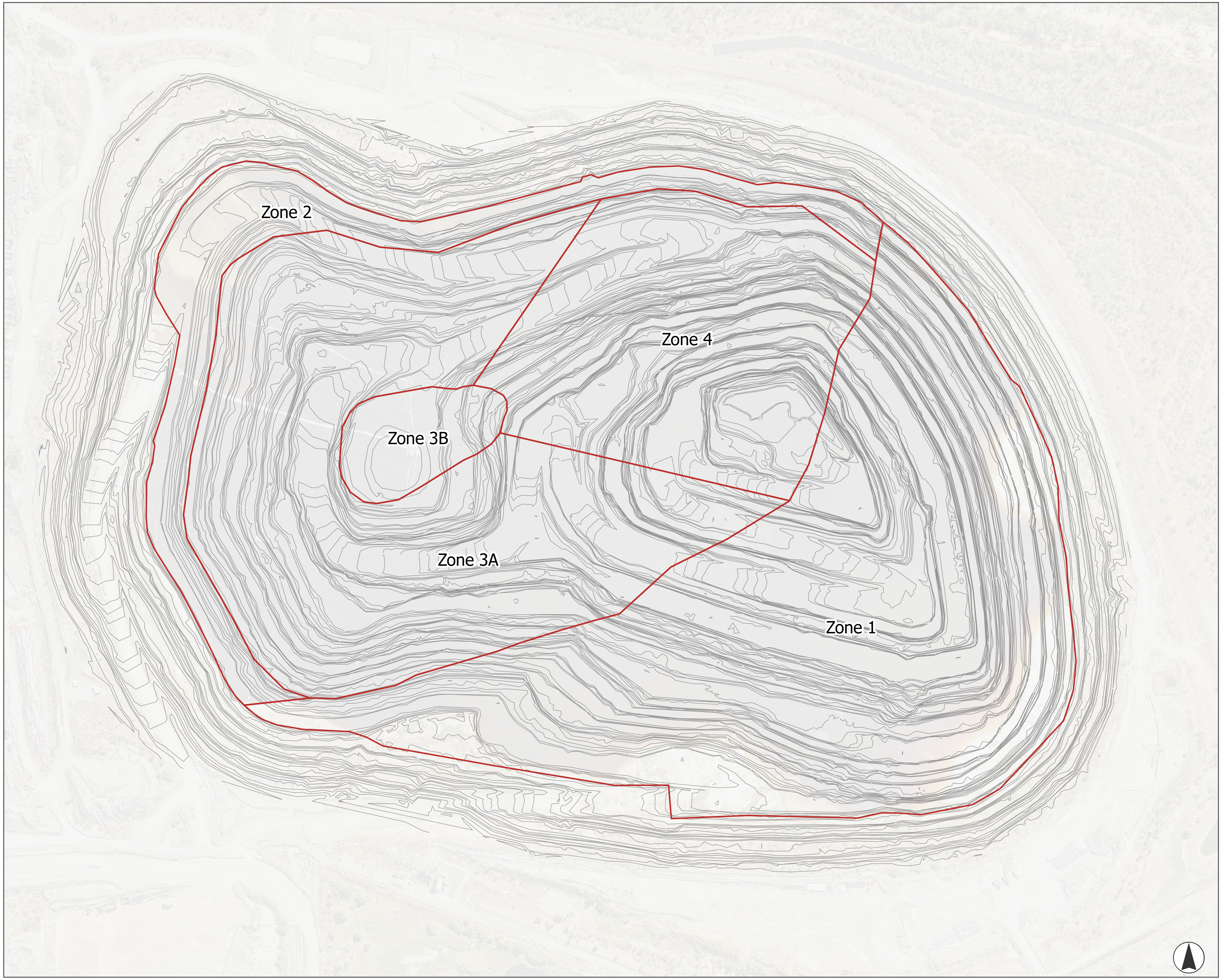
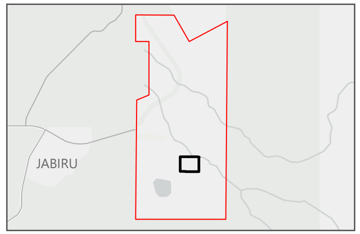
FIGURE 4-10

Pit 3 Dewatering Zones

LEGEND

- Dewatering Zone
- Contours at the end of mining (2m)





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Metres

Scale 1:5,500 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023), Coffey (2023)

4.2.6 Planned Future Activities

All of the activities described in this section are subject to the Pit 3 Capping, Waste Disposal and Bulk Material Movement application that was submitted in September 2023 to the Commonwealth and NT ministers.

4.2.6.1 Geotextile Placement and Initial Capping

Placement of geotextile and the initial capping layer will be achieved progressively over the floor of Pit 3. The construction of the initial capping will proceed in the following steps:

- construction of an access road along the inside perimeter of the pit, which will involve the installation of woven geotextile strips and the placement of rock fill;
- placement of geotextile and construction of evenly spaced 'fingers' or groynes across the tailings surface, on top of the geotextile (Plate 4-14);
- installation of decant wells and monitoring towers over the laid geotextile;
- filling the space between the groynes; and
- continuation of the placement of capping layers across the pit following the specified sequence described below.

Plate 4-14: Installation of geotextile, construction of groynes and initial capping on Pit 1

The initial capping layer will be approximately 3 m thick and expected to be installed in two lifts of about 1.5 m each. The purpose of the groynes is to cause local settlement of the tailings and develop tension in the geotextile. This allows the covered tailings to support the weight of the capping material and construction equipment without causing excessive deformation.

Surface water management during geotextile installation will respond to the characteristics of each zone and potential weather-related challenges. Zones 1 and 2 are likely to remain dry due to their natural topography, with water naturally draining towards Zone 3B. However, there might be localised ponding, requiring the temporary relocation of turret pumps to these areas if needed.

Continuous dewatering may be necessary, particularly in the event of significant storms or heavy rainfall, using the process water transfer turret pumping system.

All water pumped during this phase will be categorised as process water for storage and treatment. This classification is due to the expectation that the pumped water will come into contact with exposed tailings.

With the progressive consolidation of the tailings, the initial capping will extend into the central wicked area (Zone 3A, 3B, and 4), gradually covering the entirety of the pit's surface under the initial capping layer. Subsequently, installation activities will involve decant and monitoring towers. The decant towers and pumps will then take on the primary role in the process water management system in Pit 3. The turret pump systems will be retained for the continued management of surface water.

Upon the transition of using the process water pumping system to using the decant towers for water management, an additional opportunity will arise to capture surface water present on the capping material before it reaches the decant structures and is categorised as process water. The accumulated water will be captured using the turret pumps, and report to pond water for storage and subsequent treatment.

4.2.6.2 Decant Wells and Settlement Monitoring System

A decant system, comprising three decant wells and monitoring instrumentation will be installed in Pit 3 once there is sufficient strength gained by the initial capping to accommodate the construction equipment. The wells consist of vertically stacked concrete pipes (referred to as well liners), with the bottom ring slotted to allow water to enter the decant and a reinforced concrete footing serving as their foundation (Figure 4-11).

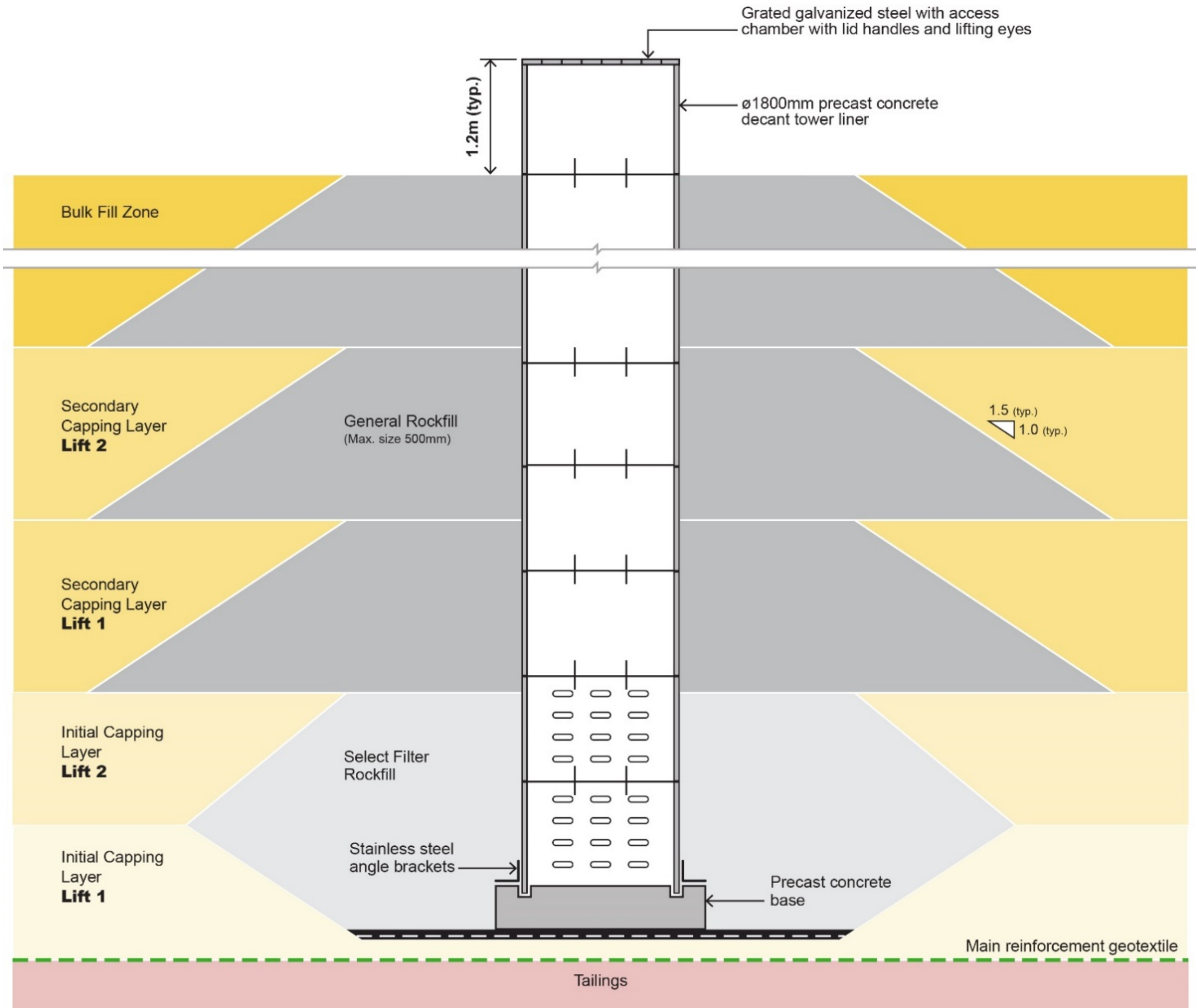


Figure 4-11: Decant Well Typical Section

The decant wells will be constructed at low points in Pit 3 with the entry points as close to the geotextile layer (and therefore tailings surface) as practicable to maximise recovery of the PTF enabling the contaminated water to be removed from the pit, transferred to the process water circuit, and treated. Initially, two slotted/perforated concrete pipes will be positioned directly above the footing to enable water migration into the well, followed by stacked solid concrete pipes. The decant well will be constructed in stages until the final level is 1.2 m above the final landform. Figure 4-12 shows the nominal location of the three wells (blue), which were chosen using tailings consolidation modelling to target the forecast lowest elevation of the tailings surface. These nominal decant well locations will be reviewed prior to installation based on the latest available consolidation model and tailings surface surveys.

The system will pump process water from the base of the decant well, and via an overland HDPE pipeline route starting at the western ramp of Pit 3 and will remain available until monitoring data has demonstrated that the target volume of PTF to be extracted has been achieved or exceeded and solute transport modelling predicts the achievement of agreed criteria (see Chapter 7 for details).

Tailings settlement monitoring wells will be installed across the pit to monitor tailings settlement (Figure 4-12 for nominal locations). Vibrating Wire Piezometers (VWPs) will be installed at depth and wired up through the towers to enable monitoring as the capping/backfill continues. VWPs will measure strength gain in the underlying tailings due to the capping load application. These wells will also be used to monitor water quality (notably water level and electrical conductivity (EC)), through the inclusion of drain slots to enable migration of water into the tower. Some may also be configured for water extraction in the later stages of bulk material movement by being fitted with submersible pumps. Elements of the design (e.g. the arrangement of slots/perforations and the type of fill) may change during detailed design.

Some decant towers (when not being actively pumped) and monitoring towers will be used to measure the standing level of water in the capping layer across Pit 3.

During the construction phase, the decant structures will be safeguarded by a bunded exclusion zone. Only smaller earthworks equipment will have access to this zone, specifically for backfilling and construction of the decant structures.

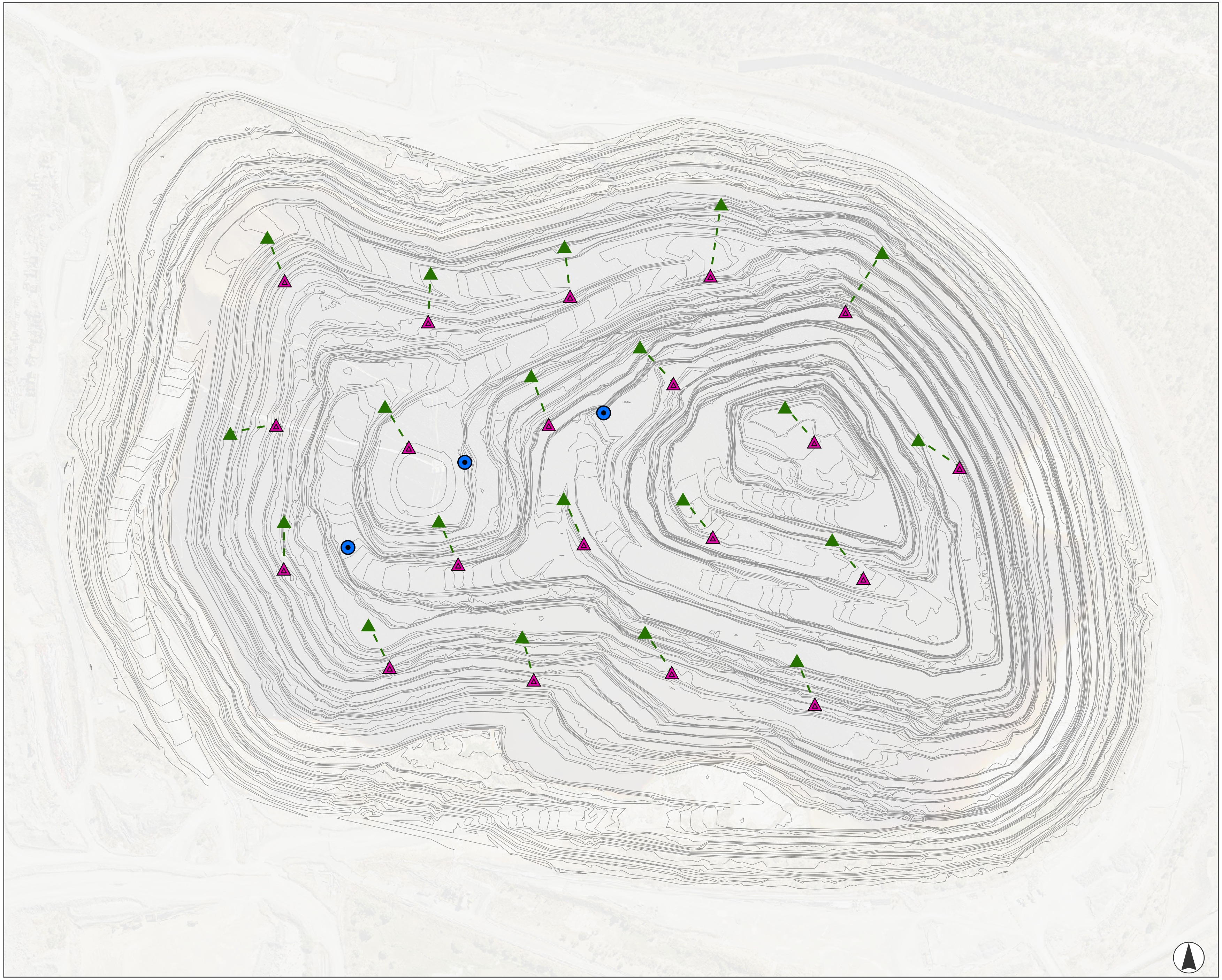
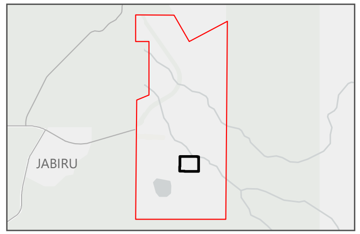


FIGURE 4-12

Nominal Location of Decant Wells and Monitoring Towers

LEGEND

- Decant Well
- Vibrating Wire Piezometer
- Monitoring Tower
- Cable
- Bathmyetric Countours (2m)



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Metres

Scale 1:5,500 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

4.2.6.3 Backfilling

As with the backfill of Pit 1, two types of waste rock (grade 1s and grade 2s), will predominantly be used to backfill Pit 3. For Pit 3, the conservative minimum elevation of the simulated long-term average water table is at approximately +14 mRL. To allow for uncertainties in a number of parameters, including the forecast vadose zone, final level of the tailings consolidation, and future groundwater fluctuations between seasons, ERA plans to allow for an offset buffer of approximately 6 m. Therefore, contaminated and mineralised material disposed into the pit will be placed below approximately +8 mRL. For this reason, +8 mRL is referred to as the 'conservative long-term average water level' or '2s cap' for Pit 3 (refer Figure 4-6).

The void volume of Pit 3 from the top of the tailings surface (at the end of the consolidation period) to the conservative long-term average water level is about 20 M m^3. The volume required for the initial and secondary capping layers in Pit 3 is approximately 3.9 M m^3 and for the remaining bulk backfill is 25.1 M m^3 (requiring a total volume of 29 M m^3 for Pit 3 from the top of the tailings surface to the final landform surface). Section 4.8 describes the bulk material movement that will be undertaken to backfill Pit 3 and create the final landform. That section also describes the discrimination and placement of the varying grades of waste rock, noting that there is ~15.1 M m^3 of grade 2s stockpiled on the RPA. Therefore, there is sufficient void space below the conservative average long-term water level to accommodate all grade 2 material planned for disposal within Pit 3 below this level.

4.3 Water Management at Ranger

Water management is a critical aspect of the day-to-day management at Ranger and a key driver of the timing of closure activities. The *Ranger Water Management Plan* (RWMP) guides on-site water management. It addresses capture, storage, supply, distribution, use, discharge and disposal, ensuring compliance with the Ranger Authorisation and protection of the surrounding environment.

The following sections provide a summary of the water treatment and management processes currently in operation and required throughout the closure phase to ensure the surrounding Kakadu National Park remains protected.

4.3.1 Ranger Water Classes

Ranger is divided into water class catchment areas that generate surface runoff and/or seepage due to rainfall (Figure 4-13). These catchments include retention ponds, sumps, collection basins and groundwater interception ponds. A description of the water classes and the ways in which the water is managed is described in Table 4-2.

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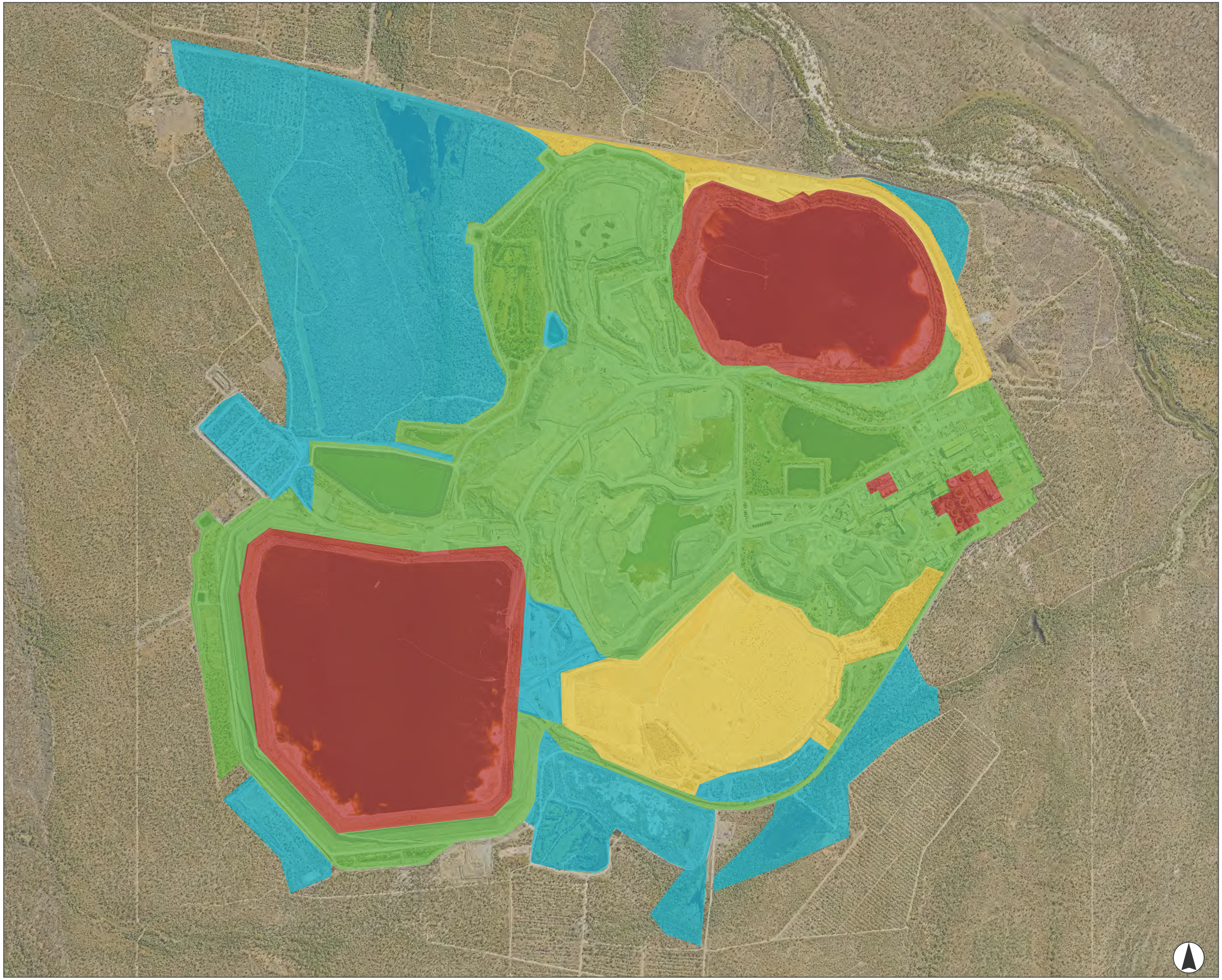

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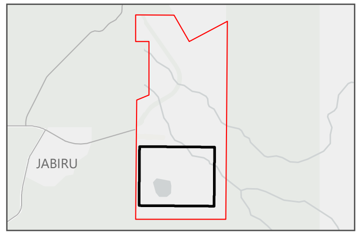
FIGURE 4-13

Ranger Water Classes

LEGEND

WBM Catchment Water Class

- Contingent
- Pond
- Process
- Release



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Metres

Scale 1:22,029 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

Table 4-2: Water quality classes at Ranger

Water Class	Description
Process water	Water that has either passed through the uranium extraction circuit; has come into contact with the processing circuit (i.e. milling, leaching, solvent extraction); or has come into contact with a process water storage facility (i.e. RWD, Pit 1 underdrain and Pit 3). Process water quality is characterised by high dissolved solids. Process water must be contained on-site unless treated via an approved treatment process.
Pond water	Water derived from rainfall on active mine-site catchments or disturbed surfaces, which subsequently needs to be actively managed or treated before it can be disposed to the environment.
Release water	Water derived from the runoff from undisturbed catchments within the mine footprint and from the various water treatment product streams, which is of a quality suitable for disposal to the environment.
Potable water	Water that is used for drinking and ablution purposes, including safety showers, and parts of the plant where high quality water is required, such as within the demineralisation plant.
Treated water	Processed through various plants and divided into categories like permeate, distillate, and brines.
Reject streams	Brines and residues from treatment processes.

For closure, both pond and process water inventories must reach zero.

4.3.2 Water Treatment Infrastructure

Figure 4-14 provides a diagram of the Ranger water circuit. The main components in this circuit are described in the sections that follow.

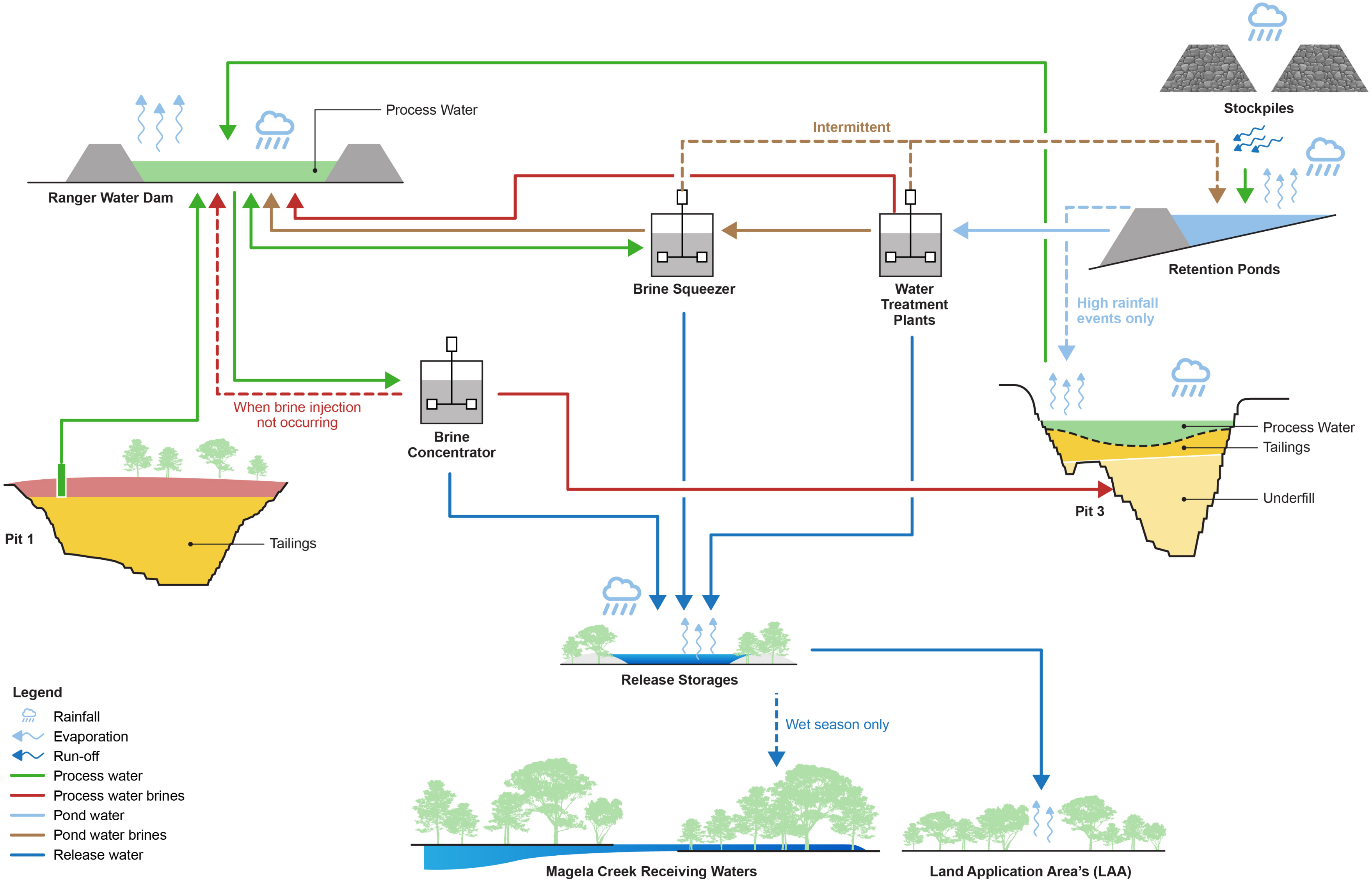


Figure 4-14: Ranger water circuit

4.3.2.1 Brine Concentrator

The Brine Concentrator (Plate 4-15) is the primary route for process water treatment, processing around 2 GL of water per year. Process water is transported to the Brine Concentrator via overland pipelines fitted with leak detection systems. The plant's primary output is a clean distillate product, which is discharged into available release storages. It also produces a waste stream of concentrated brine. This brine is preferentially injected into the underfill layer of waste rock at the bottom of Pit 3 or, if the brine injection system is not operating, it is diluted with process water and returned to the process water inventory.

Treatment of process water is a key driver for the timing of closure activities and therefore studies are underway to investigate options to accelerate this process.

The Brine Concentrator and any other infrastructure installed to expand the process water treatment capacity will be operational until they are no longer required to treat process water. The infrastructure will then be decommissioned, demolished and disposed of into Pit 3 and/or RP2 (it is possible that the operating life of the existing Brine Concentrator allows it to be disposed into Pit 3).

Plate 4-15: Brine Concentrator

4.3.2.2 Brine Squeezer

The Brine Squeezer (Plate 4-16) is designed to extract clean water from the reject of pond water treatment. This significantly reduces the volume of reject from pond water treatment that was previously directed to the process water circuit.

It is undergoing a significant upgrade and is expected to treat around 0.5 GL of process water per year once fully operational, anticipated for early 2024 (MTC approval for the plant to treat process water was received in November 2023). This plant consists of two stages of reverse osmosis treatment in series. In the first stage, high salt tolerance membranes are used to produce permeate, which is then passed to a second polishing stage of reverse osmosis treatment. This second stage yields high-quality permeate suitable for direct release.

Plate 4-16: Brine Squeezer

4.3.2.3 High-Density Sludge Plant

The High-Density Sludge Plant ceased operations in 2022 and is not currently operational. It has the capacity to treat approximately 0.5 GL per year. It generates pond quality water that requires further treatment prior to release to the environment. The plant will be maintained as a contingency. Ultimately, it will be demolished, in conjunction with other water treatment infrastructure.

4.3.2.4 Water Treatment Plants

Three Water Treatment Plants (WTP1, WTP2 and WTP3) are the primary method of managing pond water on the RPA. Each Water Treatment Plant is a micro-filtration reverse osmosis plant, treating pond water from RP2 and RP6. They produce a clean water stream (permeate) and a reject stream (pond water treatment brine). Permeate is directed to release water catchments, while the reject is typically sent to the process water inventory. However, it may be recycled into the pond water inventory if the water quality permits. With the Brine Squeezer available, reject from WTP1 and WTP2 may be diverted to it, while reject from WTP3 will be handled as described.

The Water Treatment Plants operate as needed to manage pond water accumulation, especially during the wet season. Based on median rainfall scenarios, their total capacity provides 1.4 GL per annum of permeate for release. Combined, the three plants can treat around 14,100 kL per day, allowing most of the permeate to be discharged to Magela Creek in the wet season, with the remainder irrigated to the LAAs during the dry season as needed.

The operation of the Water Treatment Plants and treatment strategy is determined by the total pond water inventory, consistent with the annual Ranger Water Management Plan. These plants will continue to treat pond water until pond water sources have ceased. It is noted that WTP3 is a modular facility and will be moved in the future if required to accommodate closure activities.

4.3.3 Water Management Areas

4.3.3.1 Retention Ponds

Four on-site retention ponds (described in Table 4-3) hold surface water runoff that has contacted mineralised materials including low grade ore stockpiles. The retention ponds serve to control sediment, dilute water, and store pond and managed release waters.

Table 4-3: Capacity and description of on-site Retention Ponds

Name	Capacity	Description
Retention Pond 1 (RP1)	390 ML	An earthen embankment that dams Coonjimba Creek and receives release quality water for discharge into Coonjimba Billabong (both passively and actively) or for active discharge into Magela Creek.
Retention Pond 2 (RP2)	1,150 ML	An earthen wall impoundment in the former Djalkmarra Creek catchment (now subsumed by Pit 3). RP2 is the primary storage of pond water with distribution networks to the water treatment elements.
Retention Pond 3 (RP3)	61 ML	An earthen impoundment within RP2. Water from RP3 is transferred to RP2 via a spillway and pumped for use on-site.
Retention Pond 6 (RP6)	976 ML	A ‘Turkey-Nest’, double-lined pond that receives water from RP2 transfers and rainfall.

RP6 was constructed in 2012 to provide 1 GL of additional water storage and management capacity. To allow for storage of either pond or process water, RP6 is double lined with a HDPE liner. As a pond water storage RP6 is connected to RP2 via a two-way pumping system. RP6 will likely continue to function as a pond water storage facility until it is decommissioned, though it may also be used as a temporary process water storage late in the closure sequence. There is mineralised material buried beneath RP6 that will be uncovered later in the project. The emptying of RP6 will allow the extraction of the mineralised material and the commencement of deconstruction of the central and eastern sections of the RWD north wall.

It is likely that RP1, RP3 and RP6 will be deconstructed in line with Phase 2 demolition and the contaminated material will be buried, along with Phase 2 demolition material, in RP2 (see Section 4.4). This timing, and the volume and destination of contaminated material from these retention ponds (to Pit 3 and/or RP2), are subject to further studies (see Chapter 8).

4.3.3.2 Wetland Filters

Wetland filters have been installed at Ranger to passively treat water prior to release. Historically, raw pond water was sent to these wetland filters, however more recently, the filters have provided a final polishing of treated water to improve the quality.

The wetland filters used at Ranger comprise the RP1 wetland filter and the Corridor Creek wetland filter. The RP1 wetland filter, although no longer in operational use, served to attenuate uranium from water using biogeochemical processes before it was discharged to RP1 or used for various on-site uses such as land application, dust suppression and construction. The Corridor Creek wetland filter (Plate 4-17) is used to treat ammonium from process and pond water permeate and uranium from surface water runoff.

Plate 4-17: Corridor Creek Wetland Filter (CCWLF)

Further site investigations will be undertaken to confirm and quantify the extent of contamination within the wetland filters. Excavating and disposing of contaminated sediments that are present within the wetlands into Pit 3 or RP2 is the current preferred on-site containment option, followed by restoration activities (see Chapter 8).

4.3.3.3 Land Application Areas

The LAAs at Ranger (refer Figure 4-2 for locations and Table 4-1 for area) allow for the controlled disposal of release water, permeate and water that has been filtered through the wetland network using a system of pipes and sprinkler heads. This approach aims to maximise loss through evapotranspiration whilst preventing surface pooling and runoff.

Throughout the rehabilitation process, as catchment areas transition to direct release and water treatment requirements decrease, LAAs will gradually become available for decommissioning.

The decommissioning of LAAs involves removing above ground infrastructure, such as risers and irrigation spray heads, along with conducting remediation works guided by the results of contaminated sites assessments (see Chapter 8). Surveys to characterise the LAA substrates, vegetation composition and structure, vegetation condition and fire history have been completed and site-specific soil contamination assessments were undertaken in 2022 and 2023. Key findings from these studies will be used to inform rehabilitation strategies for each LAA. More details are provided in Chapter 8 (Soils) and Chapter 9 (Ecosystems).

LAAs will not be rehabilitated until the areas are no longer required for water disposal. Tracks will be scarified as necessary, and infill revegetation will be carried out where required. Monitoring will determine whether the selected revegetation strategy has been successful and if any further additional works are required.

4.4 Decommissioning, Demolition and Disposal of Contaminated Material

Decommissioning of the processing plant is the only closure activity discussed in this section that has already occurred. The demolition of processing plant activities described in Section 4.4.2 will be the subject of a separate standalone application.

4.4.1 Decommissioning

Prior to initiating the decommissioning of the processing plant, the necessary ‘Permit to Decommission Facility’ was obtained from the Australian Safeguards and Non-Proliferation Office (ASNO). This permit outlined the timeframes and estimated start and completion dates for decommissioning various infrastructure components. With the receipt of the permit on 8 January 2021, the decommissioning works were authorised to proceed.

The decommissioning of all infrastructure within the processing plant has been successfully completed. The decommissioning strategy focused on controlled asset shutdown and infrastructure decontamination to ensure the future safe demolition and disposal, de-energisation and isolation of each demolition area, interim management of the demolition area, and handover to the demolition contractor.

Activities related to de-energisation and isolation were executed in accordance with ERA standards, addressing electrical and control systems, piping and structural components.

With the decommissioning of the processing plant concluded, the current rehabilitation efforts mainly involve care and maintenance activities to ensure the area remains safe prior to the commencement of demolition work. These activities include managing rainwater in process area bunds through existing sump pumps, installation of a system for pumping contaminated rainwater to retention ponds, demarcation of the demolition area boundary, temporary provision of power for lighting in de-energised buildings during inspection activities, and the completion of necessary documentation and handover procedures.

Works to ensure the continuity of services are also occurring. This involves moving service corridors, such as power and water lines, outside of the future zone of demolition.

4.4.2 Demolition and Disposal

As part of the closure process, all plant, equipment, buildings and any other infrastructure on the RPA will be removed unless their retention is required to support the monitoring and maintenance activities required after the creation of the final landform. Demolition includes the dismantling and disposal of all human-made structures and items within the RPA, including:

- fixed or demountable process plant, buildings, mechanical or electrical infrastructure;
- above and below-ground tanks;
- all pavements (bitumen and concrete) along with associated infrastructure such as kerbs, gutters and gully pits;
- concrete slabs and foundations, piping and cabling to a depth of at least 1.5 m below final landform ground level (some larger concrete foundations may remain);
- bitumen road surfaces;
- tyres and other contaminated material stockpiled in designated areas; and
- hazardous materials associated with demolition of structures.

In terms of demolition processing, the objective is to reduce most materials into approximately 1.5 m by 1.5 m segments to minimise the creation of void spaces and promote safe transport from the processing area to the pit. This process involves shearing and pulverising waste to minimise the requirements for manual handling and maximise productivity. Cold cutting, using a hydraulic shear attachment on an excavator, and hot cutting techniques for steel components, will be employed.

The processing approach for various commodities is as follows:

- all steel and non-ferrous materials will be processed to about 1.5 m by 1.5 m lengths;
- thick-walled equipment that exceeds hydraulic shear capability can deviate from the 1.5 m by 1.5 m processing and follow these guidelines:
    - mills, crushers and other equipment with substantial internal voids will be capped and filled with sand or similar before disposal in Pit 3;
    - diesel engines will be placed intact in Pit 3;
    - light and heavy vehicles can deviate from the 1.5 m by 1.5 m processing size, provided voids in Pit 3 are minimised (e.g. whole vehicle chassis can be placed once wheels are removed); and
    - ammonia tanks will be cut up and disposed in Pit 3.
- poly pipes will be cut into lengths and disposed into Pit 3; and
- concrete to be broken up to ensure compaction density can be achieved in pit.

The following items have been identified as materials that should not be processed but placed directly in Pit 3 as whole units due to expected levels of contamination post decommissioning:

- calciner;
- sand filter within the solvent extraction (SX) building; and
- asbestos containers.

The general principle with regards to the disposal of demolished and contaminated material is to maximise the amount of material disposed into Pit 3. However, some infrastructure components, such as the water treatment facilities, transfer pipes, and power supply that are servicing the Pit 3 decant towers and the RWD, will remain operational beyond the Pit 3 backfill timeframe. These materials will be disposed into RP2.

The mill, processing plant, mobile operational equipment and other waste materials will be decommissioned, demolished and transferred by truck either directly into Pit 3 (preferably) or to the temporary laydown area. Other non-contaminated material, such as administrative offices, not required to support the monitoring and maintenance activities will also be disposed into Pit 3.

The execution of mine infrastructure demolition encompasses three distinct phases:

- Phase 1: demolished materials will be disposed into Pit 3 while it is open and accessible, concurrently with bulk material movement works. All demolished and contaminated material disposed into Pit 3 will be buried to a depth below the conservative long-term average water level (currently estimated to be +8 mRL for Pit 3).
- Phase 2: demolished materials will be disposed into RP2 aligning with bulk material movement works. This material will primarily include process water treatment facilities and continued services like pipelines and power supply that will remain operational several years after Pit 3 is backfilled. All demolished and contaminated material disposed into RP2 will be buried to a depth below the conservative long-term average water level (currently estimated to be +15 mRL for RP2).
- Phase 3: materials necessary to support the monitoring and maintenance activities will be either sold or disposed of at registered facilities outside of the RPA.

Table 4-4 provides a list of the materials, volumes and potential contaminants of concern, to be disposed at Ranger. It is noted that the volume of contaminated soils and material may change as the actual demolition and detailed soil sampling occurs, as such, the volumes provided are indicative. The total amount of material estimated for disposal into Pit 3 and RP2 is 454,910 m^3 and 117,390 m^3, respectively (see Section 4.4.3). Comparing this with the available void space of 29 M m^3 for Pit 3 and 2.5 M m^3 for RP2, a significant surplus of space exists to accommodate all contaminated materials. The void space below the conservative long-term average water level in Pit 3 and RP2 is estimated to be 20 M m^3 and 366,000 m^3 respectively.

Demolition of infrastructure within a certain area is deemed to be complete when the area is available for rehabilitation (bulk material movement and final landform works). To ensure the proper management and disposal of all demolition waste and contaminated materials, the following measures will be undertaken:

- processing of demolished materials to optimise density for the disposal location and improve safety while handling;
- scraping contaminated sites (see Chapter 8);
- site grading to fill voids and level the ground where equipment and materials have been removed; and
- removal and final disposal of materials and hazardous waste.

4.4.3 Disposal of Contaminated Material

Previous operational activities over the 40 years have resulted in contaminated soils in various locations across the RPA. Previous assessments identified that soils and sediments on the RPA have become contaminated through treatment of pond water in wetlands and bunds, pond water irrigation in the LAAs, the accumulation of low-level contaminants in waters passing through billabongs, and seeps and spills in the plant areas. Contaminated soils are also expected beneath the processing plant area.

ERA maintains a Contaminated Sites Register (CSR), which identifies the location of sites that supported an activity that had the potential, or caused actual, contamination of land. The CSR also identifies areas for further assessment, management and remediation in reference to Areas of Potential Concern (AoPC) within the RPA.

The latest CSR and AoPC were based on a desktop review of previous site investigations conducted between 2006 and 2022 (see Chapter 8 for details), and provides a categorisation of the AoPC likely to require remediation and an estimate of quantities of contaminated soils (see Table 4-4 and discussed in Chapter 8).

In addition to the contaminated soils, ERA manages hazardous materials at Ranger in accordance with:

- HMP001 Hazardous Material and Contamination Control Plan.
- ERS057 ERA Standard Hazardous Substances.
- Rio Tinto E15: Hazardous materials and non-mineral waste standard.
- ERA's chemical management procedure requires compliance with the relevant legislations and standards including the *Mining Management Act 2012*; *Mining Management Regulations 2012*; Australian Dangerous Goods Code; *Radioactive Ores and Concentrates (Packages & Transport) Act 2011*; *Radioactive Ores and Concentrates (Packages & Transport) Regulations 2010*; Australian Standards; and Work Health and Safety Acts, Regulations and Codes of Practice.

Details of all hazardous materials, (listed waste under the NT *Waste Management and Pollution Control (Administration) Regulations* (Schedule 2)) disposed of by ERA via offsite or on-site disposal are recorded in a waste register. Contaminated waste to be disposed into Pit 3 and RP2 is listed in Table 4-4.

Table 4-4: Approximate amount and destination of waste materials for disposal

Waste Material	Total amount	Potential contaminant	Pit 3	RP2
Demolished material				
Demolished fixed plant and infrastructure, including structural and non-structural steel, concrete, asphalt, pipe	54,000 m^3	Uranium, Mercury, Polychlorinated Biphenyl (PCB's), Hydrocarbons, Lead Paint, Fire Suppressant (FM200), Batteries, Flocculant, Refrigerant, Sulphuric Acid, Waste Oil	26,420 m^3	27,580 m^3
HDPE piping	39,000 m^3		14,000 m^3	25,000 m^3
Listed Wastes				
Asbestos	100 m^3	Asbestos	100 m^3	0
Rubber and other hazardous wastes, including haul truck tyres	3,000 m^3		1,500 m^3	1,500 m^3
General Waste				
General rubbish	13,300 m^3		6,650 m^3	6,650 m^3
Heavy Mining Equipment	21,000 m^3	Waste Oil, Batteries, Coolant, Fuel Oil	0	21,000 m^3
Red stripe light vehicles	660 m^3	Waste Oil, Batteries, Coolant, Fuel Oil	0	660 m^3
Special Items				
Calciner (5 m round x 10 m long)	250 m^3	Uranium	250 m^3	0
Geological ore samples	75 m^3	Mixed uranium content	75 m^3	0
Shipping containers	915 m^3		915 m^3	0
Contaminated Soils				
Soils	440,000 m^3	PFAS, Uranium, Sulfuric Acid.	405,000 m^3	35,000
Total	**572,300 m^3**		**454,910 m^3**	**117,390 m^3**

4.4.3.1 Processing Plant and Water Treatment Infrastructure

As described above, the demolition will occur in three phases. Figure 4-15 shows the phase relevant to the processing plant and supporting infrastructure. At the commencement of Phase 1 demolition, Pit 3 may not be ready to accept demolition waste. Therefore, an initial demolition waste stockpiling area approximately 7.5 ha in size will be established (see Figure 4-16 for location of laydown area) until material can be transported directly into the pit.

Phase 2 demolition has been scheduled to commence when the Brince Concentrator comes available for demolition and RP2 has been emptied and is ready to accept demolished material. Phase 3 demolition has been scheduled to commence once pond water treatment is no longer required as a closure activity.

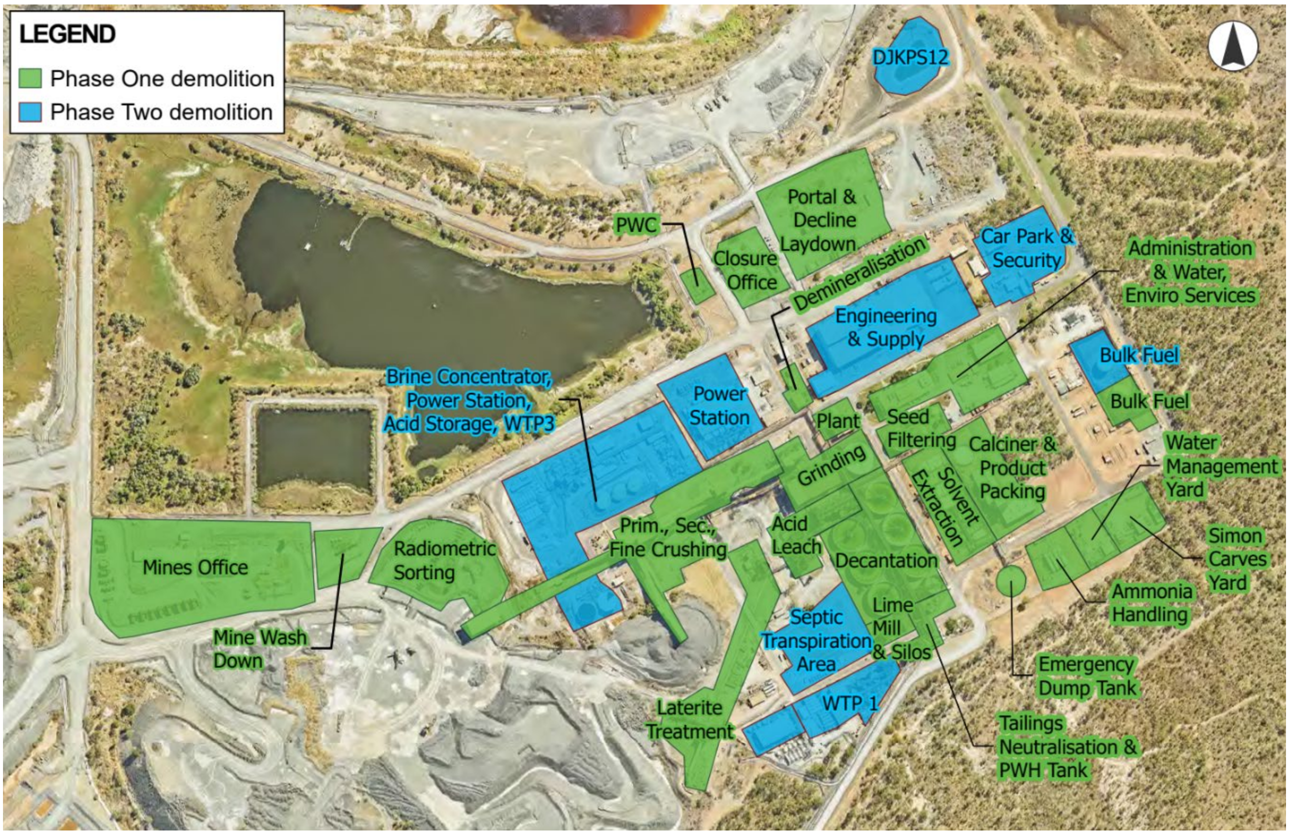


Figure 4-15: Processing Plant proposed demolition phases (Phase 1 – Green; Phase 2 – Blue)

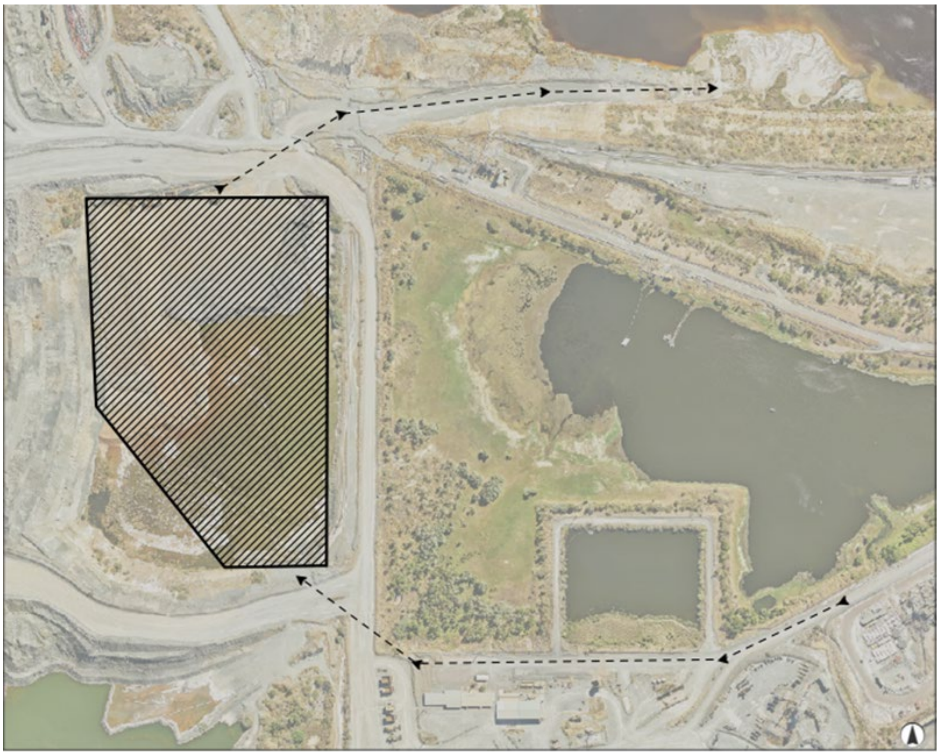


Figure 4-16: Temporary laydown area (Pit 3 at top and RP2 on right)

The bunded areas of the processing plant will be maintained or replaced with suitable alternatives during demolition activities to ensure hazardous residues or contaminated water run-off is captured and reports to the process water circuit, until either water quality measurements show the absence of contamination or the soils beneath the processing plant have been remediated / excavated and placed into Pit 3.

4.4.3.2 Asbestos

ERA will manage asbestos as per Work Instruction (Asbestos and Non-Asbestos Fibrous Silicates Management, ERW103). This work instruction outlines the relevant codes of practice developed under section 274 of the *Work Health and Safety Act 2011* and the interactions to be held with NT WorkSafe when handling, removing, transporting and disposing asbestos.

The ERA asbestos register lists approximately 100 sites containing asbestos related materials including the administration building, engineering workshops, Gagudju yard, grinding building, Orica explosive yard, power station, primary crusher, and the processing plant area. Approximately 7.4 t of asbestos sheeting and 26.8 t of piping containing asbestos require disposal, equating to approximately 100 m^3.

Asbestos and wastes containing asbestos and non-asbestos fibrous silicates from previous demolition activities are currently stored in sealed drums in a locked shipping container on-site near the administration and environment offices awaiting disposal.

All asbestos within the fenced area of the RPA will be placed in Pit 3 below the conservative long-term average water level (i.e. below +8 mRL).

4.4.3.3 Rubber

The mine's rubber waste consists of tyres from both light and heavy vehicles, as well as liners and conveyors. The current estimate is that there are at least 1,000 heavy vehicle tyres stored on-site (Plate 4-18).

Rubber waste is a 'listed waste' and waste tyres at Ranger may have traversed through 'controlled areas' (areas of the site deemed to have a higher potential for exposure to radioactive materials). All rubber waste will be disposed into Pit 3 and RP2, burying it at depth. There will ultimately be a total of approximately 3,000 m^3 of rubber waste on the RPA, of which approximately 1,500 m^3 will be disposed into Pit 3 and 1,500 m^3 will be disposed into RP2.

Plate 4-18: Rubber tyre dump on top of a waste rock stockpile

4.4.3.4 General waste

Approximately 35,000 m^3 of general waste requires disposal. This includes general rubbish, heavy mining equipment and vehicles that have traversed areas of the site deemed to have a higher potential for exposure to radioactive material, referred to as red stripe vehicles. About half of the general rubbish (~6,650 m^3) will be buried in Pit 3. The remainder of the general rubbish and all heavy mining equipment and red stripe vehicles will be either produced during the closure activities or required for the closure activities and therefore disposed of into RP2.

4.4.3.5 Calciner

The calciner is a furnace (multi-hearth dryer) that operated at ~800°C. It is located within the solvent extraction (SX) building. The calcined product is almost pure uranium oxide. The internal walls of the calciner are coated with burnt residual product and have a high level of contamination.

A permit under the *Nuclear Non-Proliferation (Safeguards) Act 1987* (Cth) is required from ASNO to possess nuclear material and to decommission facilities used in the mining and production of uranium ore concentrates. Both permits have been obtained by ERA. A condition of the decommissioning permit is that an additional permit is required prior to moving the calciner from its authorised location. This permit will be obtained before the calciner is relocated and disposed into Pit 3. The permit application will be supported by a plan to safely relocate and dispose the calciner.

This plan may be modified as the permit application progresses, however the current plan is to:

- use cranes to remove the SX roof cladding, ceiling lining, and beams to provide clear access to the calciner;
- remove all structures connected to the calciner (e.g. ductwork, centrifuge platform, screw conveyor from centrifuges to the calciner, central shaft drive motor);
- fill the calciner with expanding foam to secure the product and internal refractory lining;
- seal the calciner apertures with welded steel plates to prevent waste seeping and to shield the workforce from inadvertent contact with residual radioactive waste;
- attach baseplates and anchor bolts as necessary to facilitate rigging and lifting; and
- commission specialist heavy lift contractors to remove the calciner via crane and transport intact to Pit 3 for disposal.

4.4.3.6 Gatehouse and office spaces

The main gatehouse is currently used as the primary access and egress to the mine site and will remain so during closure. The existing medical and emergency services facilities located at the gatehouse and Inganarr area will also remain operational during closure. ASNO security requirements may be relaxed including the requirement for perimeter fencing when demolition and disposal of the mill and calciner is complete.

Decommissioning for Phase 2 demolition includes the mine office, gatehouse and the associated infrastructure (security, fire station and Inganarr).

4.4.3.7 Power stations

The power stations at the mine site include the Ranger Power Station with five 5.1 Megawatt (MW) diesel alternators and the Brine Concentrator Power Station with four 2.1 MW diesel alternators. As decommissioning, demolition and closure progresses across different areas of the RPA, the power demand decreases.

This presents an opportunity to reduce the current on-site generation capacity and gradually decommission/demolish the Ranger Power Station. Planning for this reduction in generation capacity is underway, with options such as the installation of temporary modular or containerised diesel power generators being considered. At some point, ERA will decommission the Ranger Power Station and transition to a temporary Independent Power Plant.

4.4.3.8 Nursery/Core yard

During 2018 and early 2019, ERA converted the old exploration area in Jabiru East into a nursery to support closure operations (Plate 4-19). This work included the removal of exploration infrastructure and the installation of facilities used to process and facilitate the propagation of seedlings along with an associated irrigation system and security.

Plate 4-19: Nursery (on right) and old core yard (on left) at Jabiru East (June 2023)

The nursery will be required to support the revegetation activities that are conducted throughout closure and the monitoring and maintenance phase.

In addition to the nursery, geological core samples are currently stored from the exploration at Ranger and these samples will be disposed into Pit 3 at the commencement of waste disposal activities. Further to the core samples from Ranger, an additional five shipping containers of core samples from the Koongarra uranium deposit will also be disposed into Pit 3.

Progressively, and if required, areas of the core yard may be converted into additional nursery space to increase the capacity of the plant nursery.

4.4.3.9 Landfill Sites

All waste streams generated at Ranger are managed on-site. This has been primarily through the use of landfills or disposal in mined-out pits. In addition, ERA have managed any hydrocarbon contaminated soils though the use of bioremediation pads, located to the north west of Pit 1.

The following landfill sites are located at Ranger:

- historic industrial waste landfills to the south of the RWD;
- domestic waste landfills to the north of Pit 1; and
- temporary industrial waste landfill to the west of Pit 3.

Contaminated sites sampling of the historic landfills and the bioremediation pads were completed during 2019. Several of the old domestic landfills to the north of Pit 1 were covered with waste rock during 2020 as part of the final backfill of Pit 1.

The temporary landfill to the west of Pit 3 will have the waste removed and placed into Pit 3 with the other demolition waste. Once domestic landfills are no longer required on site, they will be covered by the final landform waste rock material.

The plan for rehabilitation of the historic industrial landfill sites to the south of the RWD, and the bioremediation pads will be finalised once soils sampling and remediation action plans are developed (see Chapter 8).

4.4.3.10 Magazine

All explosives have been removed from the magazine and it has been de-registered as an explosives storage facility (Plate 4-20).

Plate 4-20: Old magazine site (June 2023)

Demolition requirements at the old explosive's magazine involve the removal of the magazine, concrete slab and associated footings. The surrounding fence will also be removed. The area will then be contoured and revegetated.

4.4.4 Other Infrastructure and Services on the RPA

4.4.4.1 Airport and ERISS

Activity subject to approval via the MCP

The airport at Jabiru East and other infrastructure, such as the Environmental Research Institute for the Supervising Scientist (ERISS) and the Telstra building (Plate 4-21), are of high value to the community. Under the current arrangements, the Commonwealth is required to rehabilitate and restore the area occupied by ERISS before vacating, including the removal of the buildings.

Plate 4-21: Jabiru airport and Supervising Scientist buildings (June 2023)

The Jabiru airport features a 1,402 m by 23 m wide sealed runway, sealed and unsealed aprons, a sealed taxiway, and has approximately 7,000 to 8,000 landings annually. ERA continues to operate and maintain the airport, and the facilities are generally in good condition. While ERA doesn't rely on the airport for rehabilitation activities, it provides an important service to the region. The airport plays a role in food and supply delivery to remote communities such as Gunbalanya, particularly in the wet season. At other times, the airport supports tourism activities, movement of freight and workforce, and the provision of health care. The Mirarr Traditional Owners have expressed they would like the airport to be retained.

There have been ongoing discussions with stakeholders, including the NT Government, DISR, the NLC and the GAC to identify a third-party operator that allows for the airport to continue to provide the important services to the region. Whilst a solution has not yet been agreed, GAC are currently exploring commercial options for discussion. ERA is committed to continue working with stakeholders to find a commercial solution. If no solution is reached before Phase 1 demolition begins ERA will remove the airport infrastructure and remediate the site in accordance with legislative requirements.

Plans for airport removal are in the early stages, with the access road remaining for ERISS and Telstra buildings. Asbestos in the tourist centre will be safely removed and disposed of in Pit 3. Soil analysis indicates on-site contamination, and further investigations will determine the necessary extent of remediation.

4.4.4.2 Miscellaneous Infrastructure and the Groundwater Bore Network

Activity subject to approval via the MCP

Miscellaneous infrastructure around the site includes roads, tracks, fences and other areas of minor disturbance that have occurred on the RPA outside of the mine disturbance area. These areas are estimated to encompass a total of 48 ha. The timing for the future rehabilitation of these areas will be based on the utilisation requirements for closure implementation work. ERA intends to commence the progressive rehabilitation of some of these areas, in particular the areas north of Magela Creek.

Progressive rehabilitation will include the removal of redundant infrastructure, scarifying the natural soil (as required) and revegetation (as required). This has been a successful rehabilitation protocol for areas disturbed during exploration on the RPA. Some linear infrastructure, for example, the boundary fence and various access roads, may be required following the completion of rehabilitation work, as part of the ongoing monitoring, maintenance, and security of the site. ERA will liaise with relevant stakeholders (e.g. Traditional Owners and the Commonwealth Government), to agree if any access tracks are to remain for ease of movement (Traditional Owners) and ongoing access for monitoring activities (Commonwealth Government).

The planned rehabilitation of the ERA groundwater bore network is divided into three stages:

- Stage 1 was completed in late 2020 and involved the collation of information on the ERA groundwater monitoring network into AcQuire, a geoscientific data management software package. This will be used to track the progressive rehabilitation of groundwater bores located across the RPA.
- Stage 2 will involve the ground-truthing of sites recorded in AcQuire. These activities commenced in 2023 and will continue in 2024.
- Stage 3 will involve the active decommissioning of redundant infrastructure.

4.4.4.3 Gagudju Yard

Activity subject to approval via the MCP

The Gagudju yard (Plate 4-22 and Plate 4-23) is no longer in use and is planned for demolition in 2024. ERA intends to engage a specialist contractor to demolish and dispose of infrastructure including demountable buildings, hydrocarbon storage tanks, concrete aprons and various other redundant materials and loose items in the Gagudju yard footprint. It will be demolished and placed at the Pit 3 laydown area.

Following the demolition and removal of materials and infrastructure, an area of approximately 2.8 ha (including surrounding disturbance) will be available for initial revegetation activities. Similar to the rehabilitation approach applied to other disturbed areas of the RPA, rehabilitation will involve scarifying the natural soil (as required) and revegetation.

Plate 4-22: Gagudju yard and surrounding disturbance (June 2023)

Plate 4-23: Gagudju workshop and surrounding infrastructure

4.4.4.4 Ranger Mine Village

Activity subject to approval via the MCP

The Ranger Mine Village has had all infrastructure and concrete removed (Plate 4-24). The accommodation and other demountable units were sold, where possible. Demolition and removal of all remaining accommodation units, camp amenities and equipment are planned to occur to align with Phase 1 demolition.

A 1.4 ha area of the site was revegetated in February 2020. The natural soil surface was prepared with 20 centimetre (cm) deep rip lines at 1 m spacing using a grader. Approximately 2,000 stems of 44 species were planted, with a combination of overstorey, midstory and understorey species. Several kilograms of additional understorey seed from 10 species were also sown in between tubestock. The revegetation occurred during a rainy period and no irrigation has been used in the area.

Plate 4-24: Ranger Mine Village – with plants establishing (June 2023)

4.4.4.5 Magela Levee

Activity subject to approval via the MCP or the FLF application

Plate 4-25: Magela Levee (June 2023)

The Magela Levee (Plate 4-25) will be removed and rehabilitated as part of the final landform earthworks and revegetation. Levee material will be returned to the original borrow pit with any excess material either placed in Pit 3 or used for any site works requiring lateritic material.

4.4.4.6 Borrow Pits

Activity subject to approval via the MCP or the FLF application

There are currently two borrow pits located on the RPA:

- borrow pit for the construction of a RWD lift; and
- borrow pit for the construction of the Magela Creek levee.

No borrow pits have been rehabilitated and there is no rehabilitation currently underway.

The borrow pit for the RWD lift will be re-contoured as part of the final landform for the corridor creek catchment. As per the original application to install the Magela Creek levee, on completion of the rehabilitation works for the borrow pit area, a gamma grid survey will be conducted in the borrow area to confirm that radiological activity is consistent with the principles of ALARA. Revegetation of the borrow area will be completed as part of the progressive rehabilitation of the Magela LAA and/or final landform.

4.4.4.7 Central Services Corridor

Operation of the corridor is the subject of a separate approvals application

A services corridor, which accommodates several waste stream pipelines and an access road, is currently located in the stockpile domain to the north of Pit 1 (Plate 4-26). The pipelines supply feed process water to the Brine Concentrator and allows movement of water from Pit 3 to the RWD. The corridor is located primarily on non-mineralised material (grade 1s), but some mineralised material (grade 2s) may be encountered in the stockpiles north of Pit 1. The mineralised material is to be excavated and placed into Pit 3, requiring a relocation of the services corridor.

Another existing pipeline corridor, allowing transfer of process water between the various water treatment plants and the RWD, runs along Corridor Creek Road. Both pipeline corridors are proposed to be replaced by a single central services corridor, to be constructed across surfaces that are already predominantly at final landform level to the west and north west of Pit 1.

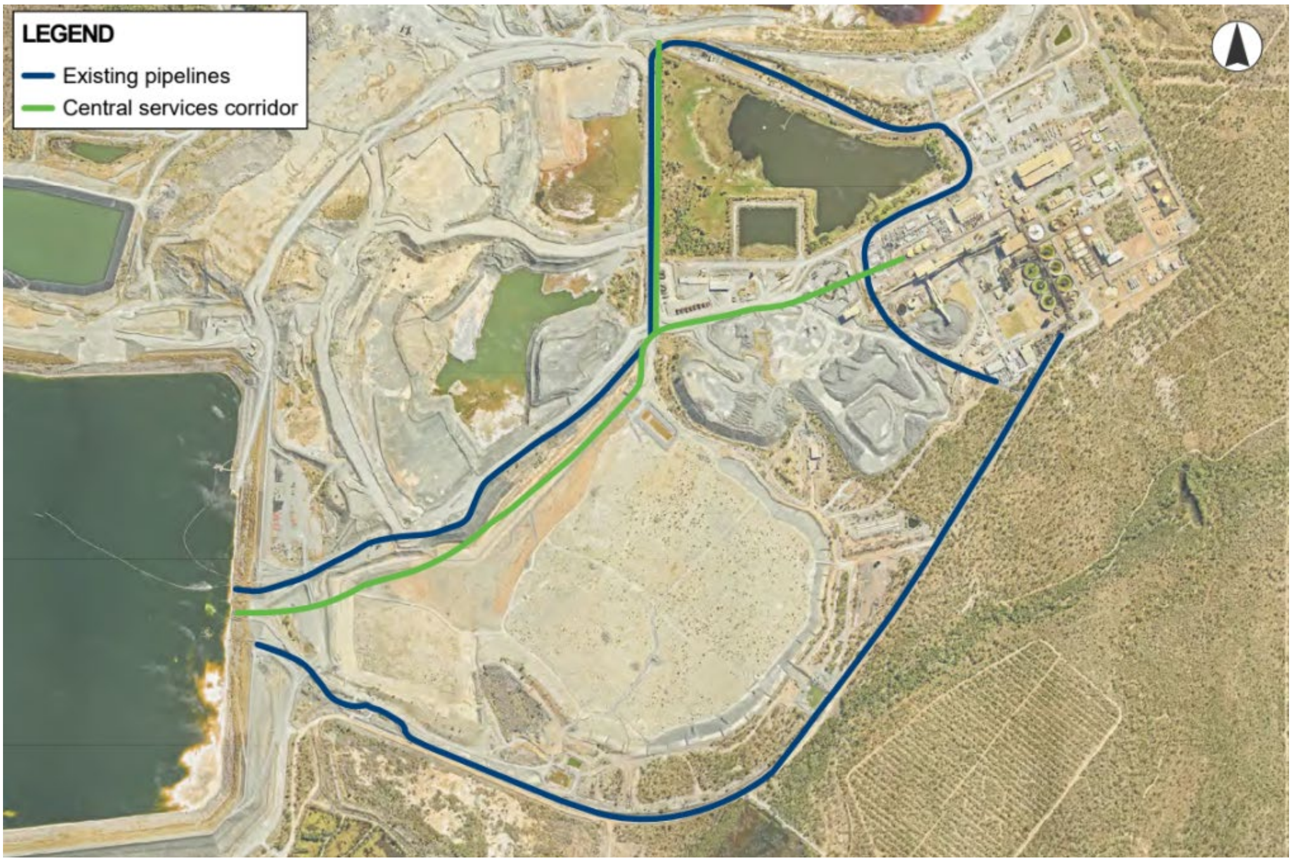


Plate 4-26: Existing pipeline corridors (blue lines) and proposed central services corridor (green line)

The new sections of the corridor will be designed to provide secondary containment for the process water lines planned to run in the corridor, in a similar manner to the current Corridor Creek pipeline corridor. The surface of the corridor will be compacted to reduce infiltration, and the corridor will be isolated from the surrounding landform by windrows. Sumps at low points along the corridor will direct surface run off from rain events to the pond water inventory. Water collected in these sumps will be monitored for EC to detect process water leaks.

Some bulk earthworks will be required to get the corridor to be as close as final landform as possible. The connection between the central services corridor and Pit 3 will run as per the current RWD to Pit 3 corridor. Existing pipe-in-pipe pipework in this section will continue to be used, rather than constructing a new corridor.

ERA intend to commence construction of the central services corridor in 2024. Approval to pass process water through the relocated corridor will be the subject of a separate approvals application.

The corridor will be decommissioned in its entirety once process water storage in the RWD or RP6 is no longer required. Pipeline materials removed from the corridor will be disposed of with the demolition materials arising from removal of the process water treatment plants. Contaminated surface material within the corridor will be scraped and disposed into RP2.

4.5 Ranger Water Dam Deconstruction

Activity is the subject of a separate application

The RWD, which was known as the Tailings Storage Facility (TSF) up until all tailings had been removed from the facility, was commissioned in 1980, forming an approximate square with sides of about 1 km in length and a crest level of +60.5 mRL. From 1980 to 1996, mill tailings were placed in the TSF. Following that period, regulatory approvals allowed mill tailings to be deposited in the mined-out Pit 1. Once Pit 1 reached its maximum tailings level in late 2008, mill tailings were re-directed back to the TSF until the mined-out Pit 3 became available for tailings storage in 2016.

Whilst recognising that the name change from TSF to RWD only occurred recently, all reference to the facility in this section uses the term RWD.

4.5.1 Tailings Transfer and Process Water Return

Mill tailings deposition into the RWD ceased in 2016, when the underfill in Pit 3 had been installed and the pit was available to receive tailings directly. The tailings transfer process involved two dredges, the 'Jabiru' (Plate 4-27) and the 'Brolga I', supported by maintenance crafts. The maximum dredging depths for the Jabiru and Brolga were 10 m and 14 m, respectively. Dredged tailings were transferred to Pit 3 through dedicated overland pipelines and deposited subaqueously and subaerially. To maintain the water levels during dredging, the process water stored within the tailings in Pit 3 was continuously pumped back to the RWD. Bulk dredging and transfer of tailings from the RWD to Pit 3 was completed in February 2021.

Plate 4-27: The Jabiru dredge

4.5.2 RWD Wall and Floor Cleaning

ERA implemented a wall and floor cleaning program to remove the remnant tailings within the RWD for placement into Pit 3. A BPT assessment determined that trucking the remnant tailings to a tip head in Pit 3 was the most suitable approach for disposal into the pit (see Appendix 4.2 for details). Earth moving equipment was employed to scrape and remove tailings from the internal walls, transferring them onto the RWD floor. Rainfall also contributed to the cleaning process by washing tailings down the slope. Cleaning of the RWD floor began in early 2021 and was completed in 2022.

4.5.3 Current Use of the RWD

The RWD currently stores process water. It undergoes annual inspections conducted by independent engineers in accordance with the Ranger Authorisation. Data collected from these inspections is reported to regulators to ensure the RWD meets design and operational standards. The RWD operates in line with the guidelines set by the Australian National Committee on Large Dams (ANCOLD, 2019) and the International Commission of Large Dams for tailings dams design, construction, operation and closure. All of ERA's tailings and process water storage facilities, including the RWD, adhere to the Rio Tinto Standard D5: *Management of Tailings and Water Facilities*, which covers development, operation, closure and post-closure aspects. The free process water inventory held in the RWD is progressively reduced through passive evaporation and water treatment by the Brine Concentrator.

4.5.4 Planned Future Activities

All of the activities described in this section will be subject to a separate application, the RWD deconstruction application.

4.5.4.1 RWD Groundwater Plume

Gradual seepage from the RWD since its construction has led to the formation of a groundwater contamination plume. The plume's extent and behaviour have been investigated for many years and documented by Weaver and others (2010) (see Chapter 7).

These investigations will inform a proposal for a suitable engineering solution to address the groundwater plume. A BPT assessment of potential remediation options for this plume is underway and will be incorporated into the RWD deconstruction application and future updates of the MCP.

4.5.4.2 RWD subfloor material management

The RWD subfloor underwent a BPT assessment to determine the best approach for managing contamination and the risks of solute egress. In June 2020, ERA applied to the MTC to adopt the preferred option from the BPT assessment, which was to leave the subfloor material in place as this option would reduce peak magnesium loads entering Magala Creek, and this approval was granted in August 2020 (see Appendix 4.2 for details).

The above mentioned BPT for RWD plume management is also investigating measures to minimise solute transport from the RWD subfloor.

4.5.4.3 RWD decommissioning

The decommissioning and deconstruction of the RWD is several years away (refer Figure 4-1). Further studies are occurring to determine the optimal method and timing for process and pond water management on site. The following describes the current base case for deconstructing the RWD, which may change as a result of these studies.

The RWD will continue to store process water until the free process water inventory draws down to ~35 ML. The inventory will then be pumped from the RWD into a ~35 ML process water storage tank.

Following the removal of all water, the RWD will be deconstructed. The RWD deconstruction plan involves reducing the walls to final landform level. The material found within the RWD walls does not contain mineralised material, so the wall material is considered suitable for use in creating the final landform. This will be confirmed with further discrimination or testing. Clay from the walls may be used to create a clay cap on the floor of the RWD, which would reduce water ingress into the existing plume below the RWD, but this option is still under investigation as part of the above-mentioned BPT.

The material in the wall will be mined using standard material movement practices with dozers, trucks and excavators. The RWD deconstruction material quantities are shown in Table 4-5.

Table 4-5: RWD deconstruction material quantities

RWD Segment	Material Movement	Brief Description
RWD East	Excavation and distribution to final landform levels: 835,121 m^3 Final landform surface area: 24.99 ha	Deconstruction of the eastern RWD walls. Utilise material to shape final landform surface in the eastern area. Excess material taken to other site fill areas.
RWD West	Excavation and distribution to final landform levels: 2,440,743 m^3 Final landform surface area: 43.07 ha	Deconstruction of the western RWD walls. Utilise material to shape final landform surface in the western area. Excess material taken to other site fill areas.
RWD South	Excavation and distribution to final landform levels: 2,881,980 m^3 Final landform surface area: 98.15 ha	Deconstruction of the southern RWD walls. Utilise material to shape final landform surface in the southern area. Excess material taken to other site fill areas.
RWD North	Excavation and distribution to final landform levels: 1,463,850 m^3 Excavation and distribution to Pit 3: 1,086,537 m^3 Final landform surface area: 31.19 ha	Deconstruction of the northern RWD walls. Utilise material to shape final landform surface in the northern area. Excess material taken to site fill areas.

The final surface of the RWD will be shaped to form the final landform. The RWD topography forms a primary drainage flow path running south to north along the historic Coonjimba Creek. Landform and erosion controls for the RWD are the subject of current studies and will be included in the RWD deconstruction application and subsequent updates of the MCP.

4.5.4.4 Removal of HV power supply and telemetry

Seeking approval for this activity via the MCP

High Voltage (HV) power distribution lines (mostly aerial but some buried) will start to be decommissioned and removed. This will occur progressively, with HV power in the area of the processing plant being retained for some time for the Brine Concentrator, Brine Squeezer and Water Treatment Plants. The removal of the HV line to the RWD including the HV spur line to the Brockman Bore will be one of the supply lines targeted for early removal and will necessitate the conversion of the Brockman borefield power supply to a diesel-powered generator or similar.

4.6 Ranger 3 Deeps Decline

Approval to decommission and backfill Ranger 3 Deeps (R3 Deeps) (Plate 4-28) was granted in April 2019.

Plate 4-28: R3 Deeps portal and offices

The R3 Deeps exploration decline was a precursor to the proposed R3 Deeps underground mine. The 2,710 m long decline was constructed between May 2012 and October 2014 reaching a depth of approximately 430 m below the surface at its deepest point. R3 Deeps was developed to enable underground exploration and in-fill drilling activities on the RPA, east of Pit 3 (Plate 4-29). The purpose of this exploration program was to increase uranium orebody knowledge and determine if future underground mining would be both possible and cost effective.

After commissioning, the decision was made to abandon the underground mining project and the R3 Deeps exploration decline was subsequently placed into care and maintenance in early 2015.

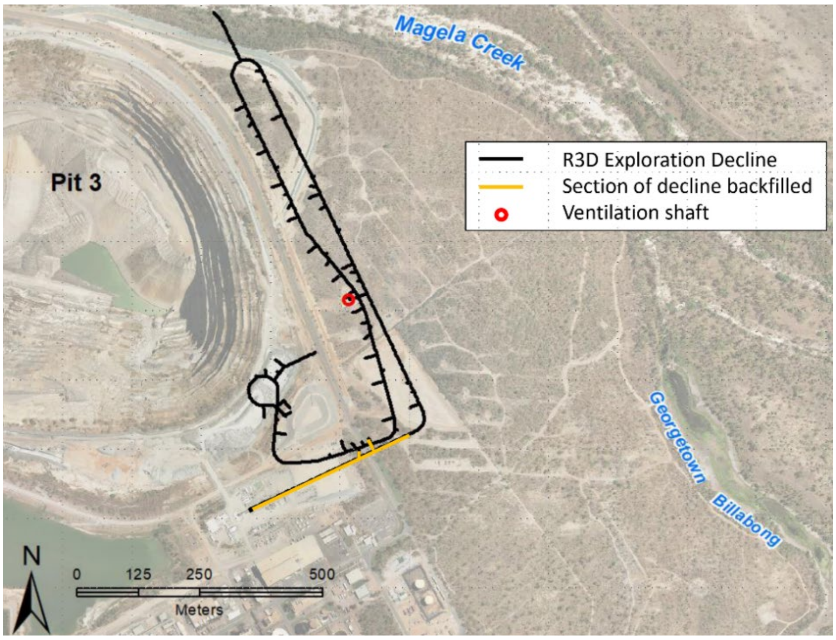


Plate 4-29: Plan view of the R3 Deeps decline

An application for the staged transition to the final closure of the R3 Deeps decline was submitted to the MTC in July 2018 and approved in April 2019. This application outlined the decommissioning strategy, environmental considerations, outcomes of a BPT assessment, and a risk assessment.

The ventilation shaft access would be backfilled with waste rock to form a plug (proposed to be undertaken in the 2018 works program). Next, the shaft would be backfilled with 2,025 m^3 crushed waste rock up to around the weathered zone (20 m below the ground surface). A 125 m^3 cement-rockfill (CRF) plug would be placed above the crushed rock from 20 m through to 10 m below the ground surface. Finally, the top 10 m would be filled with crushed rock.

In 2021, ERA initiated the final closure and backfill program. The decline was inspected, and a ventilation system was installed (Plate 4-30). Backfilling commenced on 22 June 2021 and was completed on 7 August 2021. Backfilling in the decline involved placing 13,970 m^3 of waste rock as tight as practicable.

The ventilation shaft was backfilled and plugged to avoid settlement. The 11 m long CRF plug was installed closer to the surface than originally stipulated, allowing observation of cement / rockfill mixing progress. A variation to the existing approval to account for this difference has been lodged. The steel tunnel was dismantled, and access control features were removed. Works to permanently close the R3 Deeps exploration decline and ventilation shaft were successfully completed in mid-2021.

Plate 4-30: The end of the steel multiplate tunnel (June 2022)

The area above the R3 Deeps ventilation shaft is enclosed by a security fence, and it includes a 40 m by 40 m filled pad. As a safety measure, a pile of coarse rockfill (approximately 1.2 m high) has been placed on top of the ventilation shaft in case any movement were to occur (Plate 4-31). The rockfill mound above the ventilation shaft undergoes annual inspections, including visual assessments and photographic records to identify any potential ground movements even though they are considered unlikely.

Plate 4-31: Coarse rockfill placed on top of the backfilled R3 Deeps ventilation shaft

The steel multi-plate tunnel will be dismantled/cut down to final ground level. The portal closure works will form part of the Phase 1 demolition works described above.

Signage, fencing and other minor installations associated with controlling access to the vent shaft and portal area will be removed during demolition works. Contouring to final landform and revegetation of the R3 Deeps area will form part of the broader final landform and revegetation schedule. This includes the portal area and the removal of the course rock at the top of the ventilation shaft.

4.7 Trial Landform

4.7.1 Establishment of Trial Landform

An 8 ha Trial Landform (TLF) constructed in 2008/2009 and located near the north west corner of the RWD was installed to provide information about revegetating waste rock (Plate 4-32).

Plate 4-32: Trial landform (2023)

The TLF allowed for the testing of various strategies for landform design and ecosystem establishment. This included experimenting with different types of surface substrates, varying depths of mixed materials over the waste rock layer, different planting methods, and various irrigation approaches (Figure 4-17 adapted from Pugh *et al*., 2008).

Three materials were used to construct the TLF: primary waste rock, weathered waste rock, and lateritic material. The primary material (1P) is composed of unweathered host rock, primarily consisting of altered quartz-feldspar schists, with some cherts and carbonaceous materials. The weathered material is made up of friable rock, often quartz-feldspar schist with altered mineral composition but generally low clay content. Lateritic material, on the other hand, is a near-surface, highly weathered, and occasionally reconsolidated material, typically rich in iron and aluminium clays.

The TLF examined two surface substrates: waste rock alone and a blend of waste rock with 30% lateritic material. To facilitate the different treatments, the TLF was divided into several areas. Areas 1A and 1B were constructed using a waste rock-only substrate. Areas 2A and 3A featured a 5 m thick layer of laterite/waste rock mix over a 1P rock base, ranging from 0 to 2 m in thickness. Areas 2B and 3B had a 2 m thick layer of laterite/waste rock mix over a 1P rock base that was 3 to 5 m thick (Figure 4-17).

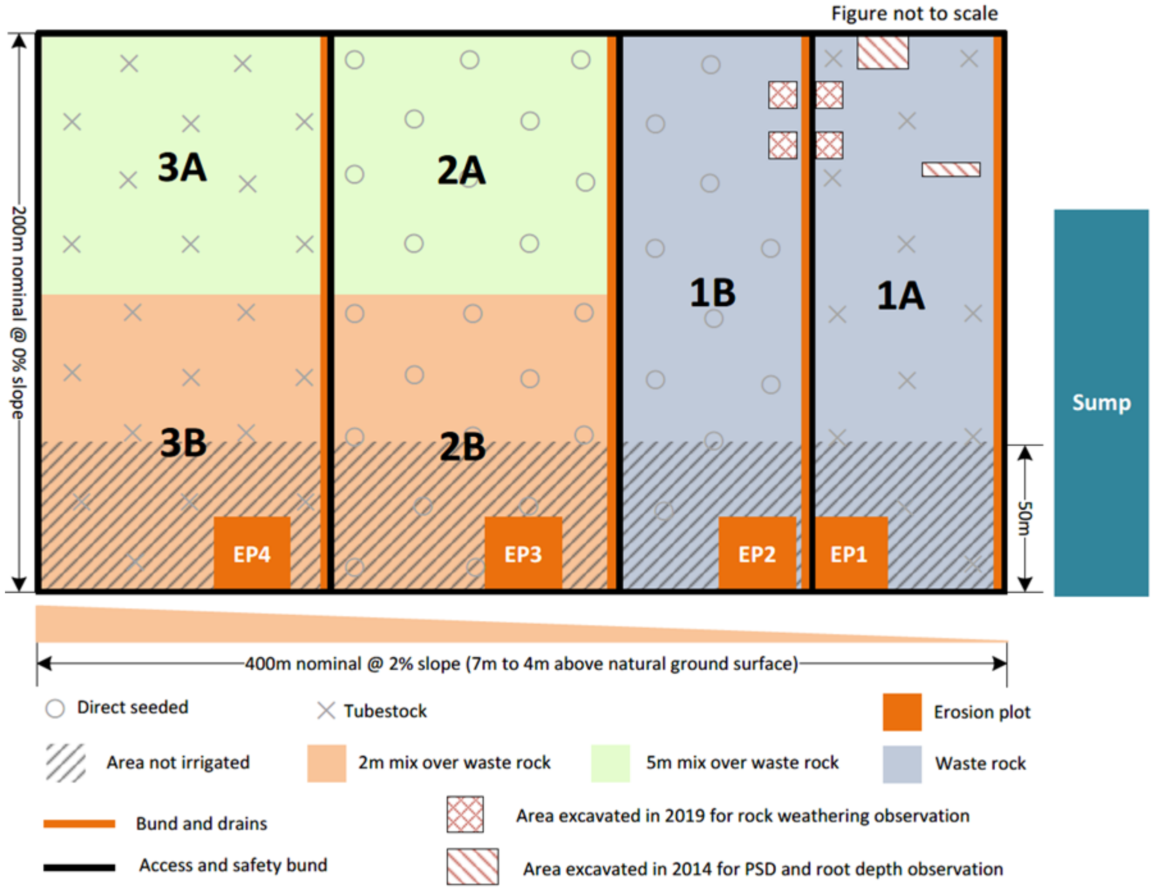


Figure 4-17: Trial landform – treatment design and associated infrastructure

The final landform surface layer will resemble the waste-rock only section of the TLF (Area 1). It will primarily consist of 1P and weathered waste rock, without deliberate mixing of lateritic material. In the TLF's Area 1, construction involved building a base layer approximately 2 m thick using tip-head dumping, followed by the placement of another 2 m thick layer using paddock dumping. This construction method led to the creation of a sub-surface consolidated horizon due to the activity of dozers and dump trucks on the TLF's base layer, beneath the final paddock-dumped layer.

Construction records show that the surface of the TLF's base layer, prior to paddock dumping, contained a relatively high proportion of visible fines compared to the underlying material.

An extensive monitoring system was installed during the TLF's construction to evaluate soil water holding capacity, runoff and infiltration (Shao, 2015). The instrumentation included 66 soil moisture probes, a weather station, and four erosion plots.

The completed TLF stands 4 to 7 m above the original natural ground surface, has a 2% slope and was constructed using 800,000 t of waste rock and lateritic material. The surface was ripped at 2 m intervals down to approximately 0.5 m deep. Vegetation establishment commenced in March 2009 with tubestock planting in Areas 1A and 3; direct seeding was performed in Areas 1B and 2 in July and December 2009, and infill planting was performed in January 2010 and 2011. An area 50 m wide on the front, north east side of the TLF was left unirrigated. The revegetation trial results are discussed in Chapter 9.

The TLF continues to be monitored and provides ongoing and useful information to inform the ecosystem establishment plan for the final landform.

4.7.2 Planned Future Activities

Activity is the subject of a separate approvals application or the FLF application

The incorporation of the TLF into the final landform may necessitate the removal of existing infrastructure and reshaping of its edges. This integration presents a distinct challenge due to several factors. Firstly, there is a preference to avoid disturbing the vegetation on the TLF. Additionally, the elevation of the TLF surface, its proximity to the perimeter of the disturbed area, and the typical criteria for slopes on the final landform collectively would require the removal of a substantial portion of mostly undisturbed vegetation. This disturbance of vegetation was not viewed favourably by Traditional Owners, and alternative landform designs are currently being assessed.

The area of backfill required to blend the rectangular shape of the TLF into the natural topography was proposed to be one of the areas for catchment management trials. The use of this area for catchment management trial work may be revisited once questions around final landform shape in the area have been resolved. Appropriate weed and fire management on the TLF will be implemented as necessary.

4.8 Final Landform

All of the activities described in this section will be the subject of a separate standalone application – the FLF application

4.8.1 Final Landform Design Principles

The constructed final landform area will be about 800 ha (Figure 4-18). The design of the final landform has been developed with the aim of producing a landform with similar indices of erosion and runoff distribution to the natural landscape.

The first landform design (Final Landform Version 1; FLv1) was based on landform design criteria that included the requirement to have slopes ranging from 0 to 6.5%, a maximum relief of 25 m and profile and plan curvature specifications (Hollingsworth and Lowry, 2005). Following conceptual design, each version of the final landform is subjected to landform evolution modelling (see Chapter 6). The most recent update to the final landform design is FLv7. This modelling assesses the geomorphic stability of the final landform over timeframes ranging from decades to millennia. Each iteration of the final landform design incorporates improvements derived from the analysis of the preceding version. These enhancements aim to increase landform stability, minimise erosion and gully formation, optimise rehabilitation success, and provide a surface that is easily traversed on foot.

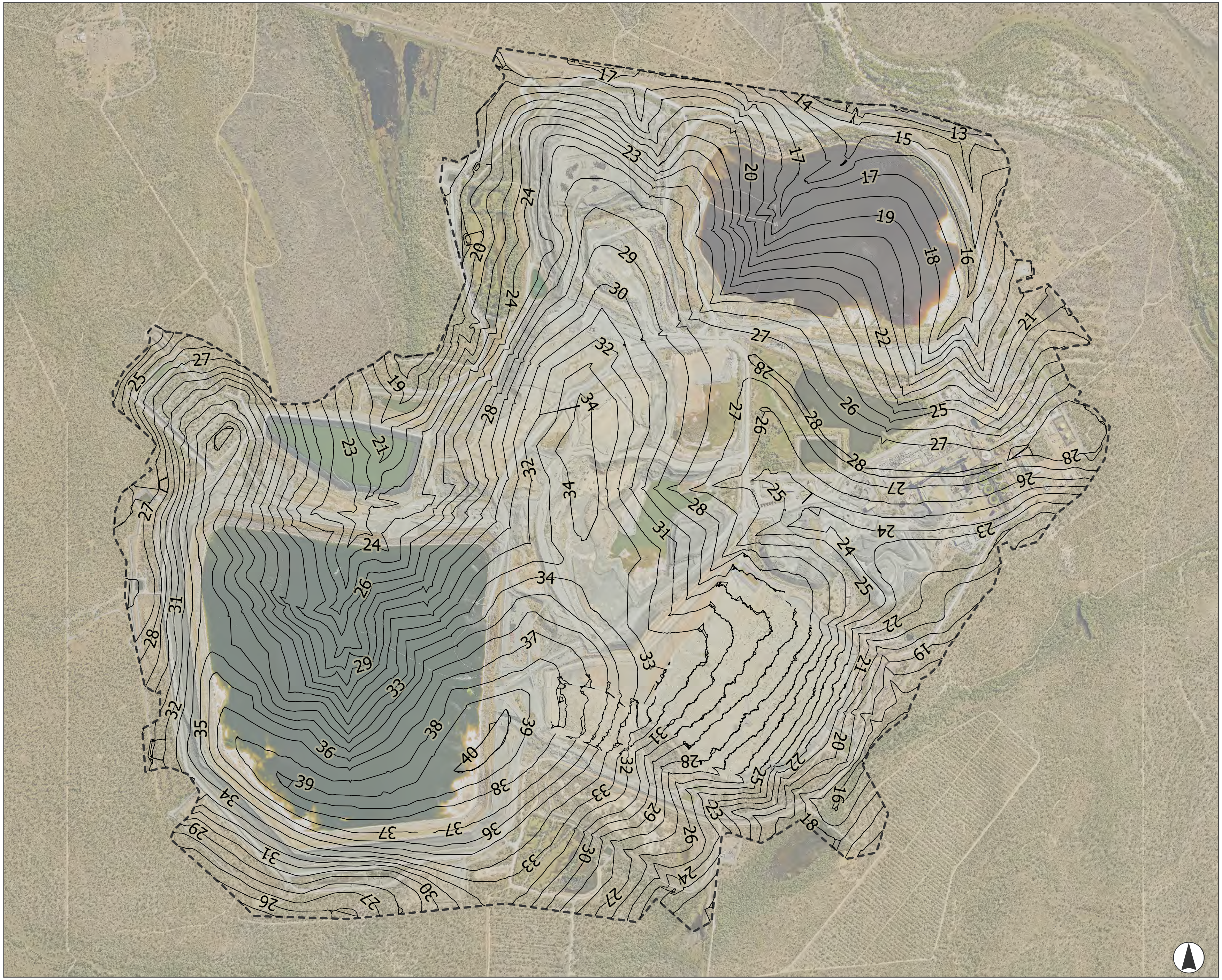


FIGURE 4-18

Final Landform v7 Topography

LEGEND

- Final Landform V7 boundary
- Final Landform v7 contours (1m)

0 250 500

Metres

Scale 1:19,548 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

4.8.2 Material Discrimination and Placement

During active mining operations, the extracted material was transported by truck and passed beneath a radiometric discriminator. The device uses scintillometer heads to measure the gamma particle emissions of each load. The extracted material was categorised into different grade classes. Grade class 1 material is categorised as non-mineralised rock (<0.02% U^3O^8), whereas grade class 2 and above materials are categorised as mineralised material (> 0.02% U^3O^8). As such, 0.02% was the 'cut-off grade' for the operation. The discriminator has a sensitivity/precision of +/-50% at 0.02% U^3O^8, allowing it to detect materials categorised as grade class 2 or above. Material was then allocated to a defined stockpile location based on this grade classification. About 17% of all material moved during the initial placement into stockpiles was discriminated using this method.

Further to the discrimination of truck loads during mining operations, ERA conducted drilling and analysis of core samples from the stockpiles to improve the understanding of grade class and inform the stockpile block model.

This assessment was originally undertaken to inform a heap leach feasibility study. In total, 430 drill holes for a combined 20,917 drill metres were sampled (gamma logged and chemically assayed at 1 m intervals). This has provided a robust understanding of the grade class of material within the stockpiles and has been incorporated into the bulk material movement model. Table 4-6 lists the grade classes, the quantity of each class and the proposed use.

Table 4-6: Waste rock material types incorporated into the model

Class	U^3O^8 content	Quantity (dry Mt)	Volume (M m^3)	Proposed Use
Low 1s – Fresh[1]	<0.007%	35.8	13.4	Preferred in top layers of backfill and erosion control.
Low 1s – Weathered[1]	<0.007%	2.7	1.8	Preferred in top layers of backfill, although less preferred to Low 1s due to higher erosion potential.
Hi 1s – Fresh[1]	>0.007 - <0.02%	36.1	18.4	Preferred destination is at least 2 m below surface.
Low 2s	>0.02 - <0.06%	25.5	13.4	Cannot be above permanent water table.
High 2s - Fresh	>0.06 - <0.08%	2.2	1.1	Cannot be above permanent water table.
Hi 2s - Weathered	>0.06 - <0.08%	0.6	0.4	Cannot be above permanent water table.
3s and up	>0.08%	0.4	0.2	Cannot be above permanent water table.
Total		**103.3**	**48.7**	There is about 1 Mt of rehandle, which brings total material movement to 104.3 Mt / 49.7 M m^3.

[1] – note that the discriminator sensitivity/precision is 0.02% with a minimum accuracy of +/- 50% at the 0.02% uranium level, and as such the volumes of the three 1s material classes is an estimate from the BMM model.

It is important to note that 33.6 M m^3 (or 69%) of the total 48.7 M m^3 subject to bulk material movement is grade class 1, and 15.1 M m^3 (or 31%) is grade 2 or higher. As discussed above, the volume of Pit 3 between the tailings surface and the conservative long-term average water level (+8 mRL) is 20 M m^3. As such, all grade 2s and above material as well as all the demolition and contaminated material (~455,000 m^3) planned for disposal into Pit 3 can be placed below the conservative long-term average water level.

As the material is loaded into trucks from the source location, the trucks will be required to stop under or nearby a specifically configured radiometric discriminator. ERA maintains procedures for fixed and mobile discriminators, including their calibration. This will occur at an average rate of 1 in 50 truckloads. Regular manual assessment of radiation levels will also be undertaken during the stockpile removal process to test the accuracy of the stockpile block model and ascertain if higher or lower levels of radiation are detected in isolated pockets in the stockpiles.

Material movements required to create the final landform are determined by comparing the current landform (historic material movements and original topography where relevant) to the final landform (including voids such as Pit 3 and RP2), and sequencing 'lots or stages' of material based on uranium grade (which may also correlate with sulfide content). Figure 4-19 illustrates the height difference between current and final landform. This is provided for context only and will be further refined for the FLF application. The mine site is subdivided into smaller areas (called stages) to allow the varying mineral grade in the waste rock stockpiles to be excavated from the source location and placed in the appropriate destination location. Figure 4-20 and Figure 4-21 represent the lots (source and destination locations) respectively.

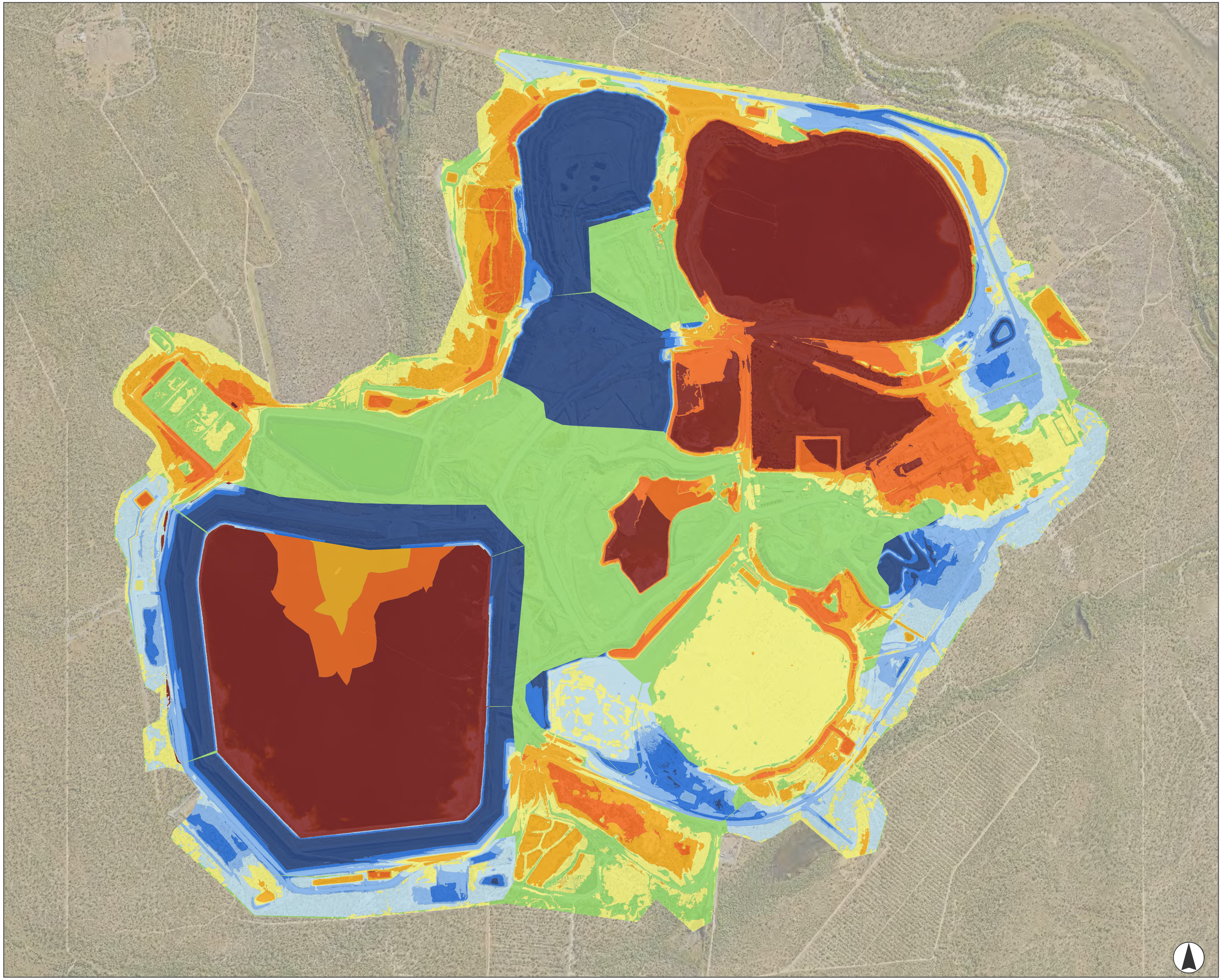


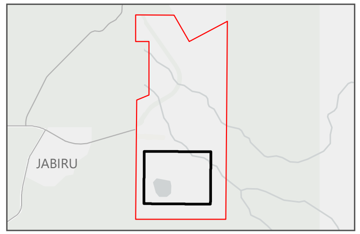
FIGURE 4-19

Difference Between Current and Final Landform (FLv7)

LEGEND

Height difference (existing ground level)

- >6m cut
- 3m - 6m cut
- 1m - 3m cut
- 0m - 1m cut
- Cut-to and then backfilled
- 0m - 1m fill
- 1m - 3m fill
- 3m - 6m fill
- >6m fill



0 250 500
Metres

Scale 1:19,548 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

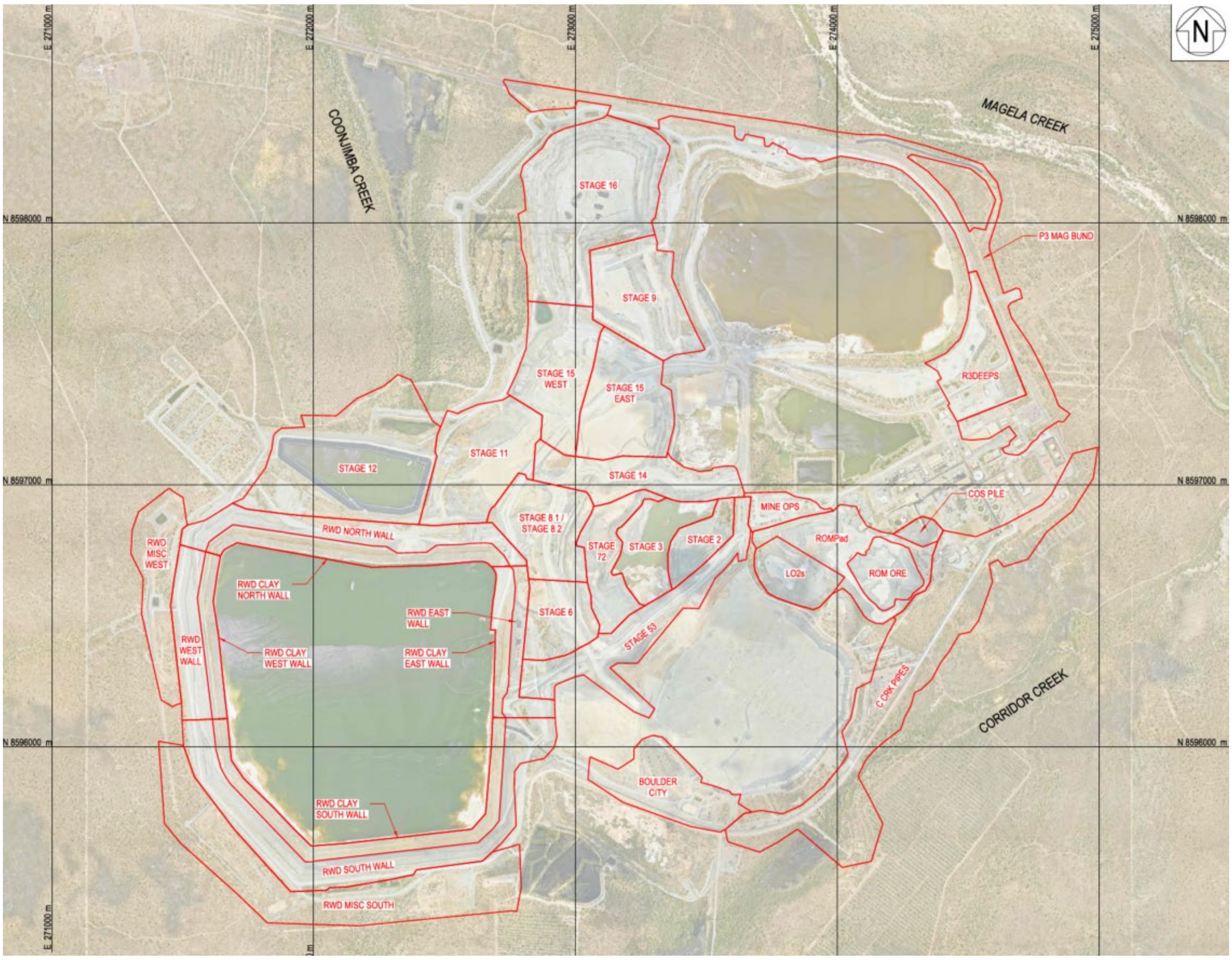


Figure 4-20: Source locations of bulk material movements with place names

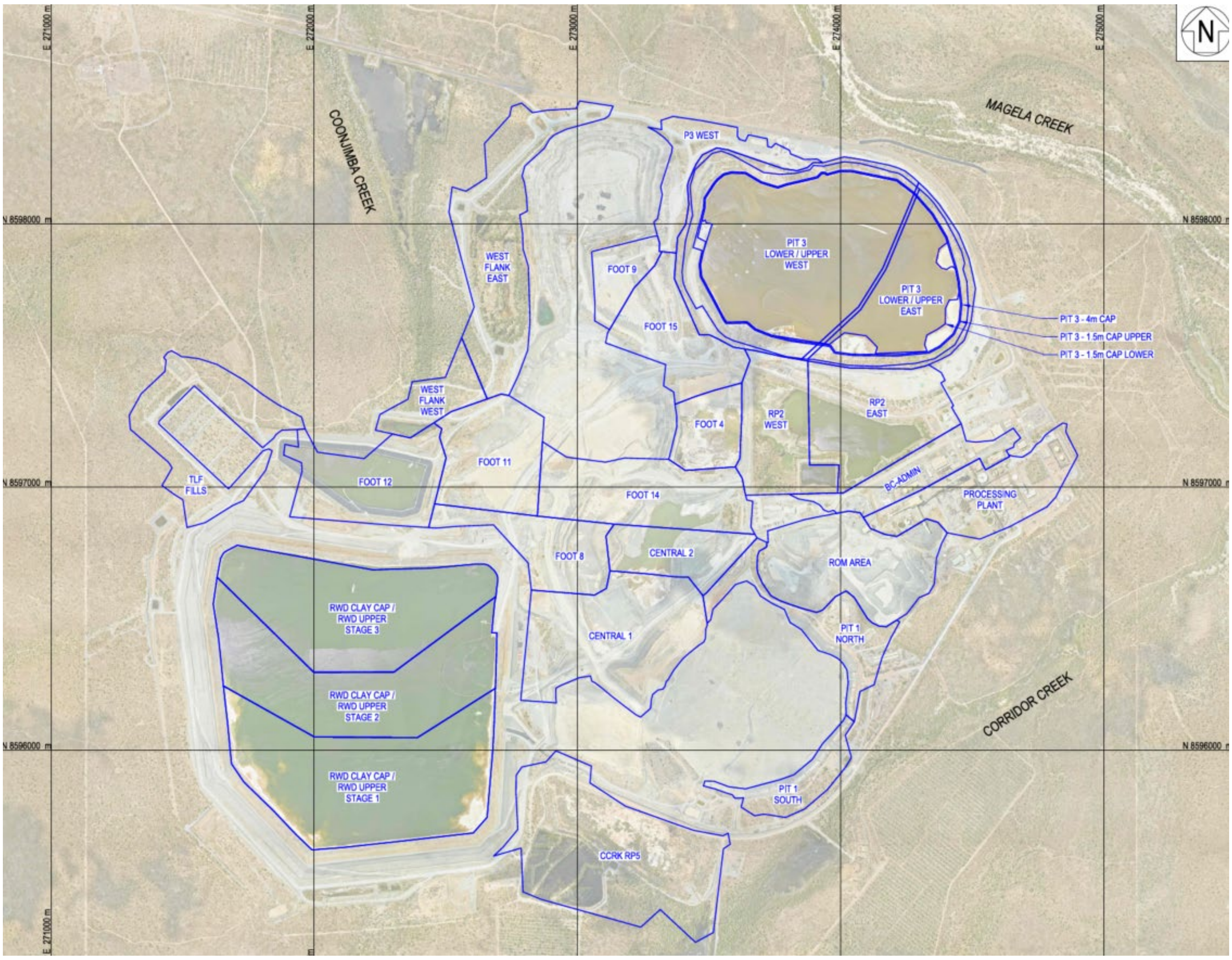


Figure 4-21: Destination locations of bulk material movements with place names

The in-situ density of the material to be moved is estimated from survey data of the material volumes compared with weight data obtained from payload monitors and truck scales. Fresh rock was measured at 2.06 wet tonnes per cubic metre (~2 t/m^3 dry density). Lateritic or highly weathered material is estimated to be 1.5 dry t/m^3. The assumption built into the model is that the current density of all the material to be moved matches its final placement density. Shrink and swell are expected to be overall neutral during bulk backfill.

The volume required for the initial and secondary capping layers in Pit 3 is approximately 3.9 M m^3 and for the remaining bulk backfill of Pit 3 is 25.1 M m^3 (requiring a total volume of 29 M m^3 for Pit 3). Later, the total bulk material volume needed to create the final landform is approximately 48.7 M m^3. This is the estimated quantity accounting for the predicted consolidation of the tailings at the end of the consolidation period.

4.8.3 Surface layer construction

The surface layer of the final landform will be constructed from non-mineralised 1s waste rock to ensure that radiation doses are as low as reasonably achievable (ALARA). The final landform surface layer over mined out pits is planned to be between 4 m and 6 m thick (depending on location) in order to provide sufficient Plant Available Water (PAW) to sustain vegetation (discussed in Chapter 9). As a conservative approach, a layer of at least 6 m will be provided wherever possible (refer Figure 4-19). The surface layer will be constructed in at least two lifts, similar to the TLF. Constructing the layer in two lifts will result in a consolidated layer between lifts, as observed in the TLF, which will be beneficial in cutting off preferential flow paths, thus slowing water percolation and improving water-holding capacity.

The first layer will be constructed using end-tipping methods. This method results in heavy equipment traffic over the layer and the development of a slightly compacted layer. The second (and final) layer will be constructed using paddock dumping methods and dozed using GPS-guided dozers to create the final landform.

The final landform will be constructed to achieve the approved final landform design. Frequent surveying and GPS guidance will enable the intended landform topography to be followed with a high degree of accuracy. Areas that do not align with the final landform design will be discovered by survey during backfilling and will be rectified as operations continue. Tolerances on the final construction compared to design are driven by the size of equipment and rock material being handled, these are likely to be in the order of +/- 0.5 m at drainage boundaries and +/- 1 m elsewhere.

4.8.3.1 Surface Preparation

A variety of surface treatments have been identified by ERA and the application of each will depend upon various factors, including slope and location. The entire TLF was ripped at 2 m intervals along the contours to a depth of approximately 50 cm. Over a decade later, the surface has a similar appearance now to what it did after the ripping. As part of a trial, a similar approach was applied to the Stage 13.1 revegetation area. This resulted in larger boulders catching the grader tynes, leaving deep linear gouges across the surface.

Stakeholder consultation with the NLC and the GAC have indicated that ripping of the landform may impact traversability and should be minimised wherever possible. To address these stakeholder concerns and with lessons learnt from the TLF and Stage 13.1, a different approach was trialled on the surface of Pit 1. A grader blade was used to apply a light scarification (i.e. shallow ‘ripping' using a grader blade with teeth 10 cm deep). Recent inspections suggest that the surface scarification is no longer visible and the surface is easily traversed on foot.

The development of the site ‘*Erosion, Sediment and Water Control Plan’*, in conjunction with lessons learnt from previous ripping and scarification completed at Ranger will be used to inform the final ripping and/or scarification plan included in the FLF application and future MCP iterations.

4.8.3.2 Cut to Only Areas

The construction of the final landform surface will require some areas to be cut down to the designed final landform surface level without subsequent backfill (i.e. cut-to only). Previous surveys of the Stage 13.1 area identified that cut-to only waste rock areas may be more compacted than natural ground for the first 0.6 m. Some areas where the final landform is created by 'cutting to' warrant further consideration. Deep ripping in these locations to assist root penetration during the cover establishment of the revegetation may be necessary. Should this occur, recontouring after the deep ripping may also be required to provide a surface easily traversable on foot.

Further investigation into the characteristics of these areas and the treatment that can be applied to maximise plant performance are planned.

4.8.4 Revegetation of the Final Landform

Seed collection and tubestock propagation

ERA has been working extensively with Kakadu Native Plant Supplies Pty Ltd (KNPS), a locally owned and run Indigenous supplier, to collect seed and provide seedlings for progressive revegetation that has occurred at both Ranger and Jabiluka over the past 17 years. This supplier has extensive expertise in local plants including seed biology, propagation, revegetation, and weed and fire management.

Seed Collection

ERA and KNPS have developed a collaborative process of planning and implementing the seed collection program. Seeds are collected within seed collection zones (confined to the boundaries of Kakadu National Park) as they are well adapted to current conditions on the RPA while still providing sufficient genetic diversity to prevent inbreeding and promote the plants adaptive potential to the waste rock growth medium of the final landform. Area-specific revegetation plans based on the rehabilitation schedule and the most current conceptual reference ecosystems (CRE(s)) determine the tubestock and seed plan. The seed collection plan is underpinned by a wealth of knowledge, research and data, including a comprehensive understanding of native species phenology, seed processing and storage requirements, seed viability and germination testing, and previous nursery experience (see Chapter 9 for details).

KNPS undertake ongoing field reconnaissance (including during other 'on country' activities such as weed and fire management) to continuously build on their knowledge of what looks likely to flower and fruit and when. Following collection, KNPS air-dry and process the seed based on a species-specific approach to optimise viability and longevity (when stored). ERA is accountable for final storage of the delivered seed and maintains the seed management database with all relevant information for each seed lot.

The closure revegetation program is highly influenced by the timing of the rehabilitation schedule, especially the bulk material movement and final landform development. Whilst some tubestock (and therefore seed) is required for research trials and small progressive revegetation areas, most of the planting will occur late in the rehabilitation schedule as areas reach the final landform. Fortunately, most species seed needed for revegetation have sufficient longevity to be collected early and stored until required. Collection of these species has already commenced and is progressing well to be fully stocked before the peak tubestock propagation and planting period commences. A small portion of the species have seed with limited storage life, which either require propagating immediately after collection (termed 'perishable') or within one year of collection (termed 'fresh'). For these species, collections must be timed to optimise seed availability and time from planting.

Tubestock propagation

Tubestock is propagated in the ERA Nursery. The current annual capacity of the nursery is about 300,000 seedlings (being approximately 100,000 tubestock at any one time and if scheduling requires year round planting then it may be feasible to produce three rounds of propagation annually), which is sufficient for the staged revegetation requirements. Tubestock is propagated to meet an agreed specification to ensure that seedlings have the best chance of survival after planting. The ERA tubestock specification is based on best practice (NGIA 2018; Standards Australia 2018), field trials, observations and local knowledge, and includes criteria relating to plant form, health, size and rooting characteristics.

Propagation of tubestock for any given area of revegetation commences approximately two to six months before the target planting date, depending on the expected growth rate of the species and the growing season (e.g. some species germinate and grow slower in the cooler dryer months). If any particular species does not have seed available for propagation (e.g. species with perishable seed or due to seasonal impacts to seed collection), they can be introduced later during the infill planting or direct seeding programs. It is highly unlikely that these will ever be the dominant *Eucalyptus, Corymbia* or *Acacia* species due to their long seed storage times and collection availability.

Irrigation installation and operation

On the waste rock final landform, newly planted seedlings will be irrigated to ensure optimal plant survival rates across all species during the dry season, and during wet seasons, which can have erratic rainfall. Irrigation infrastructure will be installed after the construction of the final landform is complete and prior to pre-emergent herbicide application and tubestock planting. Irrigation will generally be applied for a maximum of six months, depending on the season of planting and prevailing weather conditions.

Seedling condition will be monitored as irrigation is adjusted to ensure the hardening off is not too sudden or extreme. In the last few months of irrigation once seedlings have properly settled (e.g. post-planting mortality rate has stabilised, plants are showing signs of growth etc.), the irrigation will be significantly reduced so that the soil profile is saturated but allowed to dry before further irrigation. Specific irrigation amounts applied to each area will depend on the season of planting, substrate type, temperatures, wind, evaporation, infiltration and rainfall.

Monitoring and maintenance of the irrigation system during plant establishment is imperative. Any damage or malfunctioning of the irrigation equipment must be recognised early to minimise impact upon vegetation. The use of pressure-based alarms and a log recording the operation of each panel will ensure that any incidents are recognised and rectified.

Pre-emergent herbicide application

Substrates used to create the final landform will be carefully managed during construction to prevent site contamination with weeds or their seeds. Furthermore, a weed control buffer zone (approximately 200 m wide) around the revegetation sites will be established to assist preventing weed incursion into revegetation areas. The revegetation areas will receive a blanket spray of a pre-emergent herbicide four weeks prior to planting to limit the presence of weeds that may threaten young establishing seedlings.

Tubestock planting

Once propagated, tubestock of different species will be arranged into each planting tray to reflect the planned species distribution in the field. The revegetation area will be irrigated prior to planting to moisten the substrate and reduce plant stress. Controlled release fertiliser and water crystals will be applied to the base of each planting hole. Plants in biodegradable pots can be placed directly into the hole, whilst plants in plastic pots shall be removed from the pot and carefully placed into the hole to minimise loss of any loose potting mix that is not held together by the plant roots. The holes will then be backfilled with the surrounding loosened substrate, focusing on fines and removing large rocks.

4.9 Erosion and Sediment Control

To complete closure, all final landform surfaces across the site will need to be able to passively shed water into the surrounding environment, without any collection and diversion infrastructure. During mine operations, the water management plan was for the capture of most of the rainwater falling on site. It was directed to storages then passed through the Water Treatment Plants. Once the creation of the final landform is complete, the goal is that water will not be captured, it will run off in the same manner as what occurs in the surrounding natural landform.

4.9.1 Sediment Basins

Sediment basins are being investigated as an option to manage sediment in the early years of creating the final landform. The basins may be created in sequence with the BMM works scheduled for their source sub-catchment area. These basins may be located at the end of the constructed drainage lines of the final landform to capture transported sediment. An early concept is shown in Figure 4-22, noting that this concept is under assessment and as such will change.

The basins may be formed prior to the commencement of the revegetation process and would remain in place until agreed release water quality criteria can be demonstrated. It is noted that further design work is occurring on the sediment basins, the outcomes of which will be included in the FLF application and future iterations of the MCP.

4.9.2 Rock Check Dams

The placement of rock check dams within the purposefully designed drainage paths on the final landform will be used to reduce erosion and scour potential. Rock check dams will be positioned in steeper regions of the landform where overland flow rates are highest, reducing the flow velocity of water and causing the deposition of heavier suspended sediments. Whilst rock check dams will assist in the removal of heavier sediments, it is noted that they are not designed to be a primary sediment control structure (i.e. they are designed to overtop). The rock check dams will be installed progressively as the final landform is created, prior to the revegetation activities. Once the planted tubestock have reached suitable size to resist surface water runoff flow, the rock check dams may be removed. This would be dependent on the time, quality and density of the revegetation establishment in each managed drainage line.

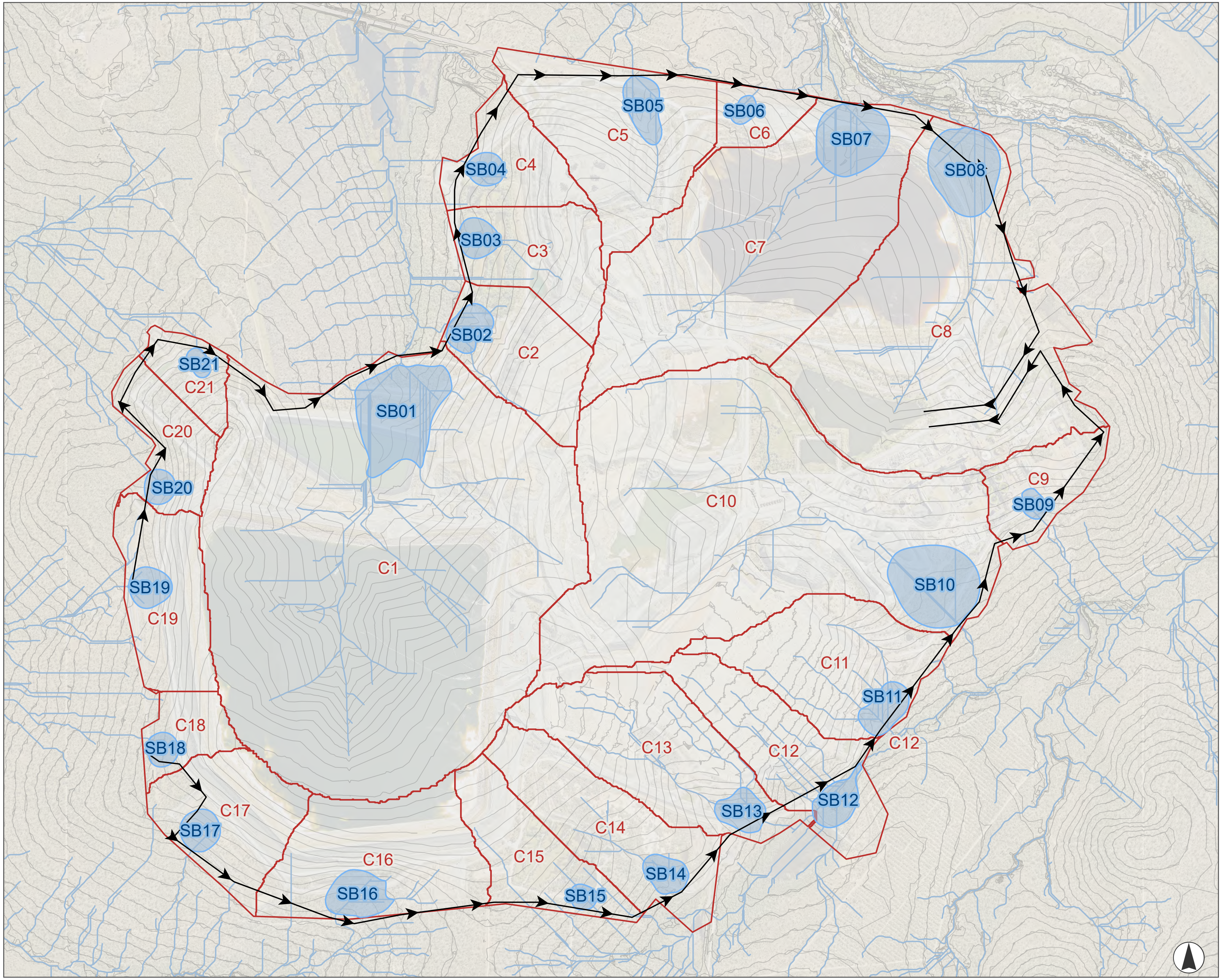
4.9.3 Access Tracks

Access tracks will be located across the final landform area to provide access for equipment and teams undertaking:

- irrigation installation, operation and removal;
- tubestock planting;
- long term monitoring;
- weed control activities;
- minor revegetation maintenance works (e.g. infill planting, secondary introductions); and
- site perimeter access for fire and weed control.

The access tracks will be constructed along final landform contours to reduce the flow and velocity of surface water runoff. Erosion and sediment control structures, and structures that promote the passage of stormwater from one side of the track to the other, will, where necessary, be incorporated into the construction of these tracks. The tracks need to be suitable for four-wheel drive access and traversable in both wet and dry conditions. Graders and excavators will be used to undertake minor earthworks to ensure the tracks can be safely passed and are not contributing excessive sediment laden runoff.

ERA will maintain access tracks throughout the monitoring and maintenance period. Before site relinquishment, ERA will liaise with relevant stakeholders (e.g. Traditional Owners and the Commonwealth Government), to agree if any access tracks are to remain for ease of movement (Traditional Owners) and ongoing access for monitoring activities (Commonwealth Government).



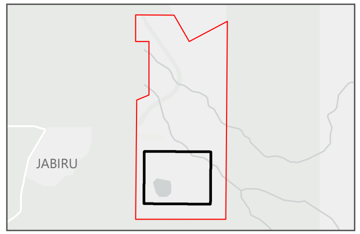
Energy Resources Of Australia

FIGURE 4-22

Sediment Basin and Catchment Arrangement

LEGEND

- Ranger Project Area
- Proposed sediment basin
- Sediment basin catchment
- Pipeline corridor
- Drainage lines
- Contour (1m)



0 250 500

Metres

Scale 1:19,534 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

5 STRUCTURE AND CONTENT OF CHAPTER 6 TO CHAPTER 11

Photo: Dewatering Pit 3 (October, 2023) in preparation for capping and backfill

ERA's focus is to create a positive legacy through world class closure and rehabilitation. There are many and wide-ranging elements to this vision. Of most relevance to this MCP is that ERA can demonstrate that each of the ERs has been achieved or is on a trajectory to being achieved.

This chapter describes the consistent approach that has been adopted in Chapter 6 to Chapter 11 of the MCP to clearly and transparently describe the progress towards achieving each ER, and the activities that are yet to be completed in order to achieve each ER. Each chapter consolidates the relevant information pertaining to one of the six Ranger themes, as follows:

- Landform – Chapter 6;
- Water and Sediment – Chapter 7;
- Soils – Chapter 8;
- Ecosystems – Chapter 9;
- Radiation – Chapter 10; and
- Cultural – Chapter 11.

5.1 Progress Status

The Ranger project is complex. It has many overlapping and interconnected aspects, and scientific questions about potential environmental impacts, that have been studied for decades. There are several ways that this information, and the progress towards achieving ERs, could be presented in the MCP. The approach adopted is to present the information under the following topics:

- ***Closure Criteria Approved***: this section in each chapter discusses whether the closure criteria have been approved by the Commonwealth Minister as part of a previous MCP or whether there is further work required. The latest MCP that was approved was 2020. Those closure criteria that were approved in that MCP are identified within this section of each chapter. Closure criteria that were approved by the 2020 MCP but have proposed changes considering subsequent studies and information are also identified within this section of each chapter, as are the closure criteria yet to be approved.
- ***Relevant Studies / Knowledge Base***: this section in each chapter summarises the studies that have been completed or are being undertaken to demonstrate that the ERs can be achieved. The sections refer to Key Knowledge Needs (KKNs), a complete list of which is provided in Appendix 5.1, and future work that is required to provide multiple lines of evidence that an ER will be achieved or on a trajectory to being achieved.
- ***Bow-tie diagrams***: this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. Depending on the theme, there may be multiple bow-ties, representing the relevant aspects being measured for that theme. Within each bow-tie diagram (see Section 5.4 for further details):
    - Threats to achieving the ER and the preventative controls that have or will be implemented to manage these threats are represented on the left side of the diagram.
    - Corrective actions that will be implemented if the monitoring program identifies that the ER would not be achieved and the consequences and residual risk of this are presented on the right side. The residual risk ratings reflect the current understanding and effectiveness of the controls and corrective actions. Class IV and Class III risks exceed ERA's risk acceptance threshold and will be the subject of further work to reduce uncertainty, strengthen the preventative controls, and/or strengthen the corrective actions.
- ***Preventative Controls***: how well do we understand and can demonstrate the effectiveness of the controls that will be put in place between now and the creation of the final landform, or shortly thereafter, to ensure that ERs can be achieved or are on the desired trajectory to being achieved. Further discussion on this topic is provided below (Section 5.2).
- ***Monitoring Program***: this section describes the monitoring program that will be implemented to confirm the accuracy of predictions towards the achievement of ERs or to detect an undesirable outcome and thus a deviated trajectory. This section in each chapter presents the monitoring program proposed for the ER theme.

- ***Corrective Actions***: this section describes how well we understand and can demonstrate the effectiveness of corrective actions that if implemented would recover a deviated trajectory to a desired trajectory within an acceptable timeframe, and would avoid unacceptable health, environmental and cultural impacts. Further discussion on this topic is provided below (Section 5.3).
- ***Trigger, Action, Response Plan (TARP)***: this is a tool that brings together much of the information from the above topics. It provides clear direction on who does what and when if the early warning triggers of the monitoring program detect movement away from the desired trajectory. The TARPs provided in this 2023 MCP are a work in progress and will continue to be refined and strengthened through future iterations of the MCP.
- ***Future work***: each of the above sections may identify areas in which future work is required. This work may be a study that is required to fill an existing knowledge gap such as an incomplete KKN, or it may be further engineering to strengthen the effectiveness of a preventative control or corrective action. This last topic in each section presents a summary of the future work that may occur to address these matters and improve the confidence of achieving the ERs. The future work presented in Chapter 6 to Chapter 11 is based on our current understanding. These studies may change or be further refined, removed or added to depending on the outcomes of the studies as they evolve.

A simple graphical representation, called a spider web diagram, has been developed to illustrate the progress of the main topics listed above (see Figure 5-1 for the spider web diagram from the 'Soils' theme as an example). This is ERA's subjective assessment of per cent complete against each topic and is provided as an indication of progress and focus areas for future work. A diagram is provided for each of the six ER themes. The diagram will be updated in each annual MCP, with the previous year's web also shown, to highlight the areas in which progress has been made from one year to the next.

Figure 5-1: Spider web diagram from the Soils theme showing subjective percentage complete

5.2 Preventative Controls

These controls are typically design elements of the project that when successfully executed will mitigate potential impacts and facilitate the achievement of the relevant ER. In many cases these controls will be implemented prior to the creation of the final landform, hence the term ‘preventative’ controls. On occasion they will be implemented after, or continue beyond, the creation of the final landform. For example, the planting of vegetation as sections reach the final landform and the pumping and treating of contaminated water, which may extend for several years after the creation of the final landform.

Table 5-1 describes the parameters that have been included in this MCP to help categorise the level of effectiveness of each control. The table includes consideration of:

- ***Design activity:*** the degree to which the proposed design reflects proven technologies, has been demonstrated to be effective through monitoring, and its progress through engineering design (e.g. concept, preliminary or detailed);
- ***Knowledge-based / administrative:*** the degree to which the control or corrective active is supported by accepted/approved scientific methods and findings, the level of remaining uncertainty, and whether it is an administrative control and therefore has merit but in isolation would not result in the achievement of the ER; and
- ***Timing*****:** the duration after implementation that the control or corrective active is predicted to be effective, which provides an indication of the ERA resources that would be available at that time to modify or rectify the matter if the control or corrective action was not as effective as predicted.

5.3 Corrective Actions

These are actions that will be implemented if the monitoring program detects a deviation from the desired trajectory and active intervention is required to recover the trajectory (e.g. exceedance of a trigger level for water quality or soil contamination, or movement away from the desired trajectory for ecosystems). The descriptions presented in Table 5-1 have also been used to categorise the level of effectiveness for corrective actions.

Table 5-1: Descriptors used to assess effectiveness of preventative controls and corrective actions

Description of Status	Effectiveness Rating
Design activity: Proven technology, already installed/constructed and monitoring has demonstrated effectiveness of the design/activity. Clearly defined and well communicated to execution teams, appropriate quality assurance program during construction/rehabilitation, supported by a suitable and feasible monitoring plan. ***Knowledge-based / administrative***: Not applicable for 'Strong' Preventative Control or Corrective Action. ***Timing***: ERA resources available and control/corrective action will be successful within 10 years of implementation.	Strong
Design activity: Proven technology, monitoring has demonstrated effectiveness of the design/activity. Clearly defined and well communicated to execution teams, appropriate quality assurance program during construction/rehabilitation, supported by a suitable and feasible monitoring plan. ***Knowledge-based / administrative***: Supported by studies and/or knowledge base with accepted/approved methods and findings, aware of uncertainties and deemed acceptable (i.e. not to have a material effect). ***Timing***: ERA resources available and control/corrective action will be successful within 15 years of implementation.	Satisfactory
Design activity: Preliminary design, not yet proven at Ranger, monitoring has demonstrated partial effectiveness of the design/activity. Clearly defined and well communicated to execution teams, appropriate quality assurance program during construction/rehabilitation, supported by a suitable and feasible monitoring plan. ***Knowledge-based / administrative***: Supported by studies and/or knowledge base with methods not yet accepted/approved, many uncertainties and insufficient information to deem whether uncertainties are material. ***Timing***: ERA resources available and control/corrective action will be successful within 25 years of implementation.	Marginal
Design activity: Concept design, not yet proven at Ranger, monitoring has not yet demonstrated effectiveness of the design/activity. Not yet defined and well communicated to execution teams, ill-defined or absent quality assurance program during construction/rehabilitation, not yet supported by a suitable or feasible monitoring plan. ***Knowledge-based / administrative***: Speculation, no supporting data, methods not yet accepted/approved, many uncertainties and insufficient information to deem whether uncertainties are material. ***Timing***: No certainty of ERA resources, uncertainty as to whether control/corrective would be successful at any point in the future.	Weak

5.4 Bow-tie diagrams

The MCP Chapter 6 to Chapter 11 includes bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER and to display residual risk. Chapter 12 of the MCP then provides a consolidated risk assessment, being a compilation of the residual risks identified from the bow-ties and the projects risks reported via the ERA risk management framework. Chapter 12 also provides the look-up tables used to rate the risks (e.g. the consequence, likelihood and risk rating matrices).

The process used to develop the bow-tie diagrams was:

- Assigned each of the ERs into the six Ranger themes and multiple aspects of each theme.
- Derived a risk event for each of the aspects, which is simply a statement about not achieving the ER.
- Developed a list of threats that may hinder the achievement of an ER. The threats were identified by:
    - Reviewing the closure criteria that has been developed for each ER, with the rationale that by not achieving closure criteria the related ER would not be achieved, and therefore that is a plausible threat.
    - Reviewing of the risks identified during the previous risk assessments and ongoing scientific studies to determine if other plausible threats should be included.
- Reviewed the planned closure activities to identify preventative controls, and then assessed the effectiveness of those controls using the descriptions provided in Table 5-1. All preventative controls have been assigned a unique identifier. 'Active' preventative controls (either currently active or planned) are coloured light green on the bow-tie diagram, whereas 'Knowledge-based or administrative controls' have been coloured dark green (see Figure 5-2; Appendix 5.2 provides a consolidated list of the preventative controls).
- Developed a list of undesirable outcomes that may occur if a deviated trajectory is detected by the monitoring program.
- Established corrective actions that would be implemented to recover the deviated trajectory back to the desired trajectory, and then assessed the effectiveness of those actions using the descriptions provided in Table 5-1. All corrective actions have been assigned a unique identifier. 'Active' corrective actions are coloured light blue on the bow-tie diagram whereas if there are any knowledge-based or administrative corrective actions they have been coloured dark blue (Appendix 5.3 provides a consolidated list of the corrective actions).
- Quantified the consequence and likelihood, and thus risk rating, for each of the undesirable outcomes using the risk look-up tables.

Figure 5-2 shows an example output from this process, with the bow-tie diagram from the 'Soils' theme being used as the example.

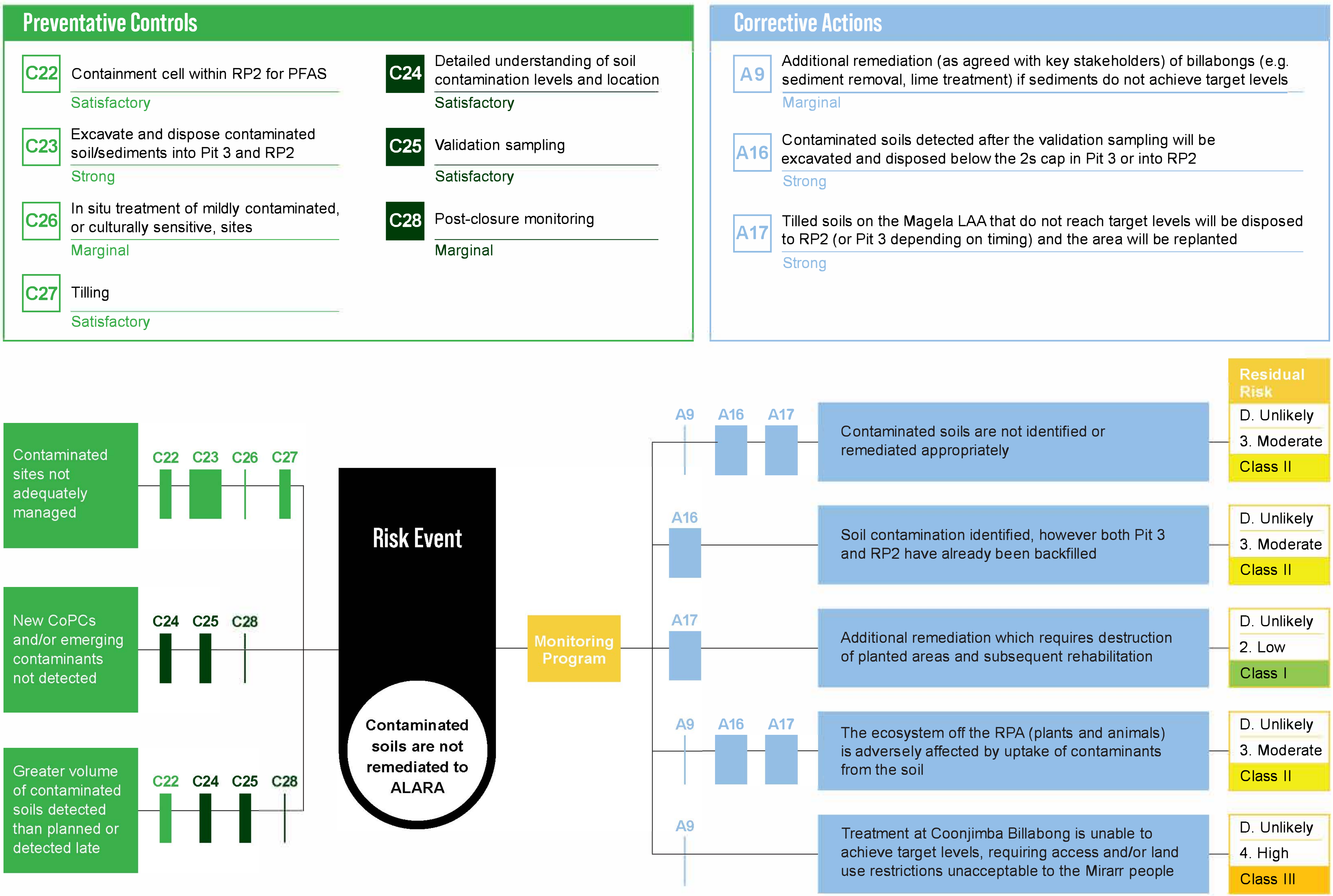
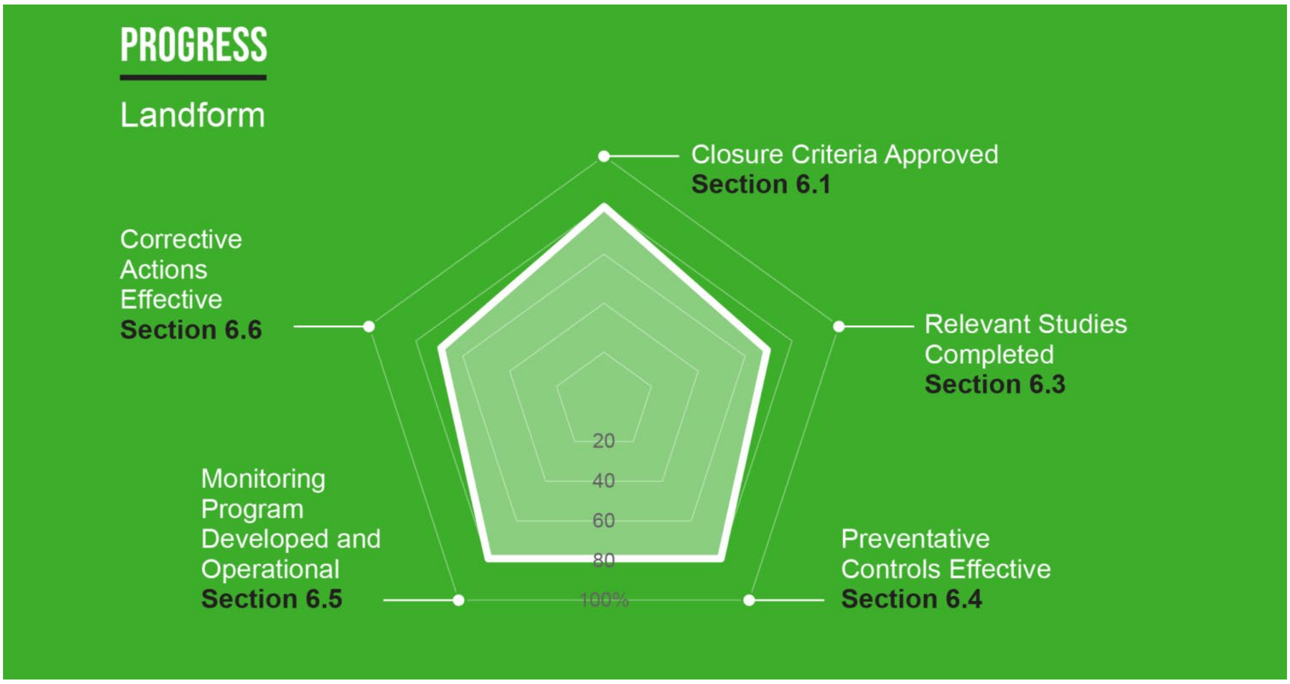


Figure 5-2: Example output from the bow-tie risk assessment process (Soils theme)

6 LANDFORM

The purpose of this MCP chapter is to consolidate information relevant to the landform theme. An indication of progress against key metrics is summarised in the spider diagram below, it shows:

- Six closure criteria have been developed for this theme, five of which received Ministerial approval. The criteria related to turbidity is currently in draft and ERA are seeking to receive Ministerial approval in this MCP. The Supervising Scientist published an updated background denudation rate, increasing from 0.04 mm/year to 0.075 mm/year. ERA is also seeking ministerial approval for this change (80%, Section 6.1).
- Project specific studies are advanced and will continue to progress throughout the closure period. ERA have commenced studies to inform an Erosion, Sediment and Water Control Plan. The outcomes of the Erosion, Sediment and Water Control Plan (erosion and sediment control structure designs) will be incorporated into the final landform design and submitted to OSS for assessment as part of the FLF application (70%, Section 6.3).
- Several preventative controls for this theme are well understood and considered to have a satisfactory effectiveness. However, uncertainties remain around some key areas including erosion and sediment controls and the future legal instruments restricting human disturbance over the 10,000-year timeframe that tailings are to remain isolated (80%, Section 6.5).
- A comprehensive monitoring program has been established and implementation has commenced on Pit 1. Monitoring will commence on the Pit 3 surface following completion of the final landform area. Future work is required to better inform the monitoring that will be undertaken to assess turbidity and bedload criteria (80%, Section 6.6).
- There is reasonable confidence in the effectiveness of corrective actions, however further work will be undertaken to improve our understanding of long-term monitoring and the practical implementation of adaptive management actions post-closure (70%, Section 6.7).



This MCP chapter has been developed to convey ERA's progress towards achieving the two closure objectives derived from the ERs for the landform theme (see Table 6-1).

6.1 Closure Objectives and Criteria

Table 6-1 lists the ERs relevant to the landform theme.

Table 6-1: Landform Theme: Environmental Requirements

Environmental Requirement	ER Reference
2 Rehabilitation *2.2 The major objectives of rehabilitation are:* *(c) Erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas.*	2.2 (c)
11 Management of Tailings *11.3 Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that:* *(i) The tailings are physically isolated from the environment for at least 10,000 years.*	11.3 (i)

ERA, working with the Closure Criteria Working Group (consisting of the OSS, NLC and GAC) have developed closure criteria associated with the ER's relevant to landform. Closure criteria represent direct measurable and quantifiable values that will be used as the basis for determining the successful fulfilment of closure objectives. Six closure criteria have been developed for this theme, five of which received Ministerial approval on 30 September 2021. ERA are seeking approval for the criterion related to turbidity and an amendment to the criterion related to denudation in this MCP. The six criteria relate to the following two matters:

- erosion characteristics of the final landform; and
- the isolation of tailings from the environment for 10,000 years.

6.1.1 Erosion Characteristics

As shown in Table 6-2, one closure outcome and one corresponding closure criterion related to erosion characteristics has received Ministerial approval.

Table 6-2: Erosion Characteristics – Approved Closure Criteria

Closure Objective	Closure Outcome	Parameter	Summary of Criteria
Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas	No bedload is transported away from the constructed landform.	Bedload	Bedload is not being transported from the constructed landform, in the absence of active management.

As shown in Table 6-3, ERA are seeking Ministerial approval for two closure criteria in this MCP.

Table 6-3: Erosion Characteristics – Closure criteria for Minister approval in the 2023 MCP

Closure Objective	Closure Outcome	Parameter	Summary of Criteria
Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas	The denudation rate on the landform is on a trajectory towards the regional background rate.	LEM model predictions of denudation rate	Modelling of erosion on the constructed landform demonstrates that the denudation rate will approach the background rate of 0.075 mm/a.[1]
	Total fine suspended sediment concentrations in receiving water downstream of the landform have returned to background concentrations	Turbidity	For Magela and Gulungul Creeks, the difference in net annual turbidity between sites located upstream of the mine- site and downstream at the boundary of the RPA, is similar to background values over five consecutive wet seasons in the absence of active sediment control.

[1] – criterion received Ministerial approval on 30 September 2021, however ERA are proposing a change to this criterion.

With regards to the criteria shown in Table 6-2 and Table 6-3:

- Landform evolution model: The method used to demonstrate achievement of this criterion will be based on Landform Evolution Model (LEM) predictions, using CAESAR-Lisflood (or similar). This criterion will be achieved if the model demonstrates the long-term predictions of denudation rates from the designed landform are approaching the background denudation rate. Denudation is the measure of weathering, or erosion of a landform surface by forces such as water and wind. It is expressed in terms of millimetres (mm) per annum. The previously approved background denudation rate was 0.04 mm/a however, a recent study by Wasson and others (2021) identified a revised background denudation rate of 0.075 mm/a. ERA are seeking ministerial approval in this MCP for the revised background denudation rate of 0.075 mm/a.
- Bedload: Bedload refers to sediment that is transported either on or near the bottom of a river, creek or drainage line in which surface water is flowing. It is typically characterised by heavier, coarser particles like sand or gravel. Currently, the approved criterion requires no bedload to be transported from the constructed landform, in the absence of active management. This parameter will be measured through post wet season observations of sediment deposition on the RPA, downstream of the constructed final landform area.
- Turbidity: Criterion regarding turbidity will be achieved when the difference in net annual turbidity between sites located upstream of the operation and downstream at the boundary of the RPA for each of Magela and Gulungul creeks over the course of five consecutive wet seasons (once the active sediment control structures described in Section 6.5.3 have been removed) is compared to natural background values. Background values are measurements of turbidity for years where no significant mine-related movement of suspended sediment has been detected in receiving waters (Supervising Scientist, 2021a). Suspended sediment loads from the rehabilitated landform to Magela and Gulungul creeks are expected to be higher than background rates initially, and progressively trend towards background rates as vegetation on the rehabilitated landform increases and loose surface material is removed via early run-off events or distributed deeper into voids in the soil profile.

6.1.2 Isolation of Tailings

As shown in Table 6-4, one closure outcome and three closure criteria have been derived from the ER related to tailings isolation.

Table 6-4: Tailings Isolation – Approved Closure Criteria

Closure Objective	Closure Outcome	Parameter	Summary of Criteria
The tailings are physically isolated from the environment for at least 10,000 years	Best available modelling demonstrates that tailings will remain isolated for at least 10,000 years	Digital elevation model	A high-resolution digital elevation model of the constructed landform matches the approved landform design, within applicable construction standards.
		Landform Evolution Model predictions of gully erosion	Modelling of erosion on the constructed landform matches results of erosion modelling conducted on the approved landform design and confirms tailings will not be exposed for 10,000 years.
		Gully erosion	Gully formation will not expose buried tailings.

Due to the 10,000-year time period associated with these closure criteria, best available modelling will be used to demonstrate that tailings will remain isolated for 10,000 years.

With regards to the criteria shown in Table 6-4:

- Digital elevation model: Once the final landform is constructed, the as built topography (in the form of a DEM) will be compared to the approved landform design to confirm it is within the permitted tolerances. These are currently expected to be in the order of + / - 0.5 m at main drainage channels and + / - 1 m elsewhere. Frequent surveying and GPS guidance during construction will enable the intended landform topography to be followed with a high degree of accuracy.
- Landform evolution model: The method used to demonstrate achievement of this criterion will be based on predictions from the CAESAR-Lisflood landform evolution model (or similar). Landform evolution models are used to simulate the changes of a landscape over a defined period of time (10,000 years in this case). LEMs are able to predict the extent of erosion and gullying using rainfall data, particle size class and high-resolution digital elevation models as inputs. This criterion will be achieved if the landform evolution model demonstrates that tailings will not be exposed as a result of gully formations on the final landform area. The model used by the OSS incorporates future climate change scenarios and conservative parameters, therefore, the LEM will confirm the criterion either has or has not been achieved.
- Gully erosion: The final landform being created will include erosion controls structures and armoured drainage channels to minimise the development of gully erosion. However, some erosion and gully formation will occur. Post wet season inspections will be undertaken to determine the presence or absence of unplanned gully erosion. Significant erosion such as gully erosion is more likely to occur in the initial stages of the life of the landform. Following the initial settling of the landform, significant unplanned erosion should not occur. Gully erosion detected over Pit 1 and Pit 3 will be remediated prior to the following wet season. It is expected that after the first five years the landform will stabilise, and less erosion will occur. This criterion is considered to be achieved when no gully erosion, beyond what would ordinarily occur in the region that could expose tailings occurs after this period.

Section 6.6 provides further detail on the monitoring framework that will be used to demonstrate that tailings are on a trajectory to be physically isolated from the environment for a 10,000-year period.

6.2 Design Elements

Chapter 4 describes the closure activities completed and yet to occur at Ranger. Of most relevance to landform, it is noted that:

- the final landform has been designed to include slopes with a maximum grade of 6.5%, a maximum difference in elevation of 25 m, and concavity in surfaces to increase landform stability and reduce erosion (i.e. a geomorphic landform with designed ridges and channels);
- the final landform surface will be scarified, although ERA will assess the need to deep rip steeper slopes to prevent erosion on the final landform surface;
- the surface will be planted with ~1,000 plants per hectare to create a self-sustaining ecosystem and to reduce the potential for erosion and gully formation;
- erosion control structures will be installed on the final landform to slow the flow of water and constructed drainage channels that will have increased water flows will be rock armoured;
- to prevent sediment laden water from leaving the recently created landform area, ERA will likely install sediment basins at the terminal point of each sub-catchment;
- approximately 67 Mt of tailings were produced over the life of mine, of that:
  - 27 Mt of tailings was directed to the then TSF;
  - 25.6 Mt was disposed directly to Pit 1; and
  - 15 Mt was disposed directly to Pit 3.
- between 2016 and 2022, the 27 Mt of tailings within the TSF was transferred to Pit 3 (therefore 42 Mt have been placed within Pit 3 and 25 Mt within Pit 1);
- in both Pit 1 (completed) and Pit 3 (yet to be completed), wicking and extraction of PTF is undertaken to accelerate the consolidation of tailings, a geotextile material is placed on top of the tailings, followed by initial and secondary capping layers of waste rock and then bulk backfill of waste rock; and
- the total depth of waste rock above the consolidated tailings in Pit 1 and Pit 3 at a minimum is ~9 m and ~27 m respectively.

6.3 Relevant Studies / Knowledge Base

The spider web diagram at the beginning of this chapter assigns a subjective 70% complete for the progress status relating to ‘relevant studies’ for landform.

The studies that have been completed to date and works yet to be completed are described below under the following sub-sections:

- Erosion characteristics (Section 6.3.1):
  - Landform design, evolution modelling and erosion predictions (Section 6.3.1.1).
  - Landform material properties and erosion characteristics (Section 6.3.1.2).
  - Pit 1 landform water quality data (Section 6.3.1.3).
  - Stage 52 landform (Section 6.3.1.4).
  - Studies to be completed (Section 6.3.1.5).
- Isolation of tailings (Section 6.3.2):
  - Tailings consolidation modelling (Section 6.3.2.1).
  - Landform design and evolution modelling (Section 6.3.2.2).
  - Stability and longevity of tailings repositories (Section 6.3.2.3).
  - Studies to be completed (Section 6.3.2.4).

6.3.1 Erosion Characteristics

6.3.1.1 Landform design, evolution modelling and erosion predictions

The design of the Ranger final landform has been developed with the aim of producing a landform with similar indices of erosion and runoff distribution to the natural landscape (Hollingsworth and Lowry, 2005). The first landform design (Final Landform version 1; FLv1) was based on landform design criteria that included the requirement to have slopes ranging from 0 to 6.5 %, a maximum relief of 25 m, and certain profile and plan curvature specifications (Hollingsworth and Lowry, 2005). Multiple landform design versions have been developed since FLv1, all working to refine the design of the landform to reduce modelled erosion and gully formation, to re-create as much as possible pre-disturbance drainage lines, and to promote a landform surface that is readily traversed by people on foot. The current version of the final landform design is Final Landform Version 7 (FLv7).

Following conceptual design, each version of the final landform is subjected to landform evolution modelling. This modelling assesses the geomorphic stability of the final landform over timeframes ranging from decades to millennia and allows OSS and ERA to compare the modelled stability of the final landform against landform closure criteria.

The most recent landform assessment was conducted on FLv6.2. The findings were reported in:

- Technical Advice #10 dated 21 February 2019 (Supervising Scientist, 2019a).
- Technical Advice #22 dated 13 October 2020 (Supervising Scientist, 2020a).

Table 6-5 presents the denudation results of LEM modelling conducted by OSS on FLv6.2, noting that the approved closure criteria is 0.04 mm/a and the proposed criteria is 0.075 mm/a.

The results suggest that the FLv6.2 final landform is not yet achieving the target denudation rate over a 10,000 year period. However, the current modelling is being undertaken under an extreme worst case rainfall scenario setting and assuming the absence of vegetation surface cover for all scenarios except the Corridor Creek catchment, which includes a basic ground/grass cover (Supervising Scientist, 2020a).

It is important to note that the CAESAR-Lisflood model has a limited capacity to model the effect of vegetation cover, allowing the user to only simulate a basic ground/grass cover. Modelling suggests that the Corridor Creek catchment (Pit 1 area) will achieve the background denudation rate over a 10,000-year period with the inclusion of a basic groundcover, under a ‘dry’ rainfall scenario. The wet-rainfall scenario uses rainfall data from Weipa in far-north Queensland as an analogue whereas the dry-rainfall scenario uses Mango Farm, near Katherine. These rainfall datasets were derived from Verdon-Kidd and Hancock (2016).

Table 6-5: Predicted denudation rates for each catchment on FLv6.2

Catchment	Denudation rate (mm per annum)	
	Dry rainfall scenario	Wet rainfall Scenario
3,000 years		
Djalkmarra	0.19	0.27
Coonjimba	0.51	1.01
Gulungul	0.15	0.24
10,000 years		
Corridor (Pit 1 area)	0.15 (0.04[1])	0.21 (0.09[1])
Djalkmarra (Pit 3 area)	0.21	0.24

[1] - Bracketed numbers indicate denudation rate with grass cover present.

The findings of the OSS modelling assessment of FLv6.2 have been taken into consideration by ERA in the development of FLv7. In February 2022, an ERA landform design group was formed. The group included a bulk material movement modeller, a 12D civil software expert, and a landform evolution modeller. The initial purpose of the group was to incorporate concave slopes and first-order drainage recommendations received from stakeholders into the design of the final landform to improve landform stability outcomes. Using the Coonjimba catchment as a test, the optimisation study applied an iterative process of design, revision and assessment.

The key design features introduced and/or changed between FLv6.2 and FLv7 included:

- incorporation of ’micro-contouring’ to improve natural contouring;
- incorporation of additional concavity in surfaces; and
- incorporation of first order drainage lines with sinuosity.

The landform design features that were tested and deemed effective in reducing erosion in the ERA modelled scenarios for Coonjimba catchment have been kept and applied to the conceptual landform design of the Djalkmarra and Corridor Creek catchments. Denudation rate is the major indicator of whether each ‘iteration’ of the design would be adopted. No changes were made to the conceptual final landform design of the Gulungul Creek catchment as the inclusion of concavity designs had no improvements.

ERA will continue to review and optimise final landform design FLv7, incorporating permanent and temporary erosion mitigations to maximise landform stability and revegetation success. Once the optimisations are showing little or no improvement in the ERA modelled outcomes, the latest iteration on the final landform design will be provided to OSS for import to their CAESAR-Lisflood model to assess the design's long-term stability as part of the FLF application assessment.

6.3.1.2 Landform material properties and erosion characteristics

A number of studies have been undertaken by both ERA and OSS to assess the material properties of Ranger landforms and to optimise and calibrate the CAESAR-Lisflood LEM. These studies also address KKN questions relevant to the stability of the final landform. The studies of most relevance include:

- Saynor and others (2009a): particle size analysis and measurement of sediment and solute transport from the TLF.
- Saynor and others (2009b): characterised the particle size of soil samples collected from woodland and open woodland vegetation communities, indicative of the type of soils found on the natural Koolpinyah surface (surrounding the mine).
- Saynor and Houghton (2011): reported on the results of particle size analysis conducted on the TLF in 2009. Samples were subjected to particle size analysis using the hydrometer and sieve method. It is noted that sampling precluded the collection and measurement of larger material.
- Saynor and others (2012): follow up particle size analysis and measurement of sediment and solute transport from the TLF. A grid-by-number surface sampling technique was adopted for subsequent sampling events derived from Wolman (1954).
- Saynor and others (2014): follow up particle size analysis and measurement of sediment and solute transport from the TLF.
- Saynor and others (2015): follow up particle size analysis and measurement of sediment and solute transport from the TLF.
- Verdon-Kidd and Hancock (2016): developed synthetic rainfall datasets (both extreme wet and dry scenarios) for use in the CAESAR-Lisflood LEM.
- Saynor and others (2017): assessed the effectiveness of rip lines on the TLF by simulating erosive processes using the CAESAR-Lisflood LEM.
- Supervising Scientist (2019b): follow up particle size analysis for samples of bedload and sediment from the TLF.
- Douglas Partners: particle size analysis for samples collected on the Pit 1 surface between October 2019 and September 2020.
- Hancock and others (2020): developed particle size distributions from previous sampling campaigns on the TLF (2009, 2012, 2014 and 2018) and Koolpinyah (2009) for use within CAESAR-Lisflood LEM.

- Lowry and others (2020): assessed the ability of the CAESAR-Lisflood LEM to accurately predict soil erosion (in the form of modelled bedload and suspended sediment loads) from a rehabilitated landform.
- Supervising Scientist (2020b): follow up particle size analysis for samples of bedload, and sediment from the TLF. Results from sampling in 2009, 2012, 2014, 2018 and 2020 indicated that the waste rock on the TLF is not weathering at a rapid rate.
- Saynor and others (2020): investigated extreme rainfall and runoff events that have occurred in the East Alligator catchment by examining historical flood-deposited sediments. Results indicated that the largest historical flood event (over the previous 8,400 years) likely occurred in 2007.
- Supervising Scientist (2023a): assessed the ability of the CAESAR-Lisflood LEM to predict the extent of erosion and gully formation over the rehabilitated Pit 1 landform.
- Supervising Scientist (2023b): using CAESAR-Lisflood, assessed the impact of extreme rainfall events on the stability of the conceptual final landform (FLv6.2).

The progressive understanding of the material properties on newly constructed landforms forms part of the closure knowledge needs and will continue to evolve as new data becomes available. Importantly, these studies improve the knowledge base regarding the erosion characteristics of Ranger surfaces, and how the CAESAR Lisflood LEM can be optimised to accurately predict the extent of erosion and gully formation on Ranger landforms.

6.3.1.3 Pit 1 landform water quality data

The backfilling and contouring of the Pit 1 surface layer was completed in August 2020, followed by 39 ha of revegetation completed over a ten month period in 2021–2022. In preparation for revegetation, the surface of Pit 1 was lightly scarified in Q3 2020. Pit 1 was walked and visually inspected for accessibility and traversability by the representatives of Traditional Owners (or themselves) once the surface preparation was completed. No additional surface preparation was applied.

A backfilled, rehabilitated landform remains, with a perimeter drain (Plate 6-1) truncating the catchment. The Pit 1 perimeter drain is lined with rock to reduce erosion of shedding water and further reduce sedimentation. Rock check dams have been installed at 50 m intervals along the perimeter drain to reduce the flow velocity of water and cause the deposition of heavier suspended sediments. The perimeter drain reports to the Corridor Road Sump (CRS) via a 10 m wide inlet channel, lined with a combination of geofabric, and rock pitching. Two sluice gates are in place in the CRS to allow for future release, however, these gates currently remain closed, with all runoff and seepage from the Pit 1 landform pumped back into RP2.

Plate 6-1: Pit 1 perimeter drain

A series of monitoring stations were installed during the 2020/21 wet season to complement the existing network that monitors the quality of water from the Pit 1 landform (Figure 6-1). Water quality has been monitored during the last two wet seasons (2021/22 and 2022/23) as detailed in the '*Pit 1 Interim Water Management Plan*'. Fixed 'fauna' cameras have been also installed at monitoring stations capable of taking a photograph every 15 minutes (including during the night), or upon triggering due to rainfall. The photographs taken by the camera/s enable a visual record of performance of the perimeter drain and inlet channel, as well as visually verifying the turbidity of the water leaving the Pit 1 surface and entering the CRS.

FIGURE 6-1

Pit 1 Drainage Features

LEGEND

- Surface water monitoring site
- Final Landform v7 contours (1m)
- Rock check dam
- Pit 1 and associated drainage
- Corridor Road sump

0 50 100

Metres

Scale 1:5,000 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

The quality of water reporting from the Pit 1 landform indicates an improvement of turbidity and EC values over the last two wet seasons. Historical studies and predictions undertaken by the OSS and others on the TLF have shown a trend of decreasing sediment load coming from the landforms over time (Saynor and Lowry 2018; Saynor *et al.*, 2017; Hancock *et al.*, 2017). In general, sediment yields for major land disturbances, such as construction or landslides, are characterised by an initial pulse of transported sediment followed by a rapid decline (Duggan 1994 cited in Saynor *et al*., 2015). This is also true for the TLF annual bedload yield, which is characterised by an exponential decline since construction (Figure 6-2).

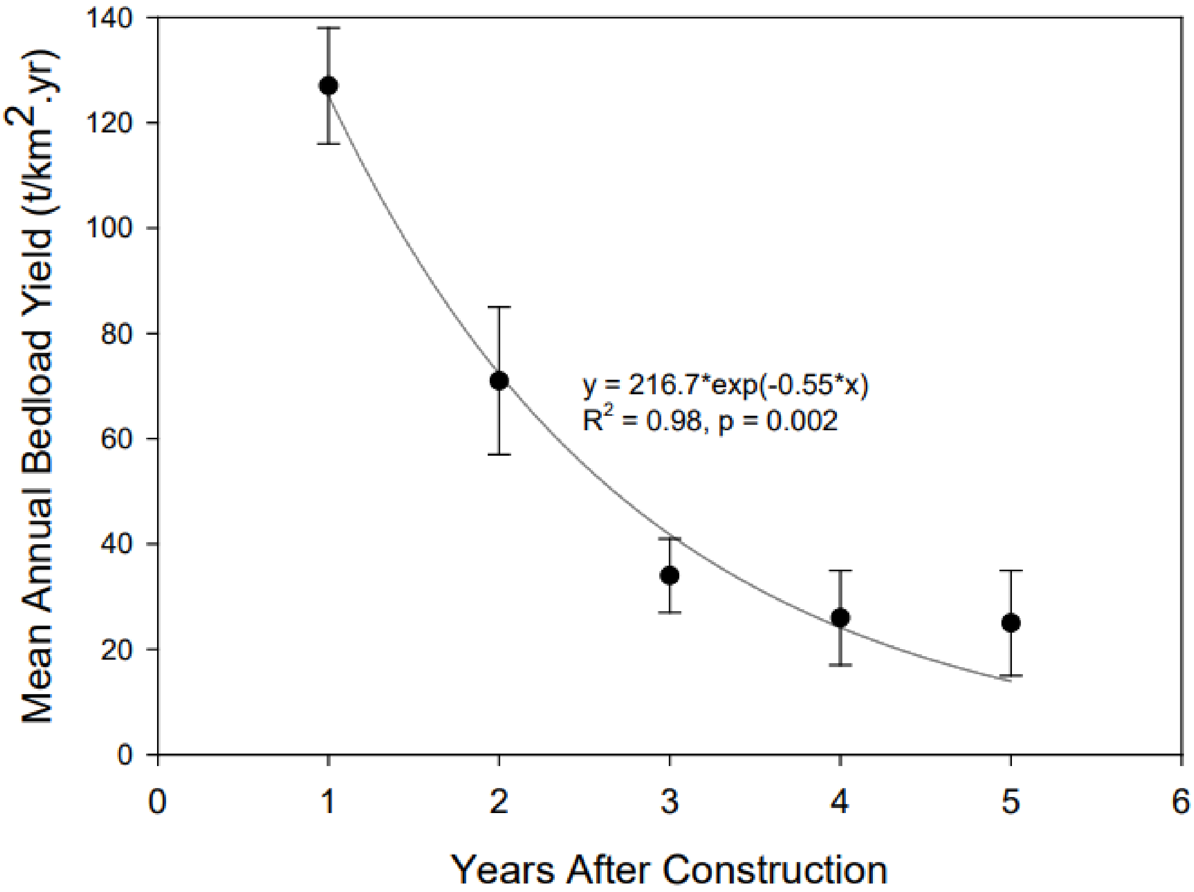


Figure 6-2: Decrease in mean annual bedload yield with time since construction on the TLF (Lowry and Saynor, 2015)

It is noted that erosion has been observed on the batters of the Pit 1 perimeter drain as water flows off the backfilled landform. The elevated turbidity that corresponds with rainfall events has been attributed to the erosion of sediment coming from the batter of the Pit 1 perimeter drain. Also, it was identified that in extreme rainfall events, CRC1 overflows into CRS. The pumping infrastructure in CRC1 was upgraded in the 2023 dry season to enable adequate transfer of water to RP2.

ERA have applied via the 2024 *Ranger Water Management Plan* to release suitable quality water from the CRS to Corridor Creek in the 2023/24 wet season. ERA will continue to work with OSS on this matter. ERA will continue to collect and analyse water quality results from the Pit 1 landform to support the development of a whole final landform *Erosion, Sediment and Water Control Plan*. Water quality datasets from Pit 1 and the Stage 52 catchment conversion trial (Section 6.3.1.4) will inform additional modelling and be used as the basis to determine when a rehabilitated landform can be converted to a release water catchment in the future. Water quality data will continue to be reported in the annual Ranger Wet Season Report in accordance with Annex D.9 of the Ranger Authorisation.

6.3.1.4 Stage 52 landform

Monitoring of surface water runoff from the Pit 1 final landform as described above has shown that runoff from a freshly constructed landform may contain suspended solids that require further management or treatment prior to release to the surrounding environment. Whilst a conceptual understanding of surface water management and erosion controls is known, the specific details of how this understanding will be applied to the FLv7 design (or later versions of the ‘to be constructed landform’) will be described in a site-wide *Erosion, Sediment and Water Control Plan*, which will be included in the FLF application.

To help better inform that Plan, an area of approximately 6 ha adjacent to the north-west of Pit 1 was constructed and revegetated in 2022/2023. The trial area was named Stage 52 and the purpose of the trial was to help test the practicality and performance of various proposed water management methods. Aspects of the Stage 52 trial include:

- the ability to collect and direct stormwater to its intended destination (pond, release or dedicated sediment management);
- erosion and sediment control structures that may be required for initial and ongoing management of stormwater runoff from the final landform; and
- improved understanding of the catchment response to rainfall in terms of the timing of peak flows (time of concentration) and the percentage of rain that becomes runoff (runoff coefficient) as well as the representative water quality (sediment/turbidity, salts, metals, nutrients and herbicides).

ERA engaged WSP-Golder to advise and design the trial (WSP-Golder, 2023). In addition to the basic infrastructure for collecting and managing surface water from the Stage 52 area, the trial included the construction and use of a High Efficiency Sedimentation (HES) basin to test methods that reduce the suspended sediment in the collected water. Several surface drains collect surface water from the 6 ha catchment area, delivering the water to a transfer sump. The collected water is treated in the transfer sump via the addition of coagulant or flocculant to promote the settling of suspended sediment. The water is then transferred to the HES forebay where suspended sediment settles, and then overtops via a level spreader weir to the HES main bay (Plate 6-2). Following treatment in the HES main bay, treated water flows via a drain, north-east towards the Dump Road Sump. Water collected in the Dump Road Sump is then pumped to the drainage channels that report to RP2.

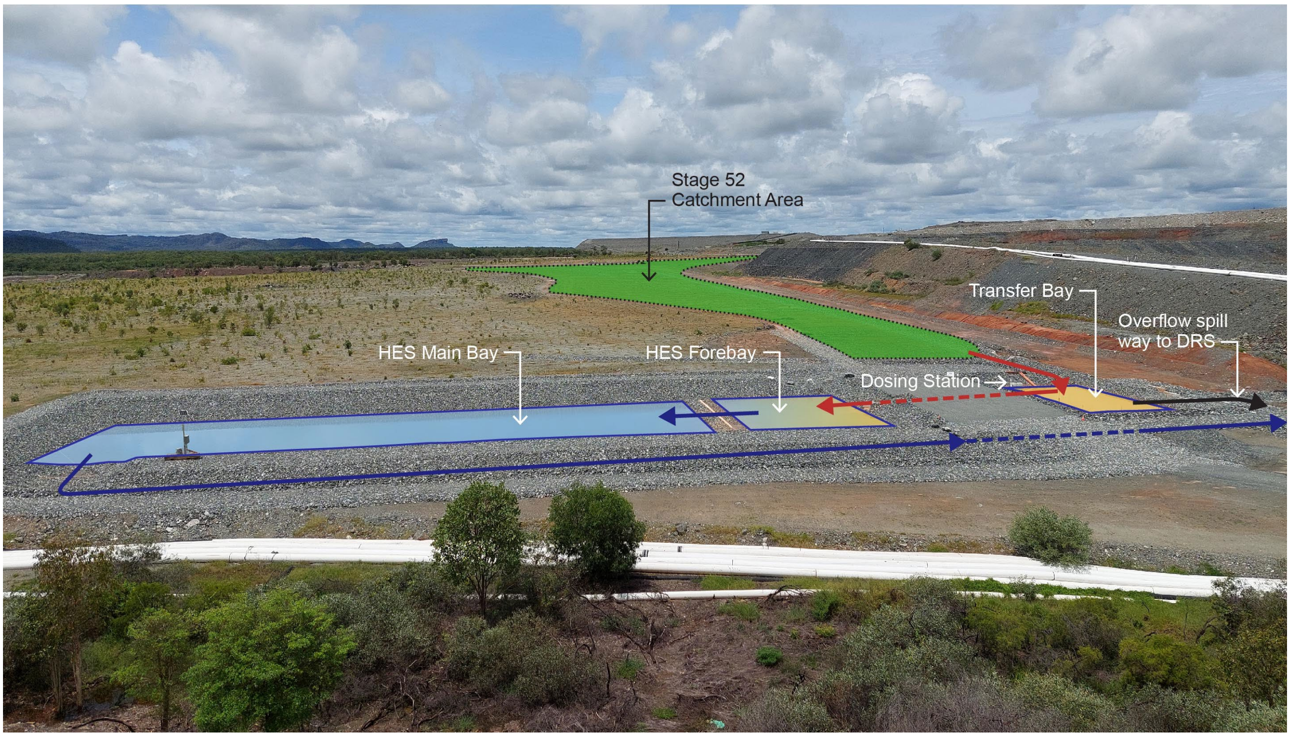


Plate 6-2: Stage 52 HES Basin (31 January 2023)

A number of water quality samples were taken throughout the 2022/23 wet season to assess the quantity and quality of the water leaving the constructed landform, and the quality of the water leaving the HES basin. Initial results indicate that the sediment load coming off the newly built landform is considerable and contains a high proportion of fine material. The use of the three stage HES, including an automated dosing system, was shown to be highly effective at reducing the turbidity and sediment load at the downstream spillway. A large proportion of the coarser material was shown to settle in the transfer sump prior to dosing, as well as in the forebay and main cell.

ERA was able to estimate the sediment load collected in the base of the three storages, however, technical complications with the timing of autosampler activation and the quality of data collected from grab samples have reduced the accuracy of the estimates. ERA is investigating methods to improve this data capture. Other water quality parameters including salts, metals, nutrients and herbicides have also been collected for the past wet season and will continue to be collected in the coming years for comparison of the inter-annual and seasonal trends.

The results obtained from monitoring through the 2022/23 wet season and beyond will inform the development of the *Erosion, Sediment and Water Control Plan*.

6.3.1.5 Studies to be completed

Erosion, Sediment and Water Control Plan

As indicated above, ERA have commenced additional studies to support the development of an *Erosion, Sediment and Water Control Plan*, forming part of the FLF application.

The primary objectives of this study are to:

- Revise the site release calculator to accommodate potential releases and scenario testing including varying site runoff quantities (flows), quality (salt and sediment loads), and varying background flows and water quality. The site release calculator is a spreadsheet-based tool that is used to determine potential release water flow rates and water quality using background flow rates and water quality. The tool uses site telemetry and grab samples to estimate the water quality parameters at MG009. It is regularly recalibrated and verified based on monitoring results.
- Advance ERA's understanding of the infrastructure design (i.e. drainage channels and sediment basins) required to manage runoff and near surface seepage from each catchment, and across all catchments as a whole. This will include the appropriate location and sizing of storage, pump and piping infrastructure.
- Build upon the existing hydrologic/hydraulic model to assess alternative scenarios in terms of rain events, catchment sizes and infrastructure location and sizing to allow an evaluation of the peak flows and discrete storm event runoff volumes.
- Determine the monitoring required to track changes in catchment water quality.
- Apply the learnings from the Pit 1 and Stage 52 final landforms.
- Determine long-term erosion and sediment control measures for the final landform.
- Develop contingencies in the event that system performance does not go to plan.

Any updates to studies relating to catchment conversion and the development of the *Erosion, Sediment and Water Control Plan* will be provided in future iterations of the MCP.

Final landform design optimisation

Concurrent to the above studies, ERA will be engaging a geomorphic landform subject matter expert to undertake a review of the final landform design and landform evolution modelling to date. The scope of work will include:

- appraisal of the current final landform design (FLv7) and where relevant, previous design iterations;
- review of previous LEM studies;
- assessment of the LEM parameters and equations including particle size distributions, erodibility parameters and rainfall scenarios;
- determine base case LEM parameters in agreement with OSS to be applied on FLv7;
- review the FLv7 design to incorporate geomorphic principles such as more defined ridges, drainage channels and concave slopes;
- determine the location, extent and sizing of rock armouring for major drainage channels based on bed shear stress (scour potential);
- verify the landform design using the LEM as defined above and determine sediment yield and denudation rate; and
- incorporate the drainage channels and potentially, erosion control measures (where possible) into the *Erosion, Sediment and Water Control Plan*.

Subsequent changes to the final landform design will be presented in future iterations of the MCP and discussed in the FLF application that is submitted to the regulators for approval.

6.3.2 Isolation of Tailings

6.3.2.1 Tailings consolidation modelling

Deposited tailings undergo a geotechnical process called consolidation. As the mass compresses due to self-weight and the application of capping and backfilling loads, the volume of tailings decreases (Fitton, 2020). The volume and rate of water expressed during consolidation of tailings is dependent upon the properties of the tailings and the mass of rock placed on top. Tailings consolidation has the ability to affect the stability of the final landform, influencing subsidence and erosive processes. Understanding tailings consolidation is important because it determines the depth in the pit that the top of the tailings will be over time, which is important to know when predicting whether tailings will remain isolated for 10,000 years.

As part of the Pit 1 closure planning and to answer KKN LAN3B (a question around the consolidation of deposited tailings and how this may influence erosional processes on the final landform), ERA commissioned a series of Pit 1 tailings consolidation models that allow the prediction of final tailings elevation within Pit 1 and the forecast volume of process water to be expressed during consolidation.

Validation of the Pit 1 tailings consolidation model was enabled by surveying 28 standpipes, attached to settlement monitoring plates, installed across the tailings surface prior to the placement of the initial capping. Validations were initially completed in 2017 and 2020, and then on a regular basis following the completion of backfilling activities. Consolidation of tailings in Pit 1 proceeded in accordance with predictions (Fitton, 2020). The average tailings level, as of June 2021, was +7.75 mRL (Figure 6-3). Based on the predicted ultimate settlement of 4.52 m, the degree of consolidation at the time of the last survey was approximately 98 to 99% complete (Fitton, 2020).

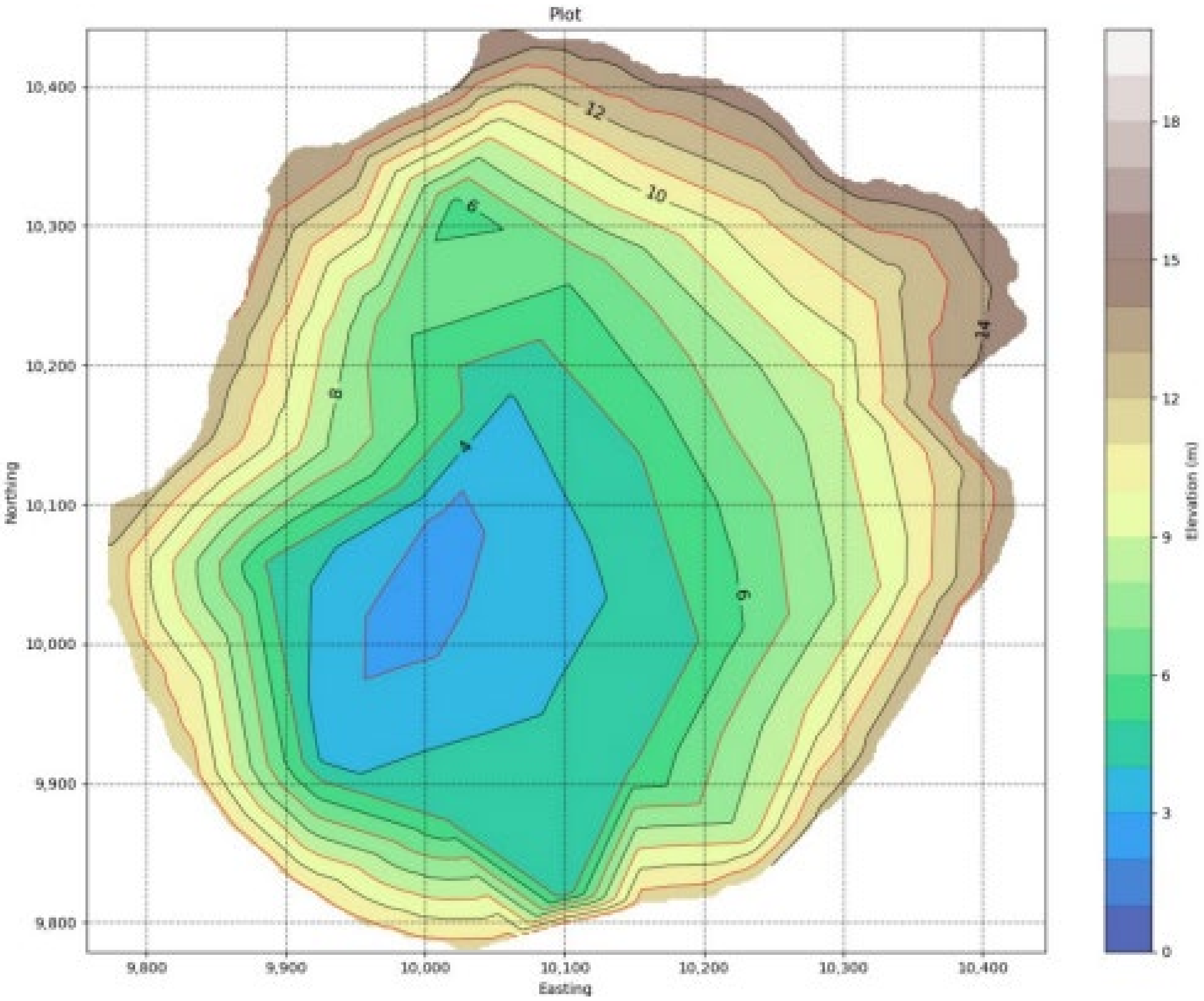


Figure 6-3: Calculated Pit 1 tailings surface as of May 2021 (S. Murphy, per. comms.1 June 2021)

The Pit 1 tailings consolidation model has since been adapted for use on Pit 3. Fitton Tailings Consultants have modelled tailings consolidation in Pit 3, with the most relevant findings presented in 2023. Following completion of tailings deposition within Pit 3, the average tailings elevation (as determined by survey on 9 December 2021) was -15.76 mRL. A bathymetric survey in March 2022 revealed varying tailings surface elevations across the pit, ranging from -12 mRL to -18 mRL. As consolidation proceeds, the tailings' thickness and surface elevation in the pit will decrease. For example, the -12 mRL to -18 mRL from the March 2022 bathymetric survey had reduced to -16 mRL to -22 mRL by the 2 April 2023 bathymetric survey, following the installation of vertical wicks. The predicted average elevation at the end of consolidation is -27.37 mRL. The actual elevation at final consolidation will vary in the pit, likely to range between -15 mRL and -46 mRL (refer Figure 4-6).

ERA will continue to monitor the consolidation of Pit 1 and Pit 3 tailings in accordance with Section 6.6.5.

6.3.2.2 Landform design and evolution modelling

As described in Section 6.3.1.1, the design of the final landform has been determined using a digital terrain model of natural analogue areas with the aim of producing over time a landform with similar indices of erosion and runoff distribution to the natural landscape (Hollingsworth and Lowry, 2005).

The results of the OSS assessment on the FLv6.2 design show the maximum potential formation of gullies after 10,000 years of up to 9 m deep in Pit 1 and 7 m deep in Pit 3. As the tailings will consolidate to minimum buried depths of ~9 m (~15 m where gullying is modelled to occur) in Pit 1 and ~27 m in Pit 3, the modelling suggests that all tailings will remain isolated (Supervising Scientist, 2020a).

It is important to note that the landform evolution model does not include localised erosion and sediment control structures (e.g. rock check dams) or a change in erosion characteristics due to the presence of subsurface bedrock (Koolpinyah surface). Also, in the 2019 assessment, the landform was fully exposed, with no vegetation included on the surface for the entire 10,000-year period. In the 2020 assessment, the OSS included a grass cover layer in the Corridor Creek catchment only (Supervising Scientist, 2020a). Table 6-6 presents the results of LEM modelling conducted by OSS on FLv6.2.

Changes from FLv6.2 to FLv7 have been made to reduce the extent of gullying on the surface of Pit 1. These include the introduction of first order drainage lines with sinuosity, moving the flow of surface water away from the Pit 1 surface and therefore, away from the buried tailings. It is expected that the assessment of FLv7 (once completed) will further reduce these modelled gully depths.

Table 6-6: Predicted gullying depth for each catchment on FLv6.2

Catchment	Gullying (maximum predicted depth, m)	
	Dry rainfall scenario[1]	Wet rainfall Scenario[2]
3,000 years		
Djalkmarra	4.5	5
Coonjimba	4	7
Gulungul	4	4.5
10,000 years		
Corridor (Pit 1 area)	7	**9**
Djalkmarra (Pit 3 area)	6.5	**7**

1 Dry rainfall scenario as defined in Verdon-Kidd and Hancock (2016).

2 Wet rainfall scenario as defined in Verdon-Kidd and Hancock (2016).

6.3.2.3 Stability and longevity of tailings repositories

KKN LAN2A seeks to understand what major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, climate). Three studies are of particular relevance.

Blong and Mitchell (1996) explored the extreme natural events that might affect the stability and longevity of the tailings repositories and violate the safe storage of mill tailings. The key objectives of the study were to:

- review available information concerning natural hazards in the Ranger area that could impact on the long-term stability of the proposed tailings repositories and cause exposure of mill tailings to the biosphere and geomorphic/pedologic processes; and
- to rank the identified natural hazards in terms of their magnitude, frequency and potential consequences.

The potential extreme natural events considered within the study included probable maximum precipitation, probable maximum floods, wind, drought, fires, erosion, sea level change, meteorite impact, seismic events, tsunami, volcanic eruptions and mass failure. Table 6-7 summarises the significant hazards and consequences for each of the final tailings repositories.

Table 6-7: Summary of significant hazards and consequences

Level of Concern	Pit 1	Pit 3
Level 1 (Lowest)	Erosion Cyclonic Winds Drought Tree Throw	Erosion Cyclonic Winds Drought Tree Throw
Level 2	Liquefaction Long Term Settlement	Liquefaction Long Term Settlement
Level 3	N/A	N/A
Level 4	N/A	N/A
Level 5 (Highest)	N/A	N/A

No hazards fell into the two highest concern categories. Pit 1 and Pit 3 had identical hazards that were determined to require further consideration of risk reduction strategies. The bowtie risk assessment presented in Section 6.4 considers these risks.

In 2017, INTERA conducted a systems assessment to identify all conditions that may affect the ability of the Pit 3 tailings repository system to contain tailings for at least 10,000 years. The key objectives of the study were to:

- identify a comprehensive list of features, events and processes (FEPs) that could cause exposure of tailings within a 10,000-year period; and
- identify the safety functions that would assure the tailings remain isolated.

The FEPs assessment identified erosion as the primary mechanism that may expose tailings. The safety function analysis determined that the buried depth of tailings limits the potential for erosion to expose tailings at the surface. This finding is supported to date by the modelling results presented above.

In 2020, ERA commissioned a Ranger Uranium Mine Closure Climate Change Risk Assessment. An update to that risk assessment was conducted in 2023 (see Appendix 2.1 for full report). The updated assessment reviewed the information derived for the NT from the latest (6^{th}) assessment reports from the Intergovernmental Panel on Climate Change (IPCC, 2022). Section 2.3.2 of this MCP provides a summary of the risk assessment findings. Of relevance to the landform theme, risks of erosion and runoff of sediment which may occur during cyclones and large storms were identified. The risk assessment determined that the risk of gullying is considered to be low, largely because of the final landform design that avoids steep slopes.

6.3.2.4 Studies to be completed

Final landform design optimisation

As described in Section 6.3.1.5, ERA will be engaging a geomorphic landform subject matter expert to undertake a review of the final landform design and LEM modelling to date.

Tailings consolidation modelling

ERA will continue to monitor the consolidation of Pit 1 and Pit 3 tailings in accordance with the Section 6.6.5. If monitoring identifies a significant variance in the rate of tailings consolidation, the tailings consolidation model will be reviewed and updated.

Any updates to the tailings consolidation model will be provided to stakeholders.

6.4 Bow-tie diagrams

As described in Chapter 5, this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. Depending on the theme, there may be multiple bow-ties, representing the relevant aspects being measured for that theme. For landform, two bow-ties have been developed and these are provided in Figure 6-4 and Figure 6-5.

Within each bow-tie diagram, threats and preventative controls are provided on the left side of the diagram, and corrective actions and consequences on the right side. The residual risk ratings reflect the current effectiveness of the controls and corrective actions. Class IV and Class III risks exceed ERA's risk acceptance threshold and will be the subject of further work to reduce uncertainty, strengthen the controls and/or strengthen the corrective actions.

Further details on the preventative controls, monitoring program and corrective actions for the landform theme are provided in Section 6.5, Section 6.6 and Section 6.7 respectively.

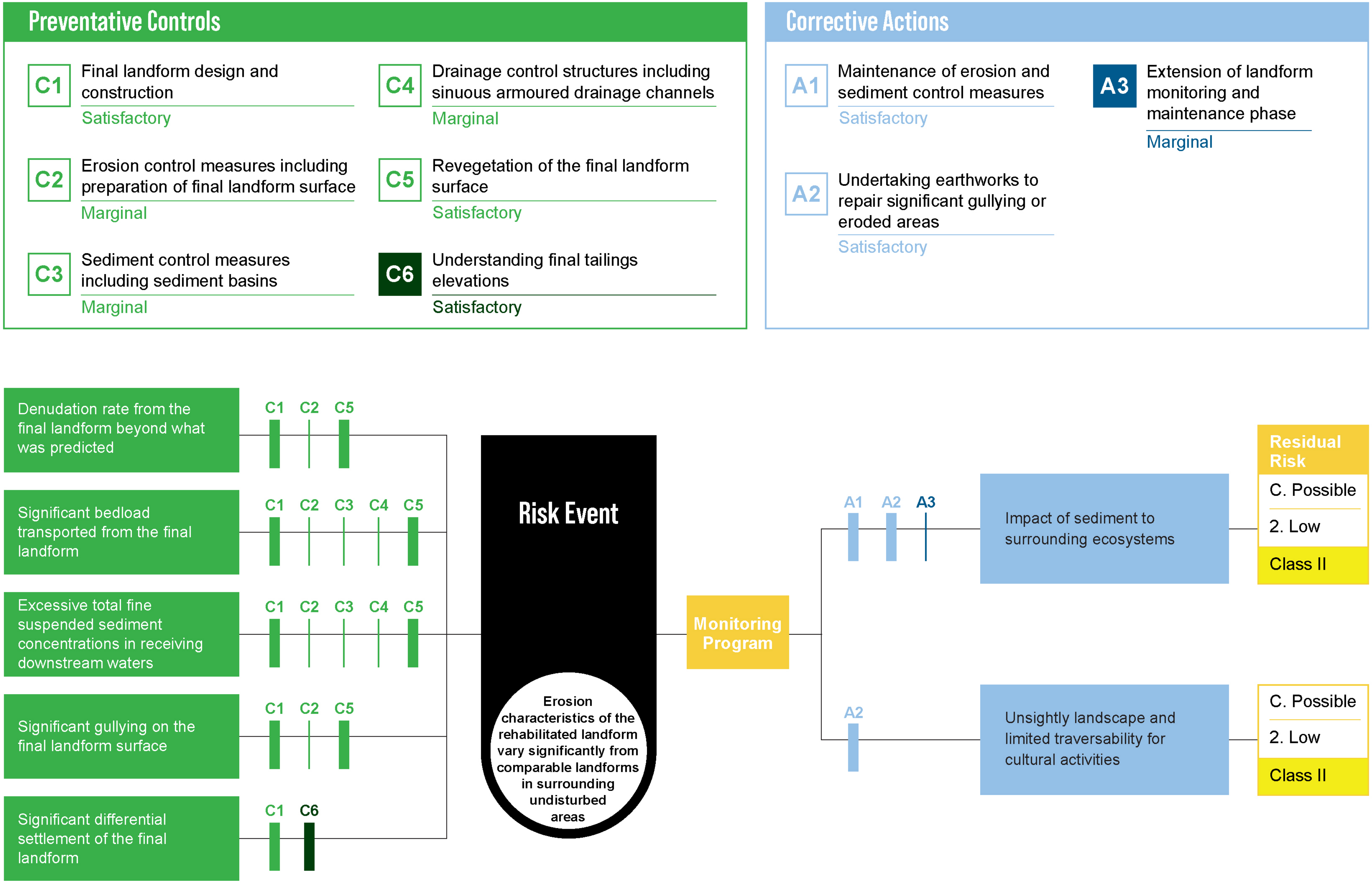


Figure 6-4: Bow-tie diagram for erosion characteristics (L1)

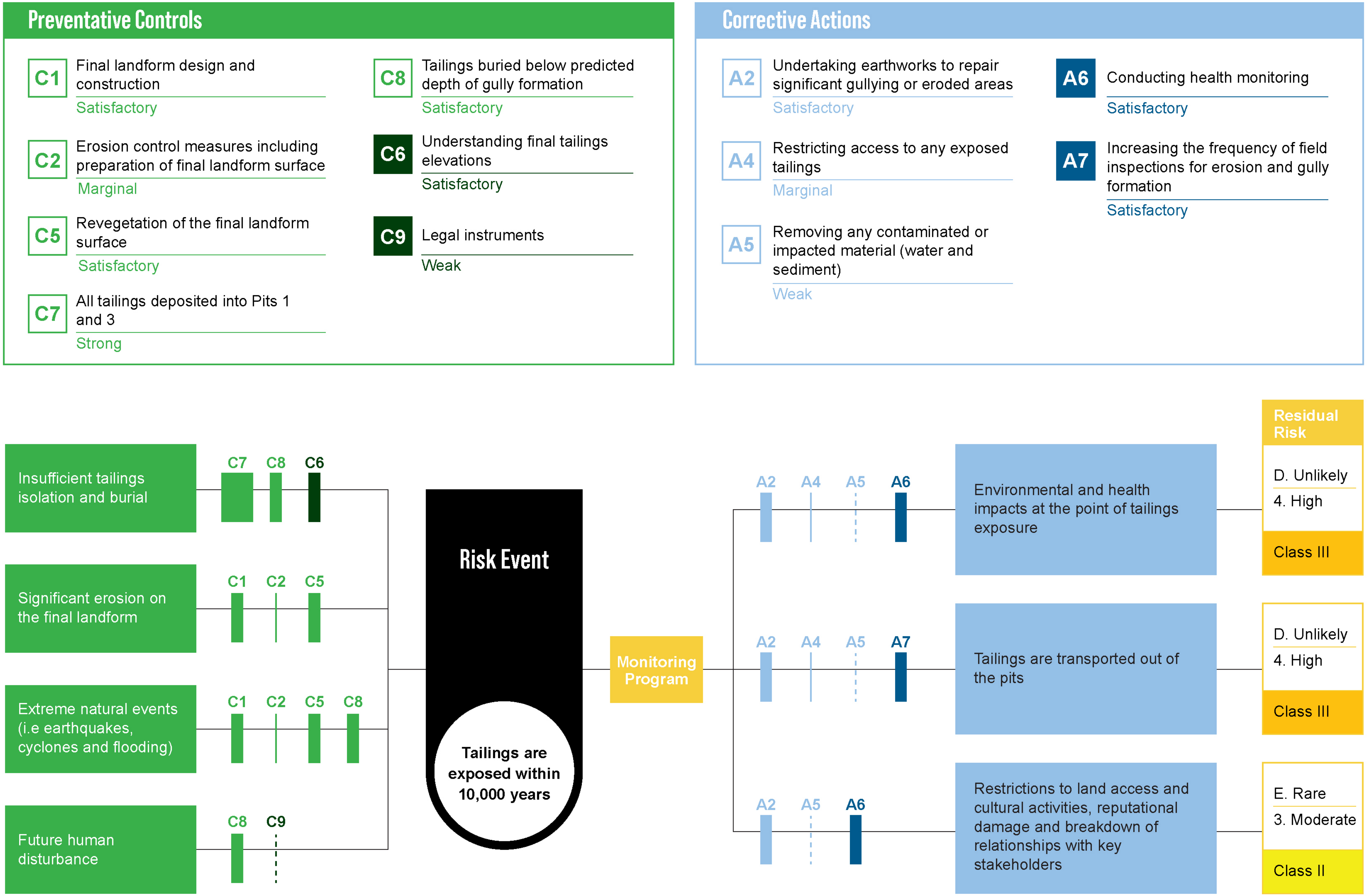


Figure 6-5: Bow-tie diagram for tailings isolation (L2)

6.5 Preventative Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well ERA understand and can demonstrate the effectiveness of the controls that will be put in place between now and the creation of the final landform, or shortly thereafter, to ensure that the landform ERs can be achieved or are on the desired trajectory to being achieved. The subjective assessment provided in the spider web diagram at the beginning of this chapter indicates that the current status of progress is 80%.

The basis of design for erosion characteristics is to minimise erosion and ensure that erosion does not vary significantly from those of comparable landforms in surrounding undisturbed areas of Kakadu National Park. ERA identified five threats that if realised, could lead to a variance in the erosion characterisations of the final landform:

- denudation rate from the final landform beyond what was predicted;
- significant bedload transported from the final landform;
- excessive total final suspended sediment concentrations in receiving waters;
- significant gullying on the final landform surface; and
- significant differential settlement of the final landform.

In addition, ERA identified four threats that if realised, could lead to tailings becoming exposed:

- insufficient tailings isolation and burial;
- significant erosion on the final landform;
- extreme natural events (i.e. earthquakes, cyclones and flooding); and
- future human disturbance.

With the above threats in mind, Table 6-8 outlines the preventative controls that will be implemented to manage these. The table also includes status and current rating of effectiveness for each preventative control (Table 5-1 describes the parameters used to rate the current effectiveness). The table is followed by a discussion of each preventative control.

Table 6-8: Preventative Controls for Landform

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C1	Final landform design and construction	Satisfactory	Modelling has demonstrated effectiveness of the current final landform design. However further work is planned to refine the final landform design and further reduce erosion and the denudation rate.
C2	Erosion control measures including preparation of final landform surface	Marginal	Currently at preliminary design with general consensus of the core principles, however further work is planned to incorporate catchment specific erosion and sediment control structures based on the assessments proposed to develop the *Erosion, Sediment and Water Control Plan.*

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
C3	Sediment control measures including sediment basins	Marginal	As above for erosion control structures and the proposed sediment basins are also currently at preliminary design. The location and size of these basins will be determined as part of the *Erosion, Sediment and Water Control Plan.*
C4	Drainage control structures including sinuous armoured drainage channels	Marginal	As above and another component that will be advanced as part of the *Erosion, Sediment and Water Control Plan.*
C5	Revegetation of the final landform surface	Satisfactory	ERA has demonstrated successful rehabilitation (~70% planting success rate) on Pit 1 after ~2 years and on the TLF after ~13 years. Monitoring data is available but further work is planned to finalise the species selection and demonstrate long-term sustainability of ecosystems on the final landform.
C7	All tailings deposited into Pits 1 and 3	Strong	'Strong' because all tailings have been deposited at depth into both Pit 1 and Pit 3.
C8	Tailings buried below predicted depth of gully formation	Satisfactory	Pit 1 has been backfilled with an average waste rock cover over the consolidated tailings of approximately ~9 m. Tailings are currently exposed in Pit 3 and therefore the effectiveness rating is currently 'Satisfactory' until they are buried. The planned average waste rock cover depth over the consolidated tailings is approximately ~27 m.
'Knowledge-based / Administrative' controls			
C6	Understanding final tailings elevations	Satisfactory	As described in Table 5-1 a rating of 'Satisfactory' is the highest rating being applied to knowledge/administrative controls as they have merit but in of themselves would not result in the achievement of an ER. The rating of 'Satisfactory' is applied to this control because the understanding is supported by comprehensive studies with accepted/approved methods and monitoring in Pit 1 that demonstrates the accuracy of the model. An appropriate monitoring and quality assurance program will also be implemented to confirm model predictions of tailings consolidation in Pit 3.
C9	Legal instruments	Weak	Not covered in any current plans and largely outside of the control of ERA over the 10,000 year period of tailings isolation.

6.5.1 Final landform design and construction

The surface layer of Pit 1 was constructed in August 2020 in accordance with the FLv6.2 design. Whilst only three years old, the relatively flat top surface has performed well in terms of minimal erosion (erosion has occurred and been rectified on the outer slopes where the surface dips quite steeply into the perimeter drain). The most recent update to the final landform design (FLv7) incorporates improvements that will be applicable to the entire final landform including channel designs, first order catchments, and concave slopes to maximise landform stability and revegetation success.

The overall control effectiveness has been ranked as 'satisfactory' considering some work is still required to inform the final landform design. The most recent assessment undertaken by OSS on FLv6.2 (Supervising Scientist, 2020a) indicates that the landform is unlikely to achieve the background denudation rate of 0.075 mm/a over a 10,000-year period. However, the current modelling is being undertaken under an extreme worst case rainfall scenario setting and assuming the absence of vegetation surface cover for all scenarios except the Corridor Creek catchment, which includes a basic ground/grass cover (Supervising Scientist, 2020a).

ERA will engage a geomorphic landform subject matter expert to review the FLv7 design to incorporate geomorphic principles, such as more defined ridges, drainage channels and concave slopes. Ongoing updates of the final landform design, incorporating stakeholder feedback, will be provided in future iterations of the MCP.

6.5.2 Erosion control measures including preparation of final landform surface

It is important that the Ranger final landform balances competing constraints. Some effective erosion control measures are not preferred at Ranger as they create a surface landform that is difficult to traverse on foot and/or increase water infiltration that may impact solute transport. Site experience in roughening regenerated landforms on the TLF by deep ripping has resulted in sub-optimal results. Single, widely spaced deep ripped furrows can be effective at reducing sediment load from a rehabilitated landform (Saynor *et al.,* 2017), however the deep ripping left sizable obstacles on the surface that did not provide a readily traversable area for pedestrian access. This issue has been raised by the Traditional Owners in reviewing revegetated areas of the TLF.

To reduce erosion and the resulting sediment movement, manage water infiltration, and maintain traversability for Traditional Owners, the final landform surface will be lightly scarified by a grader. The location and extent of scarification will be positioned to reduce surface runoff velocities that typically generate downstream scour. ERA will assess the need to deep rip any steeper slopes to prevent erosion on the final landform surface.

This preventative control has been rated as 'marginal' in Table 6-8. Surface preparation activities are a common and proven practice in mitigating erosion however, further work is required to develop a detailed execution strategy to meet the desired erosion control performance for each final landform catchment. The details regarding surface preparation activities and temporary and permanent erosion management treatments will be established through the development of the *Erosion, Sediment and Water Control Plan.*

6.5.3 Sediment control measures including sediment basins

Active water management will be required both during the construction of the final landform and for some years post construction until collected waters are suitable for direct release off-site. Sediment basins are being investigated as an option to manage sediment in the early years of creating the final landform. The basins may be created in sequence with the bulk material movement works scheduled for their source sub-catchment area. These basins may be located at the end of the constructed drainage lines of the final landform to capture transported sediment. An early concept is shown in Figure 4-22, noting that this concept is under assessment and as such will change.

The basins may be formed prior to the commencement of the revegetation process and would remain in place until agreed release water quality criteria can be demonstrated.

This preventative control has been rated as 'marginal' in Table 6-8. As noted in WSP-Golder's report (WSP-Golder, 2023) the current design for sediment basins is only at a concept stage. The detailed design will be assisted by data gathered on-site from the Stage 52 trial and will be substantially supported by additional studies associated with the development of the *Erosion, Sediment and Water Control Plan.*

6.5.4 Drainage control structures including sinuous armoured drainage channels

The placement of rock check dams within the most likely areas of erosion will be used to reduce the scour potential of drainage channels/paths. Rock check dams can be positioned in steeper regions of the landform where overland flow rates are highest, reducing the flow velocity of water and causing the deposition of heavier suspended sediments. Whilst rock check dams will assist in the removal of heavier sediments, it is noted that they are not designed to be a primary sediment control structure (i.e. they are designed to overtop). The rock check dams will be installed progressively as the final landform is created, prior to execution of revegetation activities. Once the planted tubestock have reached suitable size to resist surface water runoff flow, the rock check dams may be removed. This would be dependent on the time, quality and density of the revegetation establishment in each managed creek line.

The introduction of rock lined drains in areas where the landform design will increase stormwater flow velocities is another proven and preferred erosion mitigation technique. Rock lining of drainage structures can assist in protecting the bed and banks of drainage channels as the rock reduces the velocity and associated erosive tendencies of surface water flow.

Similar to sediment control measures, this preventative control has currently been rated as 'marginal' in Table 6-8. The detailed design for the infrastructure required to manage runoff will be substantially supported by additional studies associated with the development of the *Erosion, Sediment and Water Control Plan* and the optimisation of the final landform design.

6.5.5 Revegetation of final landform surface

Revegetation and ground cover can be one of the most effective forms of long-term erosion control. As vegetation cover is established, the plant roots will bind the soil/waste rock material together, the canopy will intercept direct rainfall on the surface, and the leaf matter and woody debris falling from vegetation will, in the longer term, help to protect the surface. Revegetation activities will occur progressively as distinct areas reach the designed final landform.

Revegetation to reduce erosion has been rated as 'Satisfactory' in Table 6-8. Whilst much progress has been made, this rating reflects the considerable number of studies that are underway but are yet to be completed to better inform final species composition and ecosystem viability on the final landform surface (e.g. waste rock characteristics to support long-term healthy growth). These studies are described in Chapter 9 and the effectiveness of this control will be improved, as those studies progress.

6.5.6 All tailings deposited into Pits 1 and 3

Tailings deposition within both Pit 1 and Pit 3 was completed in 2008 and 2021 respectively. There is no further work required to increase the effectiveness of this control, it is Strong.

6.5.7 Tailings buried below predicted depth of gully formation

The capping of tailings and backfilling of the Pit 1 void was completed in 2020. Approximately 13 Mt of waste rock was placed into the mined-out void of Pit 1, isolating the tailings from the surrounding environment. The average tailings level, as of June 2021, was +7.75 mRL and the fully consolidated tailings level is predicted to be +0.5 mRL. The Pit 1 landform elevation is at its highest along the western edge, where it reaches about +33 mRL, and lowest along its eastern edge, where it reaches about +21 mRL. Considering the depth of tailings and the elevation of the Pit 1 landform, the minimum thickness of waste rock covering tailings in Pit 1 is ~9 m.

The bulk backfill of Pit 3 will be an essential control that will prevent the exposure of tailings to the environment. The backfill of Pit 3 will place approximately 48.7 M m^3 of waste rock on top of the tailings. The 2022 consolidation model predicts the average tailings elevation at the end of consolidation to be -27.37 mRL (Fitton, 2022). The current Pit 3 landform elevation, as presented in FLv6.2, is at its highest along the south-western edge of the pit, where it reaches approximately +28 mRL and lowest along its north eastern edge, where it reaches about +16 mRL. Considering the depth of tailings and the conceptual elevation of the Pit 3 landform, the minimum thickness of waste rock covering tailings in Pit 3 is ~27 m. The final landform design may change, and the exact levels will continue to be amended in future iterations of the MCP.

This preventative control has been rated as ‘satisfactory’ in Table 6-8. The current modelling undertaken on FLv6.2 is showing predictions of 9 m and 7 m gullying for Pit 1 and 3 respectively. The effectiveness of this preventative control may be increased to ‘Strong’ if future iterations of the landform design reduce the depth of gullying and provide a greater buffer between the maximum gully depth and the top of the consolidated tailings in Pit 1.

6.5.8 Understanding final tailings elevations

Tailings consolidation modelling has been undertaken since 2003 with a number of model iterations being provided for both Pit 1 and Pit 3. These models allow the prediction of final tailings elevation and the forecast volume of process water to be expressed during consolidation. Section 6.3.2.1 details the history and current status of consolidation modelling for both pits.

The effectiveness of this control has been rated as ‘satisfactory’ in Table 6-8, reflecting that it is a knowledge-based / administrative control and therefore the highest rating is ‘Satisfactory’ (arguably the effectiveness could be rated as ‘Strong’ because the Pit 1 model was validated with 28 settlement plates). This control is based on a well-designed, validated and generally accepted model. ERA have developed an appropriate quality assurance and monitoring program to confirm the model predictions and this program has been used for Pit 1 with good success. The monitoring program will be extended to the Pit 3 tailings consolidation model. Whilst ERA have confidence in the consolidation modelling, uncertainty remains in some areas (e.g. the performance of the wicks may be less than predicted due to greater than expected collapse under the weight of the waste rock) and the effectiveness of this control will be updated as required in future iterations of the MCP.

6.5.9 Legal instruments

Legal instruments are typically used as a preventative control to reduce the risk of future human disturbance exposing tailings at mine sites, particularly uranium mines. The agreed post-mining land use of the RPA is Aboriginal land. Aboriginal land pertains to land held by a Land Trust for an estate in fee simple, in this instance, the Aboriginal Land Trust, subject to the *Aboriginal Land Rights (Northern Territory) Act 1976.*

Considering that the land will be returned to an Aboriginal Land Trust, extensive disturbance leading to the exposure of tailings is considered highly unlikely. Nevertheless, work will be required by ERA, in consultation with GAC, NLC and both the NT and Commonwealth governments, to formalise a process and mechanism to strengthen this control. At present, this control has been rated as 'Weak' in Table 6-8, which reflects the limited control that ERA will have over future legal instruments restricting human disturbance over the 10,000-year timeframe that tailings are to remain isolated.

6.6 Monitoring Program

The spider web diagram at the beginning of this chapter assigns a subject 80% progress status for landform monitoring. A series of comprehensive monitoring events (Table 6-9) will be undertaken throughout the closure and post-closure periods to track the progress and achievement of the closure criteria, and to trigger adaptive management and corrective actions (in the form of a TARP) if required (see Table 6-11). The closure and post-closure phase allow an adaptive management approach to site rehabilitation and closure, whereby the monitoring program provides ongoing feedback on the performance and accuracy of the modelled predictions and of the site's rehabilitation success and informs maintenance activities.

6.6.1 Turbidity monitoring

As discussed in Section 6.1, the difference in net annual turbidity between surface water monitoring points upstream and downstream on Magela and Gulungul creeks will be used to demonstrate achievement of turbidity closure criteria. Continuous turbidity monitoring will be undertaken during the wet season at various locations along Magela and Gulungul creeks.

Turbidity criterion is considered achieved when the difference in net annual turbidity between sites located upstream and downstream at the boundary of the RPA, for each of Magela and Gulungul creeks are comparable to background values over the course of five consecutive wet seasons once active sediment control structures have been removed.

ERA acknowledges that further work is required to develop a robust monitoring plan regarding turbidity in creeks and billabongs and are working with OSS on this matter.

6.6.2 Bedload monitoring

Post wet season inspections will determine whether bedload is moving from the constructed landform off the RPA. Field inspections of access roads and tracks will be conducted to identify any erosion on roads that may be a source of bedload moving offsite. Inspections will be undertaken biannually for five consecutive years. The results of field inspections will be captured with photographs and field notes, and records will be maintained, and corrective actions applied as necessary.

6.6.3 Inspections of temporary erosion and sediment control features

Temporary erosion and sediment control features will be inspected and maintained until their function is no longer required. Inspections of control measures will be undertaken on a monthly basis in the wet season and following rainfall that causes significant runoff (nominally >50 mm in 24 hours). A comprehensive pre-wet season inspection will be undertaken in November each year. Inspections will:

- check for erosion between rock check dams;
- check sediment basin inlets for erosion;
- check sediment basin walls for slumping or tunnelling;
- ensure the sediment storage zone within sediment basins have the required sediment storage capacity;
- assess rock check dams for build-up of sediment; and
- check the treatment and dewatering requirements for sediment basins.

Personnel undertaking the inspections will have a good working knowledge of the correct operation and maintenance procedure of the temporary erosion control structures used on-site. All inspections and any maintenance conducted (including desilting and repairs) will be recorded and records will be maintained.

Any deviation of erosion and sediment control function will induce adaptive management actions such as dewatering, de-silting or minor earthworks. The removal of sediment from sediment basins, whilst they are in place, will be undertaken if required following the wet season and minor repairs to sediment basin walls will be conducted as necessary. Reclaimed sediments will be deposited into RP2 prior to it reaching final landform.

6.6.4 Constructed landform monitoring

Following the construction of each final landform surface, a high-resolution digital elevation model (DEM) will be generated via LiDAR survey methods. It is expected that either airborne and/or terrestrial LiDAR (or equivalent) technology will be used to survey and capture the final landform topography.

The DEM will be analysed to compare the constructed surface elevation and landform to the approved landform design. One of the most important aspects of final landform construction is that ERA maintain the correct slopes of the approved final landform design. The DEM analysis will ensure that the constructed final landform meets the original design intent. If any significant deviation is identified, ERA can rectify the landform as part of closure execution activities.

Following the initial DEM survey, annual surveys will be undertaken following the wet season to detect year on year changes in surface topography across the final landform area. These annual surveys will provide direct data on landform settlement. Where the in-situ final landform varies significantly from the approved landform or subsequent survey results show critical erosion over tailings areas, the landform will be re-shaped until LEM results comply with the 10,000-year requirement to contain tailings. Annual topographic surveys will continue until changes in the landform are not significant. ERA will re-commence surveying if significant erosion (greater than what was predicted) occurs prior to site relinquishment.

This monitoring will also assist in identifying the leading indicators for landscape changes, informing the preparation works for the next year's wet season. That is, if annual topographic surveys identify potential signs of minor erosion, repair and remediation (including rock armouring) activities will be undertaken prior to the commencement of the wet season.

Annual topographic surveys will be complemented by pre and post-wet season field observations to characterise small topographic changes and to inspect the hydrological behaviour of the final landform surface. That is, to identify any unplanned gullying or erosion on the surface of the final landform area. These inspections will also inform subsequent maintenance, if required.

Following the initial settling of the landform (approximately five years), it is expected that no significant erosion will occur. ERA will, however, continue to undertake landform erosion inspections for ten years following the construction of the final landform.

6.6.5 Pit 3 tailings consolidation monitoring

Tailings settlement monitoring wells were installed in Pit 1 and will be in Pit 3 to monitor tailings settlement. These wells are also used to monitor water quality, water level and EC through the inclusion of drain slots to enable migration of water into the tower, and some in Pit 3 may also be configured for water extraction by being fitted out with submersible pumps. Some decant towers (when not being actively pumped) and monitoring towers will be used to measure the standing level of water in the capping layer across Pit 3 on a monthly basis.

During the construction phase of Pit 3, the decant structures will be safeguarded by a bunded exclusion zone. Only smaller earthworks equipment will have access to this zone, specifically for backfilling around and construction of the decant structures.

6.6.6 Material placement and landform construction monitoring

Material placement monitoring will be undertaken to ensure that bulk backfill is undertaken in accordance with the bulk material movement plan. ERA will complete monthly reconciliations of waste rock placed into Pit 3, using a combination of land based and aerial survey methods. Mine fleet management software will be integrated into the mining fleet to provide material movement data.

Frequent surveying and GPS guidance will enable the intended landform topography to be followed with a high degree of accuracy. Non-compliances will be discovered by survey during backfilling and will be rectified as operations continue or if any consolidation or compaction requires in-filling after construction. Tolerances on the final construction compared to design are driven by the size of equipment and rock material being handled. These will be of the order of + / - 0.5 m at drainage boundaries and + / - 1 m elsewhere.

Table 6-9: Landform monitoring

Aspect	Objective/s	Method	Variable	Frequency
Turbidity monitoring	Compare annual difference in turbidity between surface water monitoring points upstream and downstream of Magela and Gulungul creeks (MG009, GCLB, MCUS & GCC)	Turbidity monitoring.	Annual difference in turbidity.	Continuous in the wet season.
Bedload monitoring	Identify any erosion on access tracks that may be source of bedload moving offsite.	Field assessment of access roads.	Potential erosion or sediment deposition.	Biannually for five years post landform construction.
Temporary erosion and sediment control structure inspections	Confirm erosion control structures are function effectively	Field inspections of erosion and sediment control structures on the final landform surface.	Condition and status of erosion and sediment control structures.	Monthly during the wet season until the removal of temporary erosion and sediment control structures.
Constructed landform inspections	Comparison of year-on-year DEM change to quantity final landform surface erosion and sedimentation	Topographic Survey.	Surface elevation.	Annually until changes in the landform are not significant. Contingency for event based DEMs from 11's years through to relinquishment.
	Identify gully erosion	Field assessment of final landform surface.	Field notes.	Biannually pre and post -wet season (ten years post landform construction).
Pit 3 tailings consolidation monitoring	Confirm tailings consolidation for validation against model	Settlement monitoring towers.	Change in level of settlement.	Monthly until plateau of measured tailings consolidation.
Material Placement and Bulk Backfill	Confirm material balance allows for the construction of the approved final landform design	Fleet Management Software.	Material load placement log.	Continuous during landform construction.
		Survey.	Regular surface levels.	Monthly survey.

6.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subject 70% progress status for 'corrective actions'. The successful execution and effectiveness of the controls presented throughout this MCP chapter are expected to result in the achievement of landform closure criteria. If monitoring identifies erosion or gullying on the final landform that is greater than predicted, or a deviation of the landform trajectory, the relevant corrective action/s from the list below will be implemented:

- maintenance of erosion and sediment control measures;
- undertaking earthworks to repair significant gullying;
- extending the period required for active erosion and sediment control;
- restricting access to any exposed tailings;
- removing any contaminated or impacted material (i.e. contaminated sediment);
- conducting health monitoring; and
- increasing the frequency of field inspections for erosion and gully formation.

Table 6-10 outlines a number of corrective actions, along with their status and effectiveness.

Table 6-10: Corrective Actions for Landform

Unique Identifier	Corrective Actions	Current Effectiveness	Status of Effectiveness
'Active' corrective actions			
A1	Maintenance of erosion and sediment control measures	Satisfactory	Erosion and sediment control measures will be maintained in a working and proper order throughout the closure and post-closure periods up until relinquishment.
A2	Undertaking earthworks to repair significant gullying or eroded areas	Satisfactory	These activities will occur prior to relinquishment if greater than predicted gullying is observed. Material erosion and gullying that occurs throughout the closure and post-closure periods will be actively managed.
A4	Restricting access to any exposed tailings	Marginal	Whilst neither planned nor desirable, restricting access to an area of potential tailings exposure is a marginal corrective action until the area can be remediated as per the above corrective actions.
A5	Removing any contaminated or impacted material (e.g. water and sediment)	Weak	If monitoring detects contaminated material has been transported from the mine disturbance area it will be remediated up until relinquishment. Should this corrective action be required after relinquishment, there is uncertainty regarding resources available to execute this corrective action due to the extended period of tailings isolation.
'Knowledge-based / Administrative' corrective actions			
A3	Extension of landform monitoring and maintenance phase	Marginal	The base case premise of retaining catchment sediment basins for two wet seasons will be monitored and the use and maintenance of the basins or similarly effective controls will be extended if the runoff is not achieving agreed criteria.

Unique Identifier	Corrective Actions	Current Effectiveness	Status of Effectiveness
A6	Conducting health monitoring	Satisfactory	Accepted and common practice, and ERA resources would be available up until relinquishment. This would only occur in the event of an incident that triggered the need.
A7	Increasing the frequency of field inspections for erosion and gully formation	Satisfactory	Accepted practice, linked to data, well-designed, resources are available but in of itself would not lead to recovery of the trajectory so this corrective action would be coupled with the relevant action/s listed above.

6.8 Trigger, Action, Response Plan

Table 6-11 consolidates the monitoring and adaptive management programs described above into the form of a trigger, action, response plan. The below TARP is based on our current understanding. and may change or be further refined depending on the outcomes of future works as they evolve. This TARP will be updated as required in future iterations of the MCP.

Table 6-11: Trigger, Action, Response Plan for Landform

Bedload monitoring			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Nil erosion identified.	Minor erosion identified.	Significant erosion identified.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Closure Field Officer/Technical Officer	Continue routine monitoring as per the monitoring framework.	Report identified erosion to supervisor. Increase monitoring frequently to monthly in the wet season. Take a number of photos for month-on-month comparison.	Report escalation of erosion to supervisor. Increase monitoring frequently to fortnightly in the wet season. Continue to take photos for comparison.
Closure Superintendent – Water and Landform	No Action.	Notify Supervisor – Civil works on areas of erosion. Review the need to install erosion control measures and undertake remedial earth works.	Engage Supervisor – Civil Works to commence remediation. Execute corrective earthworks and installation of erosion control measures.
Closure Supervisor – Civil Works	No Action.	Assist in the development of a site-specific remediation plan.	Execute works in accordance with the site-specific remediation plan.

Inspections of temporary erosion and sediment control features			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Erosion and sediment control structures are operating as per design.	Significant accumulated sediment is identified within rock check dams or sediment basins that does not yet impacting the function of the structure.	Significant accumulated sediment is identified within rock check dams or sediment basins that may impact the function of the structure.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Closure Field Officer/Technical Officer	Continue routine monitoring as per the monitoring framework.	Report identified sediment deposition to supervisor. Take a number of photos for month-on-month comparison.	Report escalation of sediment deposition to supervisor. Increase monitoring frequently to fortnightly in wet season. Continue to take photos for comparison.

Inspections of temporary erosion and sediment control features			
Closure Superintendent – Water and Landform	No Action.	Notify Supervisor – Civil works on areas of identified sedimentation build up.	Engage Supervisor – Civil Works to commence remediation. Execute corrective earthworks.
Closure Supervisor – Civil Works	No Action.	Organise the removal of accumulated sediment at the end of the wet-season.	Organise the prompt removal of accumulated sediment.

Constructed landform monitoring			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	No change from previous survey. Nil or minor erosion identified and not beyond modelled erosion.	Minor change from previous survey. Minor erosion identified.	Significant change from previous survey. Significant erosion identified.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Closure Field Officer/Technical Officer	Continue routine monitoring as per the monitoring framework.	Report identified erosion to supervisor. Increase monitoring frequently to monthly in the wet season. Take a number of photos for month-on-month comparison.	Report escalation of erosion to supervisor. Increase monitoring frequently to fortnightly in wet season. Continue to take photos for comparison.
Drone Operator / GIS Data Specialist	Continue routine monitoring as per the monitoring framework.	Report identified erosion to supervisor. Increase monitoring frequently to monthly in the wet season.	Report escalation of erosion to supervisor. Continue monthly monitoring in the wet season.
Closure Superintendent – Water and Landform	No Action.	Notify Supervisor – Civil works on areas of erosion. Review the need to undertake infill revegetation activities or corrective earthworks.	Organise the execution of corrective earthworks and infill revegetation activities as required.
Closure Supervisor – Civil Works	No Action.	Assist in the development of a site-specific remediation plan as required.	Execute works in accordance with the site-specific remediation plan as required.

Pit 3 tailings consolidation monitoring			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Monitoring suggests tailings consolidation preceding in accordance with the tailings consolidation model.	Monitoring suggests tailings consolidation varies >15% across the whole pit area.	Monitoring suggests tailings consolidation varies >25% across the whole pit area.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Pit 3 Area Owner	Continue to undertake monitoring monthly until plateau of measured tailings consolidation.	Review potential causes for variance in tailings consolidation. Continue to operate the decant structures and treat the express water until the consolidation target is achieved.	Re-run the tailings consolidation model. Report escalation of identified deviation to supervisor. Continue to operate the decant structures and treat the express water until the consolidation target is achieved.

Material balance review			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Quarterly review of material balance suggests compliance with approved final landform design.	Quarterly review of material balance suggests a potential construction variance of +/- 1 m from approved final landform design.	Quarterly review of material balance suggests a potential construction variance of +/- 2 m from approved final landform design.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Mine Surveyor / BMM Superintendent	Continue to undertake quarterly reviews of the material balance.	Report identified deviation to supervisor.	Report escalation of identified deviation to supervisor.
Closure Manager	No Action.	Review potential causes for variance in material balance.	Rereview potential causes for variance in material balance and assess the need to re-design final landform.

6.9 Future Work

The spider web diagram at the beginning of this chapter provided a subjective progress status for the landform theme. Where <100% is indicated, future work is occurring, planned and/or required. The future work listed is based on our current understanding. These studies may change or be further refined, removed or added to depending on the outcomes of the studies as they evolve. The following outlines the future work for each of the metrics shown in the spider web diagram:

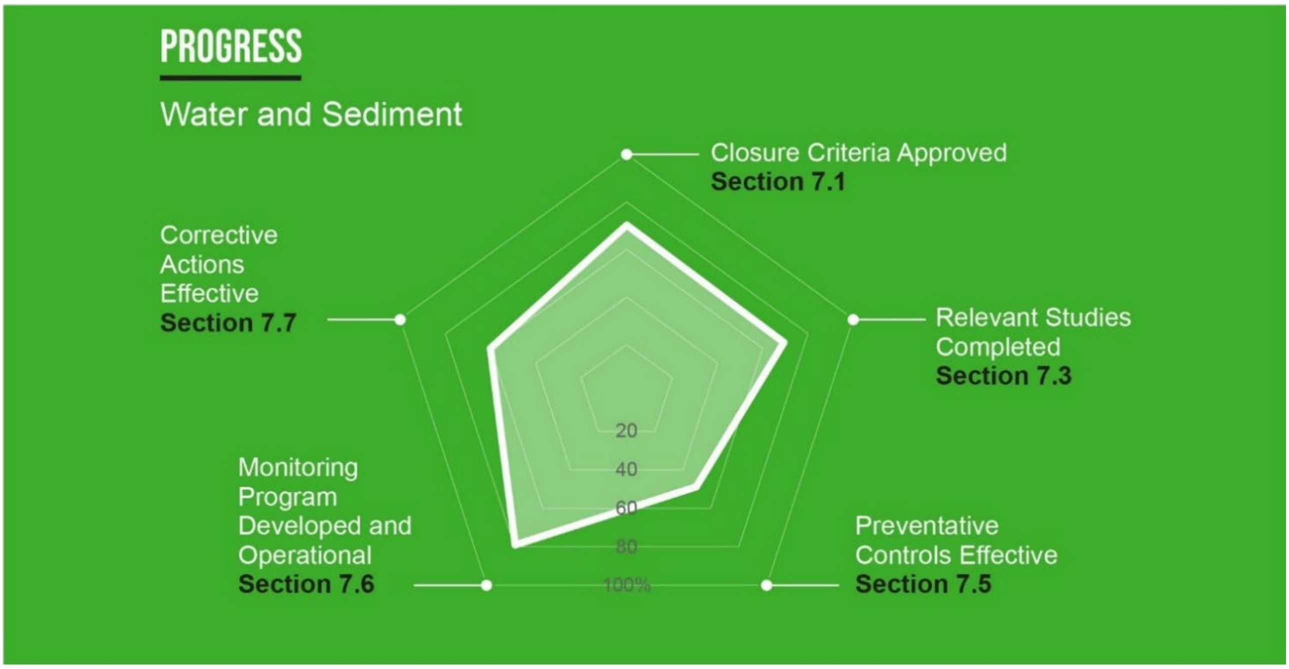
- Closure Criteria approved (80%):
  - Seek ministerial approval in this MCP to update the background denudation rate from 0.04 mm/a to 0.075 mm/a.
  - Seek Ministerial approval in this MCP for the closure criterion related to turbidity.
- Relevant studies completed (70%):
  - Development of an *Erosion, Sediment and Water Control Plan*: ERA have commenced studies to inform an *Erosion, Sediment and Water Control Plan*. These studies and the resulting plan will define the design of long-term erosion and sediment control structures that will be installed on the final landform surface. The conceptual design of the surface water management infrastructure and the details of the temporary and permanent erosion management treatments will be discussed in the FLF application that is submitted to regulators for approval.
  - The outcomes of the *Erosion, Sediment and Water Control Plan* (erosion and sediment control structure designs) will be incorporated into the final landform design and submitted to OSS for assessment as part of the FLF application.
  - ERA will engage a geomorphic landform subject matter expert to assess the landform evolution modelling parameters and equations and review the FLv7 design to incorporate geomorphic principles, such as more defined ridges, drainage channels and concave slopes. ERA will continue to work collaboratively with OSS to define the parameters to be used in future landform evolution modelling and in the iterative process of design, assess, revise and assess until the modelling demonstrates achievement of the agreed closure criteria.
  - ERA will continue to monitor the consolidation of Pit 1 and Pit 3 tailings in accordance with Section 6.6.5. If monitoring identifies a variance in the rate of tailings consolidation, the tailings consolidation model will be reviewed and updated.
- Preventative controls effective (80%):
  - The development of the *Erosion, Sediment and Water Control Plan* will increase the effectiveness of the preventative controls related to the erosion, sediment and drainage control structures that will be installed on the final landform surface.
  - Future work will be required by ERA, in consultation with GAC, NLC and both the NT and Commonwealth governments, to formalise a process and mechanisms to strengthen the legal instruments that are in place to prevent future human disturbance of the isolated tailings.

- Monitoring program developed and operational (80%):
  - Future work will be undertaken to better inform the monitoring that will be used to assess achievement of turbidity criteria.
- Corrective actions effective (70%):
  - Considering the extensive timeframe (10,000 years), there is considerable uncertainty regarding the resources that would be available to execute certain corrective actions due to the 10,000 year tailings isolation requirement.

7 WATER AND SEDIMENT

The purpose of this chapter is to consolidate information relevant to the water and sediment theme. An indication of progress against key metrics is summarised in the spider diagram below, it shows:

- Six closure criteria have been developed for this theme, three of which received Ministerial approval in 2021, with the remaining three well developed but not yet approved as further studies to inform the criteria are continuing (70%, Section 7.1).
- Project specific studies are advanced and will continue to progress throughout the closure period. Further work will be undertaken to reduce uncertainty in both groundwater and surface water modelling, and the spatial and temporal aspects of CoPC movement off the RPA, and the potential impacts to ecosystem health. Studies have commenced to further develop location specific ASS conceptual models (70%, Section 7.3).
- Several preventative controls for this theme are well understood and considered to have a satisfactory to strong effectiveness. Within each control the level of effectiveness can vary for different CoPC and on a spatial and temporal scale. Further investigation to improve the performance of controls for specific CoPC and locations is being undertaken (50%, Section 7.5).
- A monitoring program has been developed and will be implemented through the closure phase to collect data to validate the groundwater and surface water models, and to demonstrate that the receiving environment is protected from contamination. Future aquatic ecosystem monitoring is required to strengthen the knowledge base of these environments (80%, Section 7.6).
- There is reasonable confidence in the effectiveness of corrective actions, however further work will be required to improve our understanding of long-term treatment and management, and the practical implementation of adaptive management actions post-closure (60%, Section 7.7).



7.1 Closure Objectives and Criteria

Table 7-1 lists the ERs relevant to the water and sediment theme.

Table 7-1: Water and Sediment Theme: Environmental Requirements

Environmental Requirement	ER Reference
1 Environmental Protection ***1.1*** *The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:* *(c) protect the health of Aboriginals and other members of the regional community.*	1.1(c)
1.2 *The company must ensure that operations at Ranger Mine do not result in:* *(c) an adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.*	1.2(c)
(d) change to biodiversity, or impairment of ecosystem health, outside of the RPA. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region.	1.2(d)
(e) environmental impacts within the RPA which are not ALARA, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	1.2(e)
3 Water Quality *3.1 The company must not allow either surface or ground waters arising or discharged from the RPA during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.*	3.1
11 Management of tailings *11.3 (ii) - Any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.*	11.3 (ii)

7.1.1 Water Quality Management Framework

ERA is using the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG 2018) Water Quality Management Framework (WQMF) for developing agreed water and sediment quality objectives (Figure 7-1).

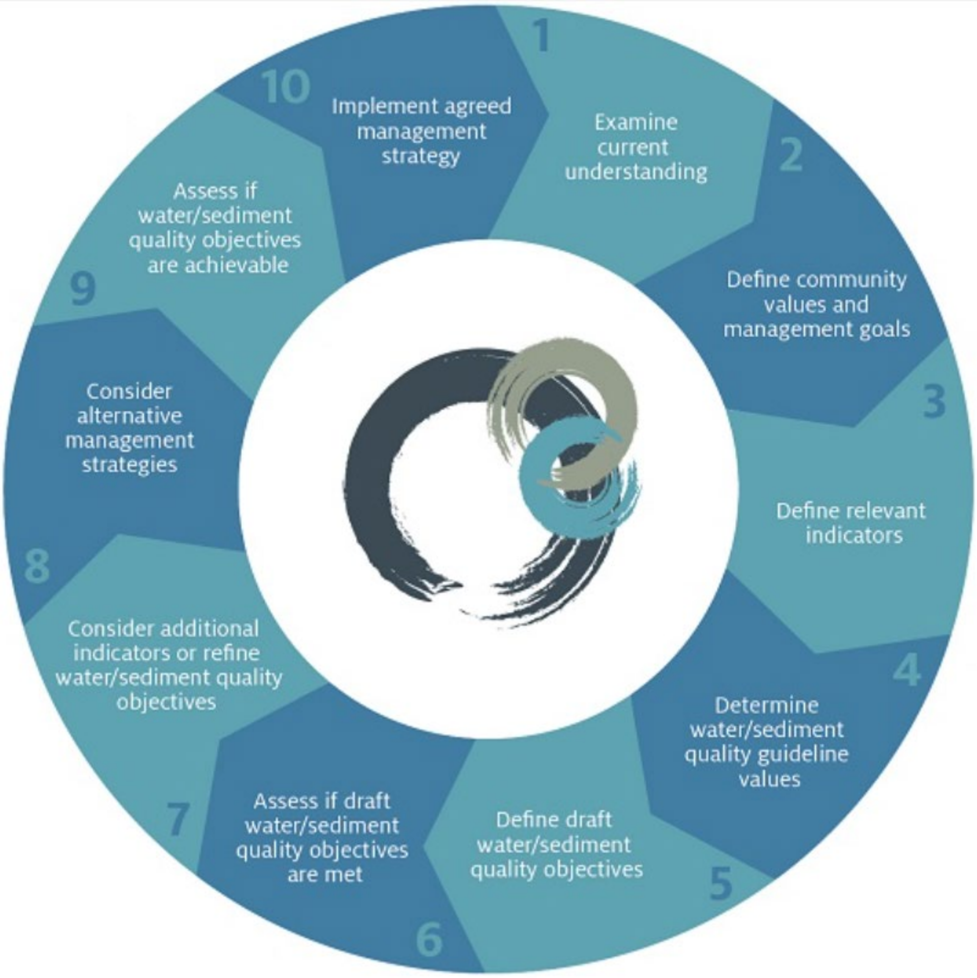


Figure 7-1: The Water Quality Management Framework (ANZG, 2018)

The language of the WQMF differs from that used in other closure criteria themes. In this section the *outcome* has been replaced with the term *management goal* from the WQMF, *parameter* replaced by *indicator* and *criteria* has been replaced with the term *water or sediment quality objectives (W/SQO)*. As explained in Section 7.1.2, under the WQMF, water/sediment quality guideline values are identified for each management goal. The most stringent of these guideline values is then chosen as the draft or final W/SQO.

The water and sediment *management goals* and *indicators* are set out in Table 7-2. The same indicator appears against several management outcomes but with different guideline values (e.g. there is a higher guideline value for drinking water than for ecosystem protection for a given indicator). In most cases the ecosystem protection guideline values are more stringent than guideline values for other management objectives including human drinking water. The guideline values for ecosystem protection are therefore proposed as the final W/SQO for application off the RPA and as draft W/SQO for on the RPA. This is indicated in Table 7-2 by underlined italicised type with the final provided in a separate column for ease of interpretation. This reflects progress against steps one to five in the WQMF (Figure 7-1).

Steps 6 to 10 in the WQMF provide a framework for assessing if draft W/SQO can be met, gathering more information, revising the draft W/SQO if appropriate, and eventual agreement on a final W/SQO for each indicator to adopt as closure criteria. This process is important to derive and agree on final W/SQO for waterbodies on the RPA where impacts are to be ALARA. As this final process has yet to be agreed with stakeholders, including Traditional Owners, these remain as draft guideline values and are presented in a separate table (Table 7-3).

7.1.2 Objectives and management goals

The ERs that have relevance to the theme of water and sediment (refer Table 7-1) are grouped under three objectives. There are approved guideline values for each of the three objectives shown in Table 7-2 (for which Ministerial approval is sought), and draft guideline values for each of the three objectives shown in Table 7-3.

Environmental Requirement 3.1 is central to the three management objectives:

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

The primary environmental objectives essentially being no detrimental impact to human health or the environment of Kakadu National Park.

Table 7-2: Approved guideline values for each management goal – most stringent and therefore adopted GV in italics and underlined

ER	Objective	Management Goal	Indicator	Guideline Values for each management theme[1]	Draft Water/Sediment Quality Objectives[2] (Closure Criteria)
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary intake of bush food and water to exceed human consumption limits.	Drinking water: Mn, NO_3, NO_2, SO_4^{2-}, U	Water quality off the RPA meets the national drinking water health guidelines (at those water bodies and times used by Traditional Owners for drinking, to be confirmed (TBC)) • SO_4^{2-} 500 mg/L, Mn 500 µg/L, NO_3 50 mg/L, *NO_2 3 mg/L*, U 17 µg/L (NHMRC, 2011 & NRMMC, 2011; v3.5 updated 2018).	$NO_2 \leq 3$ mg/L
		Mine derived hazards will not cause unacceptable visual amenity or water quality to exceed recreational guideline values for secondary contact at sites identified for recreational value.	Toxic or irritant chemicals: NO^3, NO_2, U, SO_4^{2-}, Mn	Water quality off the RPA meets the national recreational guidelines for secondary contact (at those water bodies and times used by Traditional Owners for drinking TBC) • NO_3 500 mg/L, NO_2 30 mg/L, U 170 µg/L, Mn 5 mg/L (i.e. drinking water CoPC x 10: NHMRC, 2008). • SO_4^{2-} 400 mg/L (ANZECC & ARMCANZ, 2000 irritants, no guidelines for irritants/toxicants in NHMRC, 2008).	-
			Visual clarity and surface films	No mine related change causes turbidity to be statistically significantly increased over natural background values. Oil and petrochemicals not to be noticeable as a visible film on the water or be detectable by odour.	-

ER	Objective	Management Goal	Indicator	Guideline Values for each management theme[1]	Draft Water/Sediment Quality Objectives[2] (Closure Criteria)
3.1 and 1.2(d) 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger Mine do not result in: Change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	Mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Ammonia, manganese, uranium, magnesium, (magnesium: calcium mass ratio), sulfate, copper & zinc[3].	OSS Rehabilitation Standards are met in Magela and Gulungul creeks off the RPA: *Dissolved total ammonia nitrogen; 0.4 mg/L (pH and temperature dependant)* *Dissolved magnesium; 2.9 mg/L (72-hour moving average)* *Dissolved magnesium to calcium (Mg:Ca) mass ratio; no greater than 9:1* *Dissolved sulfate; 10 mg/L (seasonal average)* *Dissolved uranium; 2.8 µg/L (72 h moving average)* *Dissolved manganese; 75 µg/L (72 h moving average)* *Dissolved copper; 0.5 µg/L (72 h moving average)* *Dissolved zinc; 1.5 µg/L (72 h moving average)*	Dissolved total ammonia nitrogen ≤ 0.4 mg/L (pH and temperature dependant) Dissolved magnesium ≤ 2.9 mg/L (72-hour moving average) Dissolved magnesium to calcium (Mg:Ca) mass ratio no greater than 9:1 Dissolved sulfate ≤ 10 mg/L (seasonal average) Dissolved uranium ≤ 2.8 µg/L (72 h moving average) Dissolved manganese ≤ 75 µg/L (72 h moving average) Dissolved copper ≤ 0.5 µg/L (72 h moving average) Dissolved zinc ≤ 1.5 µg/L (72 h moving average)
		Mine sourced solutes do not increase U in sediments off the RPA to levels that would be detrimental to ecosystem health.	Uranium in sediments	*Uranium in sediments does not exceed 100 mg/kg dry weight (whole sediment; weak acid extractable digestion method)*	Uranium in sediments ≤ 100 mg/kg dry weight (whole sediment; weak acid extractable digestion method)

[1] Most stringent GV are taken as the draft W/SQO (draft as per step 5 in the WQMF).

[2] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 7.1.3.

[3] Turbidity is included in the landform criteria – see Chapter 6.

Table 7-3: Draft water and sediment quality objectives under review

ER	Objective	Management Goal	Indicator	Water/Sediment Quality Objectives under review
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary intake of bush food and water to exceed human consumption limits.	Diet parameters TBC with expert opinion.	Local diet model demonstrates that ingestion of mine derived constituents of potential concern (CoPC) via aquatic and terrestrial bush foods and drinking water does not cause annual intakes to exceed any relevant national/international tolerable intake levels.
3.1, 1.2(e) and 2.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	Surface water and sediment quality on the RPA is demonstrated to be as low as reasonably achievable (ALARA).	As for off the RPA listed above.	The predicted water quality for the closure scenario demonstrated (and accepted by stakeholders) to be ALARA following the WQMF and the process outlined in Section 7.1.3. Parameter values TBC.

ER	Objective	Management Goal	Indicator	Water/Sediment Quality Objectives under review
3.1 and 1.2(d) 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger Mine do not result in: Change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	Mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Nutrients.	Nutrient criteria for preventing eutrophication are still under review.

7.1.3 Justification for outcome, parameter and criteria

As described above, ERA is following the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018) WQMF to provide a process for stakeholders to develop agreed water quality objectives that apply both on and off the RPA.

The WQMF provides a sequential stepwise approach (Figure 7-1) to setting management goals through to assessing, refining and deriving W/SQO. Steps 1 to 5 are relevant to developing closure criteria for both on and off the RPA. Steps 6 onward are relevant for developing criteria for impacts that are ALARA, which only applies to waterbodies on the RPA.

It is important to note that Traditional Owners have reported concerns about trying to integrate cultural values with the 'scientific, legal and technical domains of a process that will take place within a framework controlled by those from the dominant non-Indigenous culture' (Garde, 2015). The application of this framework has been, and will continue to be, discussed with stakeholders, including the representatives of the Traditional Owners through working groups, consultative forums and site visits. This is particularly important for agreeing on management goals for waterbodies on the RPA at Step 2 and reviewing the following steps to align with and meet the agreed values for these on-site waterbodies.

The following sections describe the ten-step framework, and a high-level description of information available, for developing a water management plan and assessing a remediation strategy (ANZG, 2018). Both are relevant to deriving closure criteria.

7.1.3.1 Step 1. Examine current understanding

To inform decisions at subsequent steps, develop conceptual models of how the waterway systems work, the issues they face and how to manage them.

The understanding of how the Magela Creek system works and mine related issues is well advanced after almost 40 years of research and monitoring related to the RPA and surrounds (refer to studies listed in the publicly available OSS bibliography and throughout this document).

Several key assessments and conceptual models relevant to the closure phase for water and sediment inform this step. For example:

- KKN's for closure (Supervising Scientist, 2017) have been based on source, pathway, receptor models and environmental risk assessments of Ranger (Pollino *et al*., 2013; Pollino, 2014; Bartolo *et al.,* 2013). The knowledge base is updated as progress against the KKNs is reported (see Appendix 5.1 for full list of KKNs).
- An assessment of important ecological processes in the Alligator Rivers Region, to inform an ecological risk assessment (Bartolo *et al*., 2018).
- Peer reviewed groundwater and surface water assessments and models (e.g. ERM, 2020a; INTERA, 2019, 2020, 2021a, 2021b, 2022, 2023a and 2023b; Water Solutions, 2018, 2021a and 2021b).
- Linkages between ground and surface water (INTERA, 2021b) and between hydrological processes and ecosystem dynamics (BMT, 2017).

- A site wide Acid Sulfate Soil (ASS) source, pathway, receptor conceptual model (ERM, 2020b) and characterisation of ASS on the RPA and in receiving downstream waterbodies (ERA, 2021a; CDM Smith, 2023).
- Assessments of soil and sediment contamination (ERA, 2022a; ERM, 2020c; Stantec, 2023).
- Discussions of Indigenous world views on the environment, including water (Garde, 2015).
- The aquatic pathways risk assessment (APRA) (Iles, 2023; BMT, 2023a) and vulnerability assessment framework (VAF) (BMT, 2022a, 2023b).
- An ongoing review by OSS of emerging contaminants.

7.1.3.2 Step 2. Define community values and management goal

Define community values and establish or refine more-specific management goals (including level of protection) for the relevant waterways at stakeholder involvement workshops.

The ERs listed above provide high-level management goals for the rehabilitation of the RPA relevant to the water and sediment theme. Water quality guideline values have been set for some of these goals (Table 7-2). Additional management goals for water and sediment have been identified that need to be considered further by stakeholders. For example:

- The Traditional Owners and the OSS have indicated that a goal of no change to biodiversity on the RPA is preferred.
- Garde (2015) describes the community's cultural expectations and expected uses of the rehabilitated area. Hunting, cultural and recreational use of water is included.
- Garde (2015) states the waters contained within all riparian corridors (i.e. rivers and billabongs), must be of a quality that is commensurate with non-affected riverine systems and health standards.

A stakeholder workshop in 2017 identified the water types on and surrounding the RPA and the environmental values for each water type based on the environmental requirements and stakeholder expectations (BMT WBM, 2017). The current natural World Heritage Values that occur on the RPA have been documented (Everett *et al.,* 2021).

During 2021 and 2022, Traditional Owner's visited water bodies on the RPA as part of the cultural reconnection program. Information exchanged at these visits is important for refining the management goals for the waterbodies on the RPA.

7.1.3.3 Step 3. Define relevant indicators

Select indicators for relevant pressures identified for the system, the associated stressors and the anticipated ecosystem receptors.

Indicators have been identified for the operational phase of the mine through many years of research, monitoring and application of the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) water quality guidelines (e.g. Brown *et al.,* 1985; Turner and Jones, 2010, Frostick *et al.*, 2012).

Iles and Humphrey (2014) reviewed the literature on release standards for constituents of potential concern (CoPC) present in ore, process water and waste rock sources, and identified those needing a hazard assessment and/or requiring closure criteria.

Other work relevant to selecting indicators for closure water quality management are:

- The development of endpoints and indicators for the protection of biodiversity (Supervising Scientist, 2002) and that they reflect the environmental values of water bodies both on and off the RPA. These include indicators for health and cultural uses and the Ramsar and Kakadu National Park World Heritage values (BMT, 2017, 2021).
- The review of conceptual model endpoints and important ecological processes (Bartolo *et al.,* 2018).
- The definition of key ecological components underpinning the environmental requirements of the RPA and surrounds and the interactions with underpinning processes (BMT, 2017).
- The development, in consultation with Traditional Owners, of indicators for cultural closure criteria, including some for water. Specific indicators for remediation goals for wet landscapes on the RPA will need to be identified with Traditional Owners.
- The identification of uranium as the key CoPC in reports on accumulation of metals in contaminated sediments on the RPA. Other metals showed limited enrichment even in the sediments of the waste water treatment wetlands (Iles *et al.,* 2010; Parry, 2016; Esslemont and Iles 2017; ERA, 2022a).
- The selection of indicators for drinking water and recreation from NHMRC and NRMMC (2011; v3.5 updated 2018) and NHMRC (2008) based on the surface water CoPC identified by Frostick and others (2012).

7.1.3.4 Step 4. Determine water/sediment quality guideline values

Determine the water/sediment quality guideline values for each of the relevant indicators required to provide the desired level of protection (if applicable) for the management goals for relevant waterways.

Diet and recreation

Guideline values for drinking water are from the Australian drinking water guidelines NHMRC and NRMMC (2011; v3.5 updated 2018).

In addition to comparing predicted CoPC concentrations to these guideline values, a preliminary assessment of risk from water quality to the traditional diet, including drinking water, has been undertaken and is presented in this chapter. This assessment will be updated as further refinement to the water quality model is undertaken and the results will be included in future iterations of the MCP.

The Australian recreation guidelines (NHMRC, 2008) provide recreation water quality guidelines for chemical hazards, pH and dissolved oxygen, and suggest using ten times the drinking water guidelines as a simple screening approach to identify CoPC that may merit further consideration where waters might be swallowed during recreation. NHMRC (2008) also says *"…waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes…"* However the NHMRC (2008) guidelines do not provide a list of irritants or guideline values for such chemicals, whereas ANZECC and ARMCANZ (2000) do. The recreational guideline value for sulfate was therefore taken from ANZECC and ARMCANZ (2000). The same parameters identified for drinking water are used as suggested above. It is noted that the recreational guideline values for sulfate is more restrictive than using the drinking water times ten approach.

The lower range in Magela Creek is less than the pH guideline suggested for poorly buffered low ionic strength waters by NHMRC (2008). Turner and others (2015) demonstrated that the natural range of pH in Magela Creek is 4.7 to 7.9, and highly variable, and considered it *"highly unlikely that a quantity of mine derived water sufficient to significantly alter the pH in Magela and Gulungul creeks could be released"* and removed pH from the list of compliance parameters. Considering this, pH is not considered a parameter that requires a guideline value for recreation purposes. Should future acid sulfate soils studies indicate a potential risk, consideration will be given to the inclusion of a guideline value for pH.

Dissolved oxygen is also highly variable in the seasonal waterbodies on and off the RPA and there has been no requirement for compliance monitoring of dissolved oxygen for several decades at Ranger. Dissolved oxygen is also not considered a parameter that requires a guideline value for recreation purposes.

Ecosystem protection

Guideline values for high-level ecosystem protection have been derived by the OSS and reported in their publicly available Rehabilitation Standard Series. These are identified as being applicable at the lease boundary in Magela and Gulungul creeks. Meeting these guideline values at the lease boundary provides an assurance that no change will occur to the offsite biodiversity. The scientific basis for the OSS water quality rehabilitation standards for ammonia, manganese, uranium, magnesium, (magnesium:calcium ratio), sulfate, copper, zinc, turbidity and sedimentation are described in each standard. The guideline value for uranium in surface water was found to protect against sediment toxicity effects considering the potential for accumulation and de-adsorption from sediment back to surface waters at unacceptable concentrations. This could negate the need for a uranium guideline value for sediment (Supervising Scientist, 2021b). However, ERA has adopted the OSS site-specific guideline values for uranium in both water and sediment as closure criteria.

Guideline values based on ecotoxicity studies by the OSS are available for species protection levels of 99%, 95%, 90% and 85%. Guideline values for 99 % species protection are currently used as the OSS rehabilitation standard for application off the RPA. These are adopted as draft water quality objectives for protecting the ecosystem off the RPA. While these conservative values do ensure that changes to ecosystem off the RPA are not different or detrimental and there will not be any detrimental environmental impact; adopting alternative, less conservative values, following the WQMF wheel does not mean that the objectives of different and detrimental will not be achieved. These assessments form part of the next phases of the wheel.

The closure objective for water quality on the RPA (Table 7-3), reflecting ER 1.2e is *Impacts on the RPA are ALARA (derived following the WQMF and the ALARA process outlined in BPTs, with input from stakeholders).*

7.1.3.5 Step 5. Define draft water/sediment quality objectives

Use the guideline values or narrative statements chosen for each selected indicator as draft water/sediment quality objectives to ensure the protection of all identified community values and their management goals (ANZG, 2018)*. Choose the most stringent of the guideline values for the water/sediment quality objectives* (ANZG, 2018)*.*

For water, the same indicator appears against several management objectives in Table 7-2. The ecosystem protection guideline values are more stringent than guideline values for the same parameter for other management objectives. The most stringent of the guideline values for each indicator is italicised and underlined.

This step of the WQMF would select the most restrictive of the guideline values to be proposed as draft water or sediment quality objectives and in the later steps of the WQMF these can be reviewed if not achievable. This is a relevant process for deriving closure criteria that are ALARA for on the RPA. However, for closure criteria off the RPA the most stringent guideline value is proposed (identified in Table 7-3 in the column draft water/sediment quality objective). It is still relevant to retain less stringent guideline values against the relevant management options to support an assessment of each goal.

ANZG (2018) supports narrative statements (as opposed to numeric values) as guideline values and W/SQO. For waterbodies on the RPA some narrative draft W/SQO are used (Table 7-2 and Table 7-3) to state both the objective and the process by which the numeric criteria for ALARA impacts are being derived.

7.1.3.6 Step 6. Assess whether draft water/sediment quality objectives are met

Use measurements from the monitoring of each relevant indicator to assess whether current water/sediment quality meets the draft water/sediment quality objectives (ANZG, 2018).

ERA has engaged consultants to use numerical models to predict the concentration and loads of a range of contaminants in surface water on, and downstream of Ranger after mine closure (Section 7.3.4). The predicted concentrations of these CoPC were compared to guideline values for each theme in the *Water pathways risk assessment project* (see Section 7.3.6).

Predicted concentrations of several CoPCs (Water Solutions, 2021a) are higher than the ecosystem and/or human health guideline values at some locations on and off the RPA. The models are being reviewed as are mitigation actions (see step 8) to reduce the concentration of contaminants reporting to the water bodies on and off the RPA. The water quality objectives can also be reviewed as per step 7.

If concentrations exceed the guideline values, this does not necessarily imply that impacts will occur. Rather, further assessment is required to understand the implications of exceeding the guideline values. This type of tiered assessment is common to many guideline frameworks (e.g. EnHealth, 2012; NHMRC, 2008; NHMRC and NRMMC, 2011) and is also recommended in the WQMF under steps 7, 8 and 9.

7.1.3.7 Step 7. Consider additional indicators or refine the water/sediment quality objectives

Assess the need to revise or add to the lines of evidence or indicators and the water/sediment quality guideline values (ANZG, 2018).

Guideline values for different levels of species protection are available for most CoPCs from the ecotoxicity studies of OSS or from ANZG (2018). Additional indicators and lines of evidence are being reviewed or are already available.

BMT has been working with ERA and stakeholders since 2017 in a three-phase project to:

- Identify preliminary ecological and cultural endpoints for each of the primary environmental objectives (BMT WBM, 2017).
- Map environmental values for different water types on and off the RPA (BMT, 2017).
- Develop a risk-based vulnerability assessment framework considering impact components such as duration, geographic extent and resilience, to determine how different concentrations of magnesium and manganese (potentially the most restrictive contaminants of concern) might affect these endpoints. This involves considering direct sensitivity of multiple ecosystem component indicators to magnesium and manganese concentrations and indirect sensitivity via other factors affecting vulnerability, such as habitat, diet, reproduction and dispersion (BMT, 2021 and 2022a) (Section 7.3.7 provides a description of the project).

A review of local nutrient data and a risk assessment of eutrophication is being conducted by ERA and OSS (the focus of KKN WS6; see Appendix 5.1).

The sensitivity of the following ecosystem components to mine impacted water has been assessed: riparian species, migrating fish, macroinvertebrates at different stages of creek flow, and stygofauna in the sandy creek beds (Hutley *et al.,* 2021; Crook *et al.,* 2021; Mooney *et al.,* 2020; Chandler *et al.,* 2021).

7.1.3.8 Step 8. Consider alternative management strategies

Evaluate the effectiveness of current management strategies to address the identified water quality issues and recommend possible improvements. Improved or alternative management strategies are to be formulated, assessed and prioritised.

The recent *Water pathways risk assessment* project identified risks to the aquatic ecosystem related to contaminant levels from the current mine closure strategy (see Section 7.3.6). Actions have been identified to assess options to manage the contaminant sources creating these risks.

Consideration of alternative management options, considering community, environmental and cost aspects are common to both ALARA and BPT assessments used at ERA.

The BPT assessment process compares different management options and ranks them against each other based on scores for each of the BPT criteria (see Appendix 4.2). This includes criteria categories for water quality and environment protection. All scores are combined to form a single value, and the different options are ranked. The option with the best score is typically deemed the best practicable technology.

ERA has identified a process that iteratively combines management/mitigation options assessments with a risk management framework to identify a closure strategy based on BPT and demonstrates impacts that are ALARA (Figure 7-2 (bottom)). This is a process that is followed as part of the combined BPT process and risk management framework.

ERA proposes that the analyte concentration associated with the option that is considered BPT-ALARA is the water quality proposed ALARA criteria for on the RPA. This aligns with the ALARA approach for radiation protection described by Oudiz and others (1986), shown in the top process chart in Figure 7-2.

7.1.3.9 Step 9. Assess whether water/sediment quality objectives are achievable

Use information gained from Steps 6 to 8 to assess whether the water/sediment quality objectives are achievable.

As discussed, at Step 6 predicted water quality post-closure will be compared with the agreed objectives for ecosystem protection on-site and offsite. This was done in the *Water pathways risk assessment* project and management/mitigation actions identified where GV exceedances resulted in high or critical risks. The risk assessment will be conducted again as updated information on predicted water quality for different management options becomes available. As shown in Figure 7-2 this is an iterative process.

7.1.3.10 Step 10. Implement agreed management strategies

Document and implement agreed management strategies, including, in some cases, a suitable and agreed adaptive management framework.

The results of the iterative management options assessments and proposed management strategies will be discussed with stakeholders through consultative fora. Proposed management strategies will be documented in applications to stakeholders and regulators for approval for key activities. Monitoring and adaptive management frameworks will be developed with input from stakeholders. This is a topic being advanced with guidance from the Alligator Rivers Region Technical Committee (ARRTC). Applications will include descriptions of mitigations and management actions and the results of BPT and risk assessments to demonstrate the proposed strategy and resulting water quality results in impacts that are ALARA.

Stakeholder feedback will occur again at this stage. Future MCPs will be updated with a record of progress.

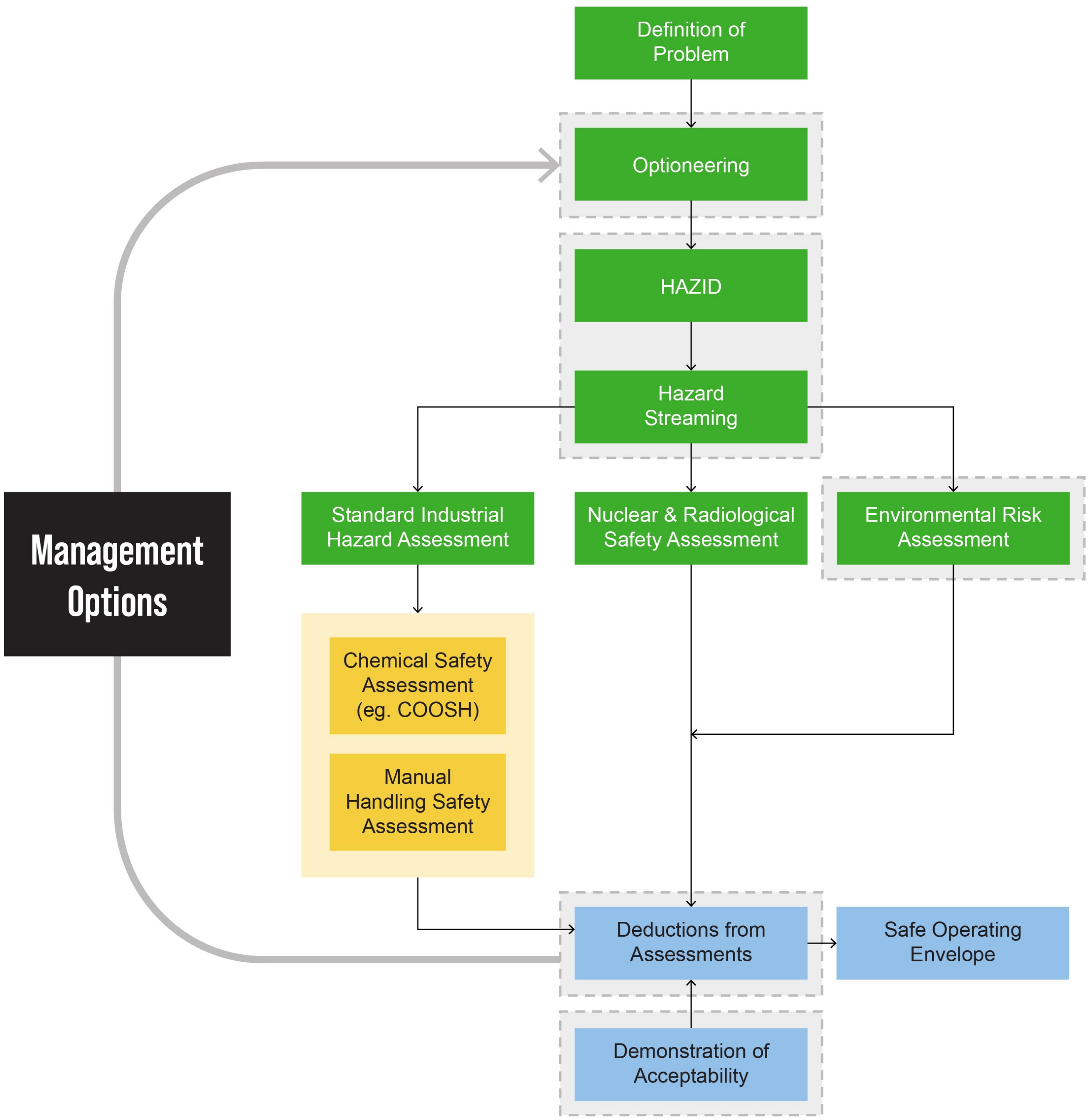


Figure 7-2: (Top) The main features of the ALARA procedure (Oudiz *et al.*, 1986) and (Bottom) Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (from Bryant *et al.*, 2017)

7.2 Design elements

Chapter 4 describes the closure activities completed and yet to occur at Ranger. Of most relevance to the water and sediment theme, it is noted that:

- Implementation of water treatment and management processes to ensure both pond and process water inventories reach zero at closure (Section 4.3.2).
- Use of wetland filters to passively treat water prior to release (Section 4.3.3).
- Tailings has been deposited deep into both Pit 1 and Pit 3 (Section 4.1.1 and Section 4.2.3 respectively).
- A constructed underdrain on top of the underfill for Pit 3, to facilitate the removal of process water released during the consolidation of overlying tailings (PTF), and to enable abstraction via the underdrain bore of water displaced upward from the underfill (Section 4.2.2).
- Installation of wicks into the tailings of Pit 1 and Pit 3 to facilitate tailings consolidation. Overall, the wicking system complements the underdrain system by providing additional measures to accelerate tailings consolidation and the extraction of PTF for treatment (Section 4.1.2 and Section 4.2.4 respectively).
- Injection of brine produced from the Brine Concentrator into the Pit 3 underfill to allow for proper and permanent disposal as per the outcomes of a BPT (Section 4.2.2).
- All mineralised material (grade 2s and above) will be placed below the height in the pit that will ultimately form the post closure conservative long-term average water level (Section 4.8).
- All demolished and contaminated material will be disposed into Pit 3 and RP2 and buried below the predicted long-term average water level (Section 4.4.2).
- The RWD sub-floor material will remain in situ and may be capped with a layer of clay sourced from the walls of the RWD before proceeding with the creation of the final landform to manage contamination and the risks of solute egress into the existing groundwater plume below the RWD (Section 4.5.4.2).
- The final surface landform of the RWD will be constructed to form a drainage flow path running south to north to restore for Traditional Owners the pre-mining Coonjimba Creek.
- Erosion control structures and sediment basins will likely be installed on the final landform (see Chapter 6 for description).

7.3 Relevant Studies / Knowledge Base

The spider web diagram at the beginning of this chapter assigns a subjective 70% complete for the progress status relating to ‘relevant studies and knowledge base’. This acknowledges the substantial understanding gained through many studies over several decades, whilst recognising that further work is required.

This section describes the relevant studies that have been undertaken and the knowledge base obtained to inform the achievement of the closure criteria and thus the ERs. A summary of the studies and knowledge development relevant to the water and sediment theme are summarised below (Section 7.3.1 to Section 7.3.10). A number of these studies are ongoing and a summary of the works yet to be completed are also described (Section 7.3.11).

7.3.1 Ranger Conceptual Model

Several KKNs (WS1, 2 and 3; see Appendix 5.1) ask questions around characterising contaminant sources and predicting their transport into the environment via groundwater and surface water. Groundwater flow, surface water flow and solute migration within and from the RPA over temporal and spatial scales has informed decommissioning and closure decisions in alignment with regulatory environmental controls and rehabilitation requirements.

Numerous iterative studies and models over the life of the mine have been developed to understand and document these often-complex hydrogeological processes and characteristics. These models assess the setting, identify the source areas, the CoPCs, transport pathways and receptors such as soil, groundwater and surface water on and off the RPA during closure and post-closure.

Understanding and quantifying groundwater to surface water interaction forms a key component for linking the groundwater solute transport model to the surface water model. The groundwater to surface water interactions relate to the timing and location of groundwater flow, and in turn the potential for solute transport from groundwater into the receiving environments. Understanding this relationship and accurately representing it in the modelling is vital to accurately predict the possible contamination concentrations in the receiving environment.

A significant body of work has gone into the development of a conceptual model for Ranger including an updated site-wide conceptual model in 2019, and refinements to various components of the model throughout 2020-2023 (INTERA, 2021b, 2022, 2023a). The Ranger conceptual model comprises multiple interrelated conceptual models spanning three different spatial scales (INTERA, 2016):

- regional- scale conceptual model: describes the geologic and hydrologic features and processes within the part of the Magela Creek watershed that encompasses the mine;
- sitewide-scale conceptual model: focuses more tightly on the geologic and hydrogeologic setting and hydrology in the mine area and describes the important elements for understanding CoPC migration within the overall mine area;
- smallest scale conceptual model: focuses even more tightly on the CoPC sources at the individual mine workings or features.

Groundwater generally flows northward across the operational area towards Magela Creek. This groundwater movement occurs within reasonably defined groundwater sheds, which broadly correlate with surface water catchments. The main groundwater sheds relevant to Ranger activities are (Figure 7-3):

- Corridor Creek (associated with the Corridor Creek and Georgetown Creek catchments);
- Djalkmarra (associated with the former Djalkmarra Creek catchment);
- Coonjimba; and
- Gulungul.

All groundwater sheds feed into the Magela groundwater shed. Groundwater movement from the Corridor Creek, Djalkmarra and Coonjimba groundwater sheds move into the Magela Creek groundwater shed on the RPA (Figure 7-3). However, the connection between the Gulungul and Magela groundwater sheds occurs approximately 5 km to the north of the RPA, at the confluence of Gulungul Creek and Magela Creek (Figure 7-3). INTERA (2021b) details a conceptual understanding of the surface water / groundwater interaction into Magela Creek based on a review of bore level and creek flow data, as well as a review of groundwater and surface water chemistry.

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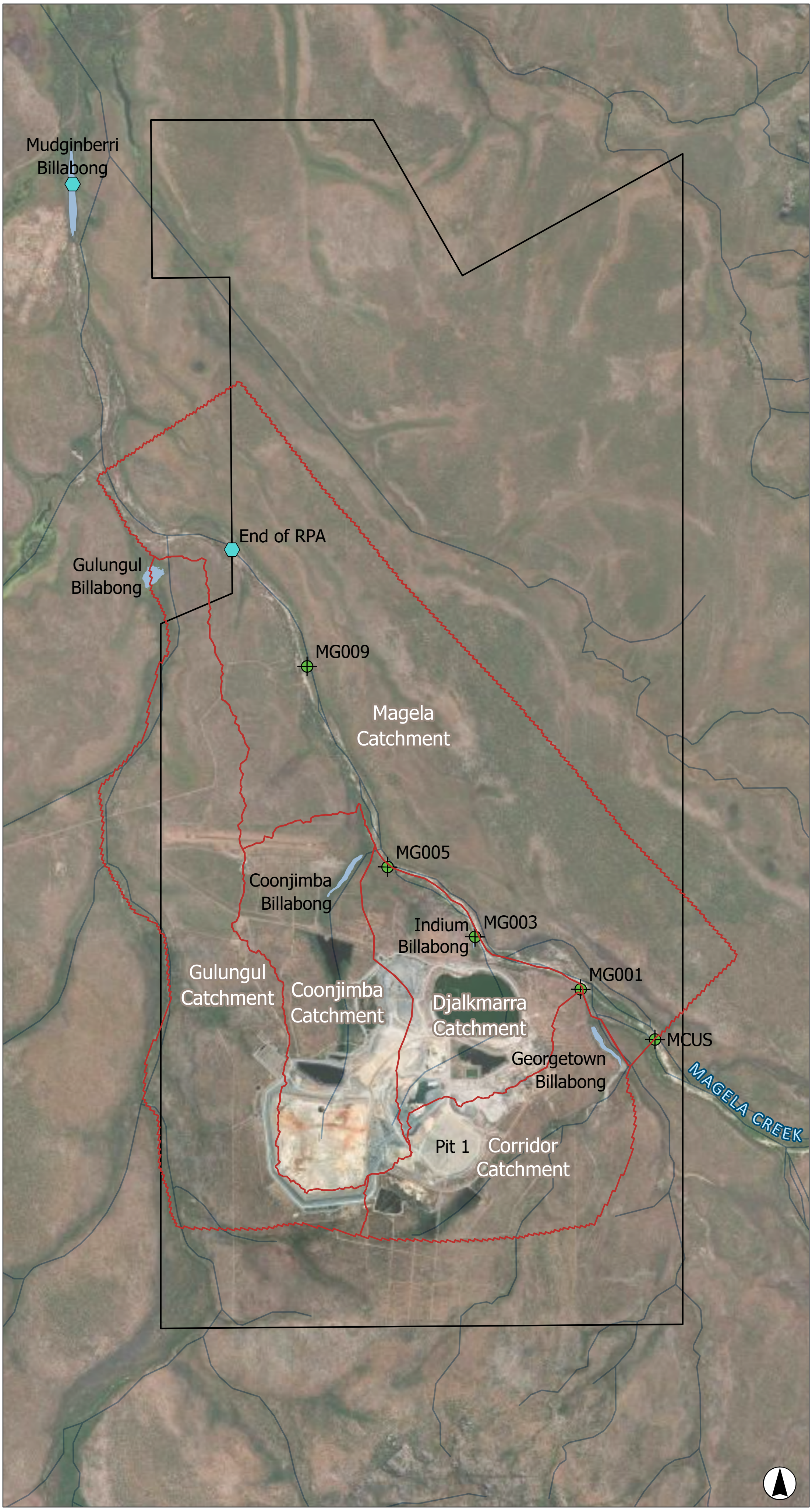
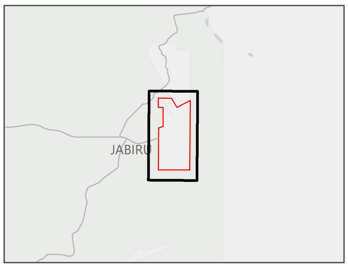
FIGURE 7-3

Ranger Mine Sitewide Groundwater Sheds



LEGEND

- Ranger Project Area
- Groundwater Watershed Boundary
- Waterbody
- Watercourse
- Modelling Assessment Point
- Surface Water Monitoring Site



0 1 2

Kilometres

Scale 1:65,000 at A4

GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

7.3.2 Source Terms and CoPC

Groundwater source terms are an important aspect in assessing environmental impacts from activities at Ranger. The source terms are used as inputs for groundwater transport models constructed to estimate loading of CoPCs from groundwater to surface waters after mine closure. Evaluation of source terms has been conducted for:

- previous models of groundwater loading from Pit 3 and Pit 1 (INTERA, 2014a, 2014b respectively);
- development of the areas of interest conceptual models as part of the overall Ranger conceptual model (INTERA, 2016);
- the updated conceptual models for Ranger mine source terms in groundwater (INTERA, 2019, 2021b and 2022);
- updates to select Pit 3 source terms (INTERA, 2022, 2023a, 2023b) for use in the Pit 3 uncertainty analysis; and
- updates to RWD inside plume source terms (INTERA, 2023c).

Groundwater source terms at Ranger and their location are summarised in Table 7-4.

Table 7-4: Ranger source terms and their locations

Source Term	Location
Pit 3 tailings	in Pit 3
Pit 3 Pit Tailings Flux (PTF)	in Pit 3
High Density Sludge (HDS)	in Pit 3
Brine	in Pit 3
Other potential sources	in Pit 3 and/or RP2
Saturated Zone Waste Rock (SZ WR)	in Pit 3 and Pit 1 backfill and within the extent of the final landform
Vadose Zone (VZ) WR leachate	within the extent of the final landform
Pit 1 tailings	in Pit 1
Pit 1 PTF	In Pit 1
RWD Plume	beneath and in the vicinity of the TSF
Stockpile plumes	beneath the historical stockpiles
Processing plant area (PPA) plume	beneath and downgradient of the PPA
RP2 plume	beneath and downgradient of RP2
LAAs	beneath and downgradient of the LAAs

The 20 solutes that are possible CoPCs for Ranger sources are summarised in Table 7-5. A solute is defined as a CoPC if its concentration in the source term is greater than the background threshold value (BTV) concentration determined for the solute by ERM (2020a). ERM (2020a) developed BTVs specific for the hydrolithologic units (HLUs) at the mine when data were available. A HLU can consist of a single geologic unit, part of a geologic unit, cross geologic units and mining related units in the subsurface that will be in contact with groundwater. HLUs can be aquifers or aquitards depending on their permeability. All material in which groundwater flows is assigned to a HLU, and the HLUs are the building blocks for the material components of the groundwater flow model.

Table 7-5: Solutes that are potential CoPC at Ranger and their BTVs in HLUs

Solute	Abbreviation	Unit	HLU Specific BTV Concentration		
			S-WC	D-WC	S-BC
Aluminium	Al	µg/L	27.6	ND	TFW
Cadmium	Cd		ND	ND	ND
Calcium	Ca	not included in ERM (2020a) study			
Chromium	Cr		ND	ND	ND
Copper	Cu	µg/L	3.8	ND	TFW
Iron	Fe	not included in ERM (2020a) study			
Magnesium	Mg	mg/L	11.1	57.9	21.7
Manganese	Mn	µg/L	483	87.5	190
Nickel	Ni		ND	ND	ND
Nitrate	NO_3-N	mg/L	3.17	0.554	0.022
Total Phosphorus	P total		ND	ND	ND
Lead	Pb	µg/L	0.9	ND	TFW
Polonium 210	Po210	not included in ERM (2020a) study			
Radium 226	Ra226	mBq/L	27.3	50	130
Selenium	Se		ND	ND	ND
Sulfate	SO_4^{2-}	mg/L	1.88	4.3	1.5
Total Ammoniacal Nitrogen	TAN	mg/L	0.005	0.005	TFW
Uranium	U	µg/L	3.03	21.9	7.74
Vanadium	V		ND	ND	ND
Zinc	Zn	µg/L	13	ND	TFW

Green highlighted cells = background threshold value (BTV) for HLUs with sufficient bores and data
Orange highlighted cells = proxy values recommended as BTVs for HLUs and analytes with low detection frequencies and/or insufficient data
µg/L – micrograms per litre
mg/L – milligrams per litre
mBq/L – millibecquerels per litre
ND – no data
TFS – too few samples
TFW – too few wells

7.3.3 Groundwater Modelling and Uncertainty Analysis

INTERA conducted a sitewide Ranger groundwater uncertainty analysis (INTERA, 2020) that aimed to provide probabilistic predictions of CoPC transport from mine site sources to surface water receptors. Results from the uncertainty analysis supported the assessment of expected environmental outcomes after mine closure from all solute sources and for all groundwater sheds at the Ranger site (this work addresses KKN WS2 and informs KKN WS3; see Appendix 5.1).

Further to the original Ranger groundwater uncertainty analysis (INTERA, 2020), an uncertainty analysis was conducted to provide probabilistic estimates of CoPC loading to Magela Creek derived from Pit 3-specific source terms only, based on updates to pit closure activities and newly acquired knowledge for model inputs INTERA (2023a). Figure 7-4 shows the modelled annual loads of magnesium associated with Pit 3 related sources over 300 years for the 398 realisations run for the Pit 3 uncertainty analysis. Figure 7-4 also shows the 'base case' groundwater model predictions of magnesium loads which assumes mean values of all parameters varied in the Pit 3 uncertainty analysis. Figure 7-5 shows the individual contributions of each modelled Pit 3 source in the realisation which provided the median (P50) modelled peak load of magnesium from the 398 realisations run. There have been no changes in the conceptualisations of the other mine site sources since the Ranger groundwater uncertainty analysis and, as such, there was no need to re-assess loading from these sources at this time.

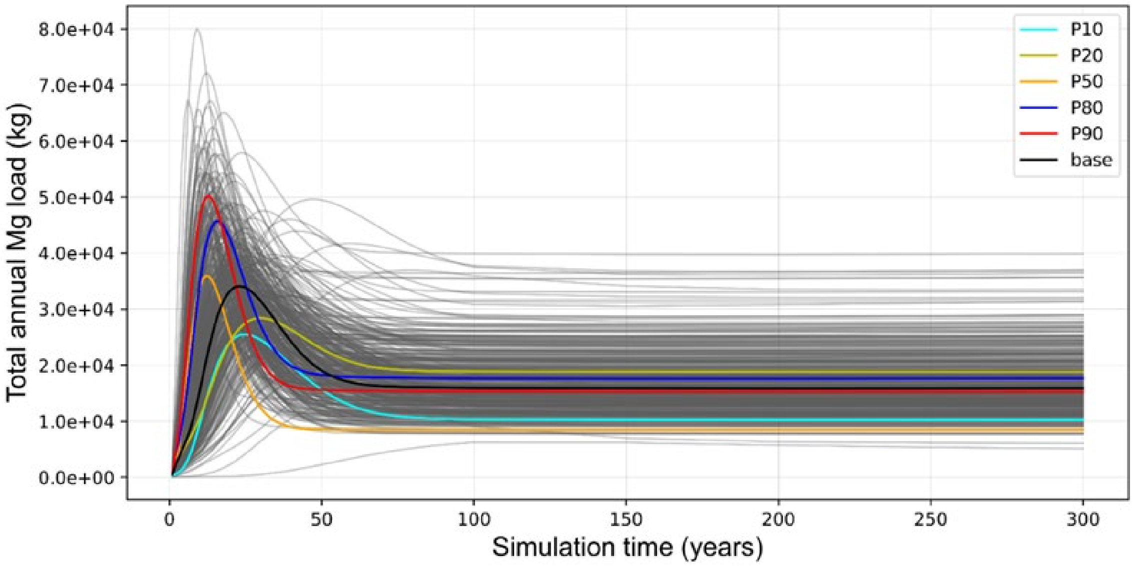


Figure 7-4: Horsetail plot of Pit 3 uncertainty analysis modelled magnesium loads from Pit 3 sources

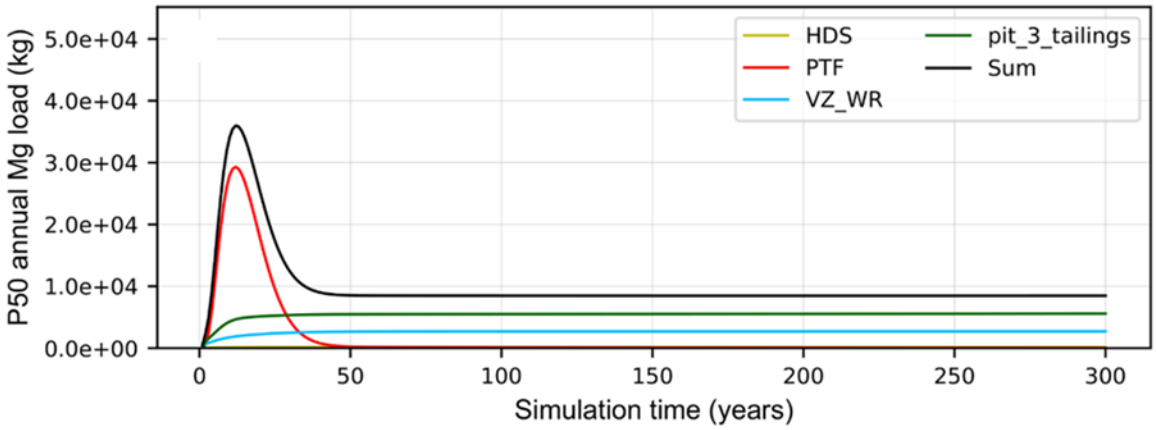


Figure 7-5: P50 (peak) realisation load contributions from Pit 3 sources

The majority of the predictive prior parameters in the Ranger groundwater uncertainty analysis were left unchanged for the Pit 3 uncertainty analysis. Data and information acquired since the Ranger groundwater uncertainty analysis were used to update tailings volumes and properties, PTF volume and CoPC concentrations for Pit 3 source terms. Updated predictions of loads from Pit 3 to Magela Creek were developed for the 20 solutes that are potential CoPCs at Ranger. Mean concentrations were estimated for each solute and each Pit 3 source term in INTERA (2021a) and updated based on new information in INTERA (2022, 2023a). CoPCs within each source term were only modelled where the mean concentrations were greater than the background threshold value (ERM, 2020a).

ERA is also investigating additional design refinements to the final landform design that are expected to reduce loads from final landform and RWD plume sources. These changes are expected to be more material in terms of reductions in sulfate loads relative to the small increase in sulfate concentrations in the SZ WR source term.

The groundwater modelling has conservatively assumed conservation of mass within the groundwater solute transport pathway. In reality, some reactivity of solutes is expected within the groundwater system which will reduce the loads relative to those predicted. This is likely to be the case for more reactive elements including manganese, uranium, sulfur and nitrogen. ERA is undertaking further work to better understand these reactive transport processes to quantify likely reductions in loads relative to those predicted from the groundwater modelling.

7.3.4 Solute movement in shallow groundwater

The analysis of solute movement in shallow groundwater considered the outputs from the Pit 3 uncertainty analysis model on water/solute flux out of the model and modelled concentrations of different solutes in the shallow groundwater. The analysis considered four CoPC: magnesium, sulfate, TAN and uranium.

These four CoPCs were chosen as they inform the post-closure groundwater monitoring plan (Mg, SO_4 and U); potential areas with risk for ASS (SO_4); potential for uptake of nutrients between Pit 3 and Magela Creek (TAN); and potential for human health risk (U). The modelling outputs provide further understanding regarding the nature of solute exfiltration from the toe of the landform and improves understanding of solute transport pathways which can be used to inform conceptual models (and future studies) regarding biogeochemical processes in the transport pathway which may affect load predictions. While these model outputs relate to Pit 3 related sources, the improved understanding will flow through to future studies regarding final landform and detailed project design.

7.3.5 Surface Water Model

The Ranger Surface Water Model (RSWM) was developed to provide predicted concentrations of 21 mine derived CoPCs (the 20 noted in Table 7-5 plus the Mg:Ca ratio), in surface waters of the Magela Creek catchment, from Magela Creek upstream (i.e. no mine) to Mudginberri Billabong. The model was developed using the OPSIM water balance modelling system and was specifically designed to model CoPC concentrations within Magela Creek from the annual loads predicted from the Ranger groundwater uncertainty analysis model, and to address KKN WS3 (see Appendix 5.1).

Water quality calibration was undertaken using historical data sourced from ERA, the NT Government and OSS. Following review of site-specific literature and available data, a suite of natural runoff water quality relationships were developed, which included flat concentration, first flow, first event, exhaustion, flat load and flow versus concentration rating curve. The developed suite of relationships were applied singly, or in concert, to each CoPC iteratively until a best fit calibration was achieved (Water Solutions, 2020, 2021a, 2021b). It is noted that due to the nature of available data some of the calibrations were poor and a numerical goodness of fit was not possible for the 21 modelled CoPC and locations. ERA is presently working on alternative methods to demonstrate the model fit in consultation with OSS.

The model is useful for estimating surface water CoPC concentrations at discrete locations as it effectively models the mixing of solutes in low concentration background loads with site loads by applying a mass balance approach. The model is used as a predictive tool for understanding potential impacts to downstream receiving environments.

The RSWM has been widely described in various reports and has been signed off as a predictive tool by OSS and ARRTC (KKN Projects 1260-01, 1260-06 and 1260-07; Appendix 5.1). It is a daily timestep, node-based numerical model that models flows in the creeks and catchment runoff as well as background CoPC loads from the natural catchments. The site loads are added at discrete nodes to represent the groundwater flow to the receiving creeks and full mixing of solutes with the background flow is assumed. Discretisation of annual groundwater loads to daily surface water loads is based on conceptual models of groundwater flow to Magela Creek documented in INTERA (2021b).

Conservation of mass is assumed for all CoPC movement within the Magela Creek system and no allowance is made for any reactivity of CoPCs with creek flows. Work undertaken by ERA (Parry, 2023) and OSS (Cook, 2023) indicates that there is likely to be some reduction in loads of manganese and ammonia loads within the surface water transport system which are not considered in the RWSM. While the RSWM does include a decay constant for solutes within billabongs, this has a limited impact on concentrations in Magela Creek and is not material to impacts associated with Pit 3 solute movement but is relevant to the assessment of solute movement in the Corridor Creek and Coonjimba Creek catchments. Modelling of solute movement through billabongs will be refined as part of the assessment processes for impacts associated with RWD deconstruction and final landform development. The assessment of these components will include additional measures (mitigations/controls) to reduce solute loads from RWD and VZWR sources.

The outcomes from the full suite of model runs are provided in Appendix 7.1. The following results are provided in the tables below as these model outcomes provide inputs to the impact and risk assessment chapters that follow (see Figure 7-3 for locations):

- Table 7-6: Peak groundwater loads at selected locations for all Ranger sources + background; and
- Table 7-7: 10,000-year groundwater loads at selected locations for all Ranger sources + background.

The values used in this assessment are a flow-weighted 3-day average of the predicted surface water concentrations of each CoPC (reported in µg/L and mBq/L) at selected assessment nodes.

Predictions are based on the P50 peak annual groundwater load for each CoPC from the Pit 3 groundwater uncertainty analysis and Ranger uncertainty analysis and include background loads. It is noted that these predictions do not include expected solute reductions from reactive transport or final landform design elements currently being investigated and are therefore considered to be conservative. Updated modelling will be undertaken for the final landform application which includes consideration of additional controls and design elements being investigated.

Cells coloured red indicate an exceedance of the most stringent guideline values (99% species protection level) adopted for ecosystem protection. The cells coloured yellow indicate an exceedance of adopted ecosystem protection criteria that is predicted to occur due to background conditions in the absence of any contribution from the mine. The implications of the results presented in Table 7-6 to Table 7-7 are discussed in the Section 7.3.6 to Section 7.3.10.

Table 7-6: Predicted peak concentrations for peak groundwater loads at selected locations (all Ranger sources + background)

	CoPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra>bgd	^{210}Po	Al	Se	SO_4	Mg:Ca
Most stringent GV for each CoPC	SPL 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA*	0.5	1	0.06	NA	1.5	3.3*(Cr^{3+})	6*	8	NA	NA^	0.8*pH<6.5 Back-ground > GV so compare medians	5	NA	9
	Other (226Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L >bgd (aquatic biota)				10000 seasonal av. (ASS)	
MG003																						
Exceedance Probability	1%	2110	690	200	265	1.1	108	15	0.4	0.2	0.01	140	0.7	0.16	0.78	0.53	-1.2	6.98E-11	107	0.1	6830	3
	10%	1960	680	3.1	228	1.0	94	2.8	0.3	0.2	0.01	120	0.7	0.15	0.68	0.41	-0.8	4.32E-11	94	0.1	5790	3
	25%	1930	670	3.1	224	0.9	92	2.8	0.3	0.2	0.01	110	0.7	0.15	0.50	0.46	-0.7	3.65E-11	71	0.1	5620	3
	50%	900	550	3.1	90	0.4	38	2.7	0.3	0.1	0.01	90	0.5	0.120	0.23	0.26	-0.7	3.17E-11	36	0.1	2350	2
	75%	730	320	3.0	24	0.0	13	2.5	0.2	0.0	0.01	70	0.4	0.10	0.12	0.16	-0.8	3.17E-11	12	0.1	667	2
	90%	350	210	3.0	16	0.0	9	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.8	3.12E-11	6.0	0.1	354	2
	99%	230	170	3.0	8	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.7	3.07E-11	6.0	0.1	206	1
MG005																						
Exceedance probability	1%	2100	690	200	263	1.1	107	15	0.4	0.2	0.01	130	0.7	0.16	0.78	0.52	2.6	6.97E-11	107	0.1	6790	3
	10%	1960	680	3.1	227	1.0	93	2.8	0.3	0.2	0.01	120	0.7	0.15	0.68	0.47	2.5	4.32E-11	94	0.1	5750	3
	25%	1930	670	3.1	223	0.9	91	2.8	0.3	0.2	0.01	110	0.7	0.15	0.51	0.46	2.3	4.29E-11	71	0.1	5590	3
	50%	900	550	3.1	89	0.4	38	2.7	0.3	0.1	0.01	90	0.5	0.12	0.23	0.26	2.0	3.65E-11	36	0.1	2340	2
	75%	720	320	3.0	24	0.0	13	2.5	0.2	0.0	0.01	70	0.4	0.10	0.12	0.16	1.8	3.17E-11	12	0.1	665	2

	CoPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra> bgd	^{210}Po	Al	Se	SO_4	Mg:Ca
	90%	350	210	3.0	16	0.0	9	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	1.5	3.12E-11	6.1	0.1	354	2
	99%	230	160	3.0	8	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	1.3	3.07E-11	6.0	0.1	199	1
MG009																						
Exceedance probability	1%	2690	780	200	304	1.1	109	15	0.4	0.3	0.01	180	0.8	0.17	0.78	0.61	4.3	6.99E-11	107	0.1	9040	4
	10%	2420	750	8.2	268	1.	96	3.0	0.3	0.2	0.01	140	0.8	0.16	0.69	0.55	3.4	5.01E-11	95	0.1	7600	3
	25%	2240	720	7.1	249	1.0	93	2.9	0.3	0.2	0.01	130	0.7	0.16	0.52	0.52	3.1	4.8E-11	73	0.1	6940	3
	50%	1250	560	5.1	127	0.5	46	2.8	0.3	0.1	0.01	110	0.6	0.13	0.26	0.32	2.6	4.12E-11	39	0.1	3730	3
	75%	770	310	3.5	26	0.1	13	2.6	0.2	0.0	0.01	90	0.4	0.11	0.13	0.16	2.3	3.23E-11	12	0.1	906	2
	90%	390	210	3.0	17	0.0	9	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.15	1.6	3.13E-11	6.1	0.1	366	2
	99%	230	170	3.0	9	0.0	5	2.5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	1.4	3.08E-11	6.0	0.0999	253	1
Mudginberri Billabong																						
Exceedance probability	1%	1860	770	150	142	0.6	56	12	0.3	0.1	0.01	140	0.7	0.16	0.79	0.40	3.3	6.8E-11	108	0.1	3870	3
	10%	1740	720	6.6	133	0.5	52	3.3	0.3	0.1	0.01	120	0.7	0.15	0.56	0.37	3.0	4.7E-11	80	0.1	3600	2
	25%	1680	700	6.0	127	0.5	49	3.1	0.3	0.1	0.01	120	0.6	0.15	0.35	0.36	2.9	4.5E-11	53	0.1	3420	2
	50%	1500	630	5.8	115	0.4	45	3.1	0.3	0.1	0.01	110	0.6	0.14	0.18	0.33	2.7	4.3E-11	30	0.1	3060	2
	75%	800	360	4.9	63	0.2	24	2.8	0.3	0.1	0.01	100	0.5	0.12	0.13	0.23	2.5	3.8E-11	18	0.1	1900	2
	90%	430	230	3.7	29	0.1	12	2.6	0.2	0.0	0.01	90	0.4	0.11	0.11	0.16	2.3	3.8E-11	13	0.1	1070	2
	99%	280	180	3.1	12	0.0	7	2.5	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	2.0	3.1E-11	9.6	0.1	406	2

* Assessed as eutrophication risk.
^ Assessed under radiation dose assessment – see Chapter 10.

Table 7-7: Predicted peak concentrations for 10,000 year groundwater loads at selected locations (all Ranger sources + background)

	CoPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra> bgd	^{210}Po	Al	Se	SO_4	Mg:Ca
Most stringent GV for each CoPC	SPL 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA*	0.5	1	0.06	NA	1.5	3.3*(Cr^{3+})	6*	8	NA	NA^	0.8*pH<6.5 Back-ground > GV so compare medians	5	NA	9
	Other (226Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L >bgd (aquatic biota)				10000 seasonal av. (ASS)	
MG003																						
Exceedance Probability	1%	1480	650	200	106	0.2	40	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	2.6	6.81E-11	106	0.1	2340	2
	10%	1400	640	3.0	90	0.1	35	2.7	0.3	0.1	0.01	110	0.5	0.12	0.67	0.25	2.5	3.55E-11	92	0.1	1810	2
	25%	1380	630	3.0	86	0.1	34	2.7	0.3	0.1	0.01	100	0.5	0.12	0.49	0.25	2.3	3.53E-11	69	0.1	1570	2
	50%	800	540	3.0	37	0.1	16	2.6	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	2.0	3.30E-11	33	0.1	912	2
	75%	580	310	3.0	10	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	1.7	3.08E-11	7	0.1	313	1
	90%	310	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	1.5	3.07E-11	6.0	0.1	69.5	1
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	1.3	3.07E-11	6.0	0.1	61.6	1
MG005																						
Exceedance probability	1%	1470	650	200	105	0.2	40	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	2.6	6.80E-11	106	0.1	2320	2
	10%	1400	640	3.0	89	0.1	35	2.7	0.3	0.1	0.01	110	0.5	0.12	0.67	0.25	2.5	3.54E-11	93	0.1	1800	2
	25%	1380	630	3.0	86	0.1	34	2.7	0.3	0.1	0.01	100	0.5	0.12	0.49	0.24	2.3	3.53E-11	69	0.1	1560	2
	50%	800	540	3.0	37	0.1	16	2.6	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	2.0	3.29E-11	33	0.1	908	2

	CoPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra> bgd	^{210}Po	Al	Se	SO_4	Mg:Ca
	75%	580	310	3.0	10	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	1.7	3.08E-11	7	0.1	312	1
	90%	310	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	1.5	3.07E-11	6.0	0.1	69.5	1
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	1.3	3.07E-11	6.0	0.1	61.6	1
MG009																						
Exceedance probability	1%	1610	710	200	103	0.2	39	15	0.3	0.1	0.01	120	0.50	0.12	0.77	0.3	2.6	6.79E-11	106	0.1	2290	2
	10%	1520	680	3.3	88	0.1	34	2.8	0.3	0.1	0.01	110	0.49	0.12	0.67	0.2	2.5	3.56E-11	93	0.1	1800	2
	25%	1450	660	3.0	85	0.1	34	2.8	0.3	0.1	0.01	100	0.49	0.12	0.50	0.2	2.3	3.54E-11	71	0.1	1540	2
	50%	840	550	3.0	44	0.1	18	2.7	0.2	0.0	0.01	80	0.44	0.11	0.24	0.2	2.0	3.35E-11	37	0.1	990	2
	75%	560	290	3.0	12	0.0	6	2.5	0.2	0.0	0.01	60	0.40	0.10	0.09	0.1	1.8	3.10E-11	7	0.1	455	2
	90%	320	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	1.6	3.07E-11	6.0	0.0999	68.5	1
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	1.4	3.07E-11	6.0	0.0997	61.5	1
Mudginberri Billabong																						
Exceedance probability	1%	1360	740	150	48	0.1	22	12	0.3	0.0	0.01	130	0.6	0.14	0.78	0.23	2.7	6.7E-11	108	0.1	1090	2
	10%	1270	690	4.4	45	0.1	21	3.2	0.3	0.0	0.01	110	0.5	0.13	0.55	0.21	2.5	4.0E-11	79	0.1	816	2
	25%	1230	670	3.5	43	0.1	20	3.1	0.3	0.0	0.01	90	0.5	0.12	0.34	0.20	2.3	3.8E-11	51.7	0.1	738	2
	50%	1100	600	3.4	39	0.1	18	3.0	0.2	0.0	0.01	80	0.5	0.12	0.16	0.20	2.1	3.7E-11	28	0.1	686	2
	75%	610	350	3.3	24	0.1	11	2.8	0.2	0.0	0.01	70	0.4	0.11	0.11	0.16	2.0	3.4E-11	16	0.1	568	2
	90%	360	230	3.0	14	0.0	7	2.5	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	1.9	3.1E-11	10	0.1	400	2
	99%	250	180	2.9	7	0.0	6	2.5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	1.7	3.0E-11	7.5	0.1	140	1

* Assessed as eutrophication risk.
^ Assessed under radiation dose assessment – see Chapter 10.

7.3.6 Aquatic Pathways Risk Assessment

The Aquatic Pathways Risk Assessment (APRA) is a tool that categorises the potential risk to aquatic ecosystems as a result of the modelled surface water concentrations of CoPC introduced to Magela Creek from the Ranger site.

The main steps in the APRA process are:

- create a conceptual model to identify contamination sources, pathways, processes and receptors to underpin the APRA;
- identify endpoints requiring protection, and threats to these endpoints based on the conceptual model;
- identify a set of guideline values and develop consequence descriptors for those endpoints;
- compare predicted water and sediment quality to the endpoint guideline values; and
- use APRA-specific risk tools (i.e. risk lookup tables for consequence and likelihood that include a numeric scoring system) to rate risks.

Figure 7-6 shows the integrated source-pathway-process-receptor conceptual model underpinning this risk assessment. Of note:

- blue boxes show the contaminant sources and transport pathways included in the solute transport models used to predict future water quality;
- orange boxes show sediment and soil contaminant sources and fate;
- grey box shows the end points being assessed. The endpoints are aligned with the values derived from the Ranger ERs; and
- solid green boxes show the assessment method used (i.e. exposure concentration versus guideline values).

Risk ratings are determined using the matrix shown in Table 7-8, where the likelihood is determined using the descriptors provided in Table 7-9 and the consequence is determined using the sliding scale approach illustrated in Table 7-10.

As biodiversity consequences are related to exposure intensity, duration and/or repetition of exposure, the rating of consequences takes these factors into consideration. For species protection, meeting the 99% SPL guideline value results in very low (nil/negligible) consequences. Exposure to concentrations exceeding any guideline value for 1% or less of the flow period, or an exceedance of the 95% SPL guideline value only for less than 10% of the flow period, is characterised as having a low consequence due to the unlikely adverse impacts associated with such short/infrequent periods of exposure above guideline value levels. Higher likelihoods of exposure above any of the guideline values results in medium to very high species protection consequences depending on the exposure likelihood, the species protection level exceeded, and whether the location is on or off the RPA.

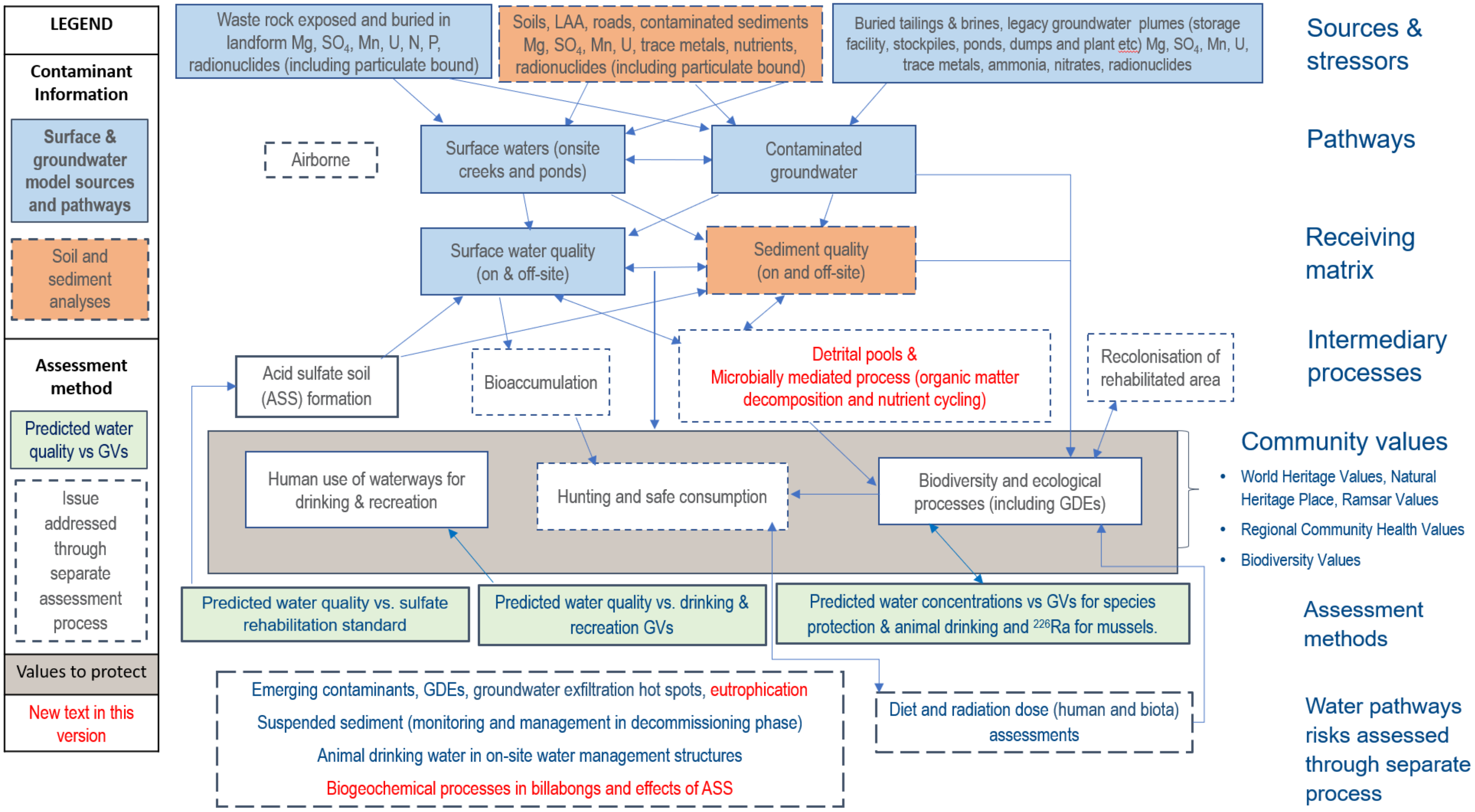


Figure 7-6: Conceptual model underpinning the APRA (BMT, 2023a)

Table 7-8: Risk rating matrix

Likelihood	Consequence Severity				
	Very Low	Low	Moderate	High	Very High
Almost Certain	Class II	Class III	Class IV	Class IV	Class IV
Likely	Class II	Class III	Class III	Class IV	Class IV
Possible	Class I	Class II	Class III	Class IV	Class IV
Unlikely	Class I	Class I	Class II	Class III	Class IV
Rare	Class I	Class I	Class II	Class III	Class III

Table 7-9: Likelihood lookup table

Likelihood	Rare	Unlikely	Probable	Likely	Almost Certain
Frequency (multiple events)	Less than once per 100 years	Once in 10 to once in 100 years	Once per year to once in 10 years	Twice per year to once per year	More than twice per year
Probability (single events or probability distribution)	<5%	5-20%	21-50%	51-75%	>75%

Table 7-10: Sliding scale consequence lookup table (example for manganese)

<table>
<tr><th colspan="8">Predicted manganese in water Vs GV: 73, 153, 240, 443 µg/L for 99, 95, 90 and 80% SPL[1]</th></tr>
<tr><th></th><th colspan="2">Exposure Likelihood</th><th colspan="5">Consequence to species</th></tr>
<tr><th rowspan="6">Exceedance probability predicted by RSWM</th><th>Off-site</th><th>On-site</th><th>Very Low</th><th>Low</th><th>Medium</th><th>High</th><th>Very High</th></tr>
<tr><td>≤1%</td><td>≤1%</td><td rowspan="5">No GV exceedance

Mn conc 0–73</td><td>1% exceedance any GV</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>-</td><td>>1–10%</td><td>74–153</td><td>154–240</td><td>241–443</td><td>>443</td></tr>
<tr><td>>1–10%</td><td>>10–25%</td><td rowspan="3">NA</td><td>74–153</td><td>154–240</td><td>>240</td></tr>
<tr><td>>10–25%</td><td>>25–50%</td><td rowspan="2">NA</td><td>74–153</td><td>>153</td></tr>
<tr><td>>25%</td><td>>50%</td><td>NA</td><td>>73</td></tr>
</table>

[1] SPL – Species Protection Level; Conc – concentration; Mn – manganese; GV – Guideline Value.

Table 7-6 and Table 7-7 provided the modelled concentrations of CoPCs for various scenarios and compared predicted peak CoPC concentrations to the most stringent guideline value for each CoPC at various locations.

The results show that manganese is the only CoPC that exceeds guideline values at modelled peak and 10,000-year scenarios. Consequences were very low for all CoPCs for drinking water, recreational water, animal drinking water and ASS formation.

It is noted that all predicted aluminium (Al) concentrations, including for the No Mine scenario, exceeded the SPL guideline value. Thus, the species protection guideline values for Al were not suitable and consequences could not be scored using the approach agreed for other CoPCs (see Appendix 7.1 for details). In other words, the guideline value currently used in the APRA for Al is so low that the quality of water upstream of the mine also exceeds the guideline value, and therefore it is not a good indicator of mine-derived impacts. Table 7-11 shows the colour coded comparison of manganese concentrations to the guideline values at each of the sites and for various exceedance probabilities based on predictions from all Ranger sources plus background based on the composite predictions from the Pit 3 uncertainty analysis and the 2020 Ranger groundwater uncertainty analysis. As with the results reported in Table 7-6 and Table 7-7, these predictions do not account for reactivity of manganese within the groundwater and surface water system and therefore overstate likely concentrations of manganese associated with the modelled closure conditions.

Table 7-11: Comparison of manganese concentrations against consequence categories in Table 7-10 (colour legend below table)

Location	Exceedance probability	No Mine	Peak P10 Composite UA	Peak P50 Composite UA	Peak P90 Composite UA	10k P10 Composite UA	10k P50 Composite UA	10k P90 Composite UA
GS01/MG001 (Magela upstream of Pit 3)	1%	14.4	42.6	75.8	59.7	23.5	30.8	29.1
	10%	11.5	32.9	57.9	45.8	16.5	22	20.8
	25%	6.67	29.9	52.4	41.6	14.5	18.8	17.8
	50%	4.50	20.0	33.0	26.7	11	13.1	12.7
	75%	4.50	12.6	17.4	14.9	6.66	7.62	7.42
	90%	4.49	8.39	10.5	9.6	5.5	6	5.89
	99%	4.45	4.50	4.50	4.5	4.5	4.5	4.5
409/MG003 (Magela mid-stream d/s of Pit 3)	1%	14.4	174	265	334	68.2	106	155
	10%	11.6	152	228	292	57.3	89.8	133
	25%	6.89	149	224	285	54.8	86.3	130
	50%	4.50	60.5	89.5	111	25.8	37.4	52.4
	75%	4.50	16.3	24.3	22.4	8.31	9.92	11
	90%	4.49	11.8	16.0	14.5	5.78	6.45	6.38
	99%	4.47	6.78	7.76	8.16	5.2	5.58	5.6
421/MG005 (Magela mid-stream d/s of Pit 3)	1%	14.4	173	263	333	67.7	105	154
	10%	11.6	151	227	290	57	89.2	132
	25%	6.91	148	223	283	54.5	85.9	129
	50%	4.50	59.9	88.5	110	25.6	37.1	51.9
	75%	4.50	16.2	24.2	22.3	8.28	9.88	10.9
	90%	4.49	11.7	15.9	14.5	5.78	6.45	6.37
	99%	4.47	6.75	7.69	8.06	5.19	5.56	5.59

Location	Exceedance probability	No Mine	Peak P10 Composite UA	Peak P50 Composite UA	Peak P90 Composite UA	10k P10 Composite UA	10k P50 Composite UA	10k P90 Composite UA
GS09/MG009 (d/s of Coonjimba Billabong on lease)	1%	14.4	185	304	403	66.2	103	151
	10%	11.7	163	268	352	56	87.5	130
	25%	7.23	157	249	326	53.9	84.9	127
	50%	4.50	78.0	127	165	29.5	44	62.5
	75%	4.50	17.7	26.4	28.3	10.6	12.3	13.6
	90%	4.49	11.9	17.1	15.3	5.73	6.37	6.29
	99%	4.49	7.22	8.89	9.54	5.16	5.53	5.57
Mudginberri Billabong	1%	14.5	N/A	142	186	NA	48	69
	10%	8.42	N/A	133	175	NA	45	65
	25%	5.09	N/A	127	167	NA	43	62
	50%	4.90	N/A	115	150	NA	39	56
	75%	4.77	N/A	63	81	NA	24	33
	90%	4.53	N/A	29	36	NA	14	18
	99%	4.37	N/A	12	14	NA	7	8

Red = Very High; Orange = High; Yellow = Medium; Dark Green = Low; Light Green = Very Low as per Table 7-10.

7.3.7 Vulnerability Assessment Framework

A Vulnerability Assessment Framework (VAF) was developed to understand the sensitivity and adaptive capacity of the ecological components (species, communities, ecosystems) that underpin the environmental and cultural values of the area, and factors that affect their potential exposure to mine-derived solutes. The VAF is applied to understand potential environmental consequences associated with levels of a particular CoPC where it is predicted to exceed the 99% guideline value species protection level.

The VAF development involved the following steps:

a) identification of environmental and community values (ECVs) and indicator ecological components, including ‘key species’ that are important from biodiversity and cultural perspectives, as well as important habitats and other groups;

b) development of conceptual models of key processes and linkages with ecological components underpinning ECVs;

c) assessment of the direct (i.e. toxicity) and indirect (i.e. food resources and habitats) sensitivity of ecological components to contaminants; and

d) assessment of the adaptive capacity of ecological components.

The VAF was originally developed to assess vulnerability of aquatic ecosystems to magnesium (Mg) and has been updated and refined to assess ecological component vulnerability to manganese (Mn).

The VAF decision tree (Figure 7-7) was developed to assess the capacity of ecological components to:

- ‘persist in place’, based on direct and indirect sensitivity traits at the individual organism level, and assemblage-level responses;
- ‘shift-in-space’ by seeking alternate habitats, based on the mobility traits at the individual organism level and most taxa within assemblages; and
- for those components that have no or limited capacity to ‘shift-in-space’ or are able to ‘persist in place’, assess potential resilience at the local and population levels. This considers the geographic range, population status, habitat breadth, fecundity and dispersal capacity of biota.

The modelled Mn concentrations for the P50 composite source scenarios described above were input into the Mn VAF. The predicted peak Mn concentrations at MG003, MG005 and MG009 (refer to Table 7-6 and Table 7-7) are very similar. At all sites better than a 95% species protection level (SPL) was met 50% of the time, and at least an 86% SPL was met 99% of the time (1% exceedance). Mn concentrations exceed the 99% GV of 73 µg/L Mn for 50% of the time. Based on ecotoxicological studies undertaken by OSS and others, various ecological components are considered potentially sensitive to manganese at the concentrations predicted to occur in the RPA. While similar concentrations of manganese have been observed within water bodies in the RPA in the past, a detailed understanding of the ecosystem’s vulnerability to prolonged exposure to these concentrations requires more detailed investigation which includes consideration of a range of factors such as the timing of elevated concentrations relative to different ecological processes and other stressors.

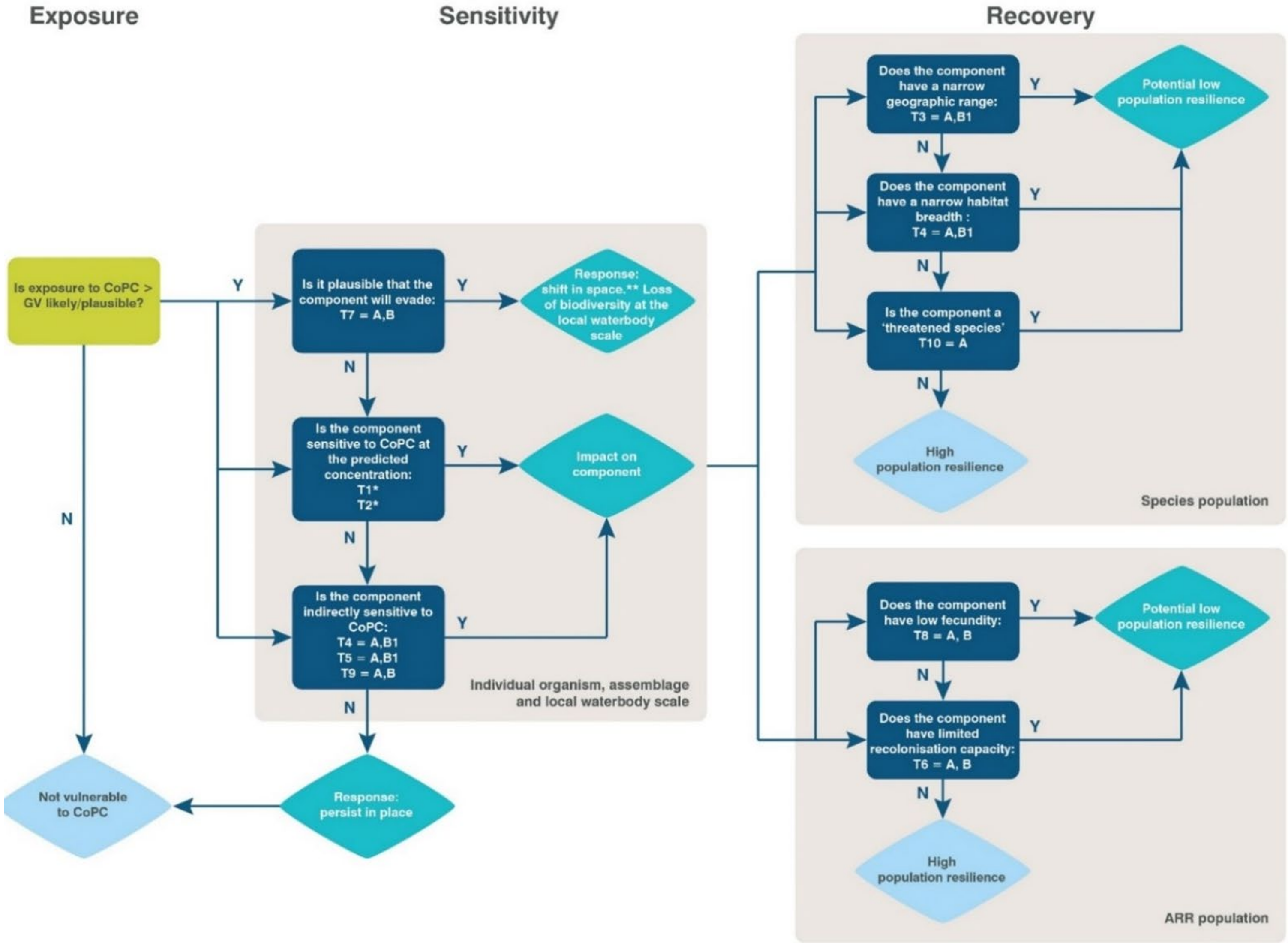


Figure 7-7: Decision tree for vulnerability assessment framework

7.3.8 Eutrophication

The potential for nutrients in groundwater and surface water from mine related sources to result in ecosystem changes due to increased enrichment has been identified as a potential risk to meeting the ERs applicable to Ranger. Tailings in Pit 1, Pit 3 (and the associated PTF) and plumes in the Coonjimba Catchment associated with historical storage of tailings and process water in the RWD are recognised sources of bioavailable nitrogen (predominately in the form of ammonia but also nitrates) and phosphorus.

Nutrients present in fertilisers used for rehabilitation purposes also present a potential source of bioavailable nitrogen and phosphorus that may increase eutrophication risks in surface water systems downstream from these sources. Nitrates associated with open cut mining operations was also a historical source of nitrates, however this source is considered to have already depleted and elevated levels of nitrate are no longer observed in waste rock sources and is therefore not considered to represent a post-closure source of nitrogen.

While concentrations of phosphorus in tailings, PTF and RWD related plumes are above background guideline values, the overall incremental load to surface water catchments associated with this CoPC are very small and unlikely to have a material environmental impact. Incremental Total N associated with TAN and nitrates in tailings, PTF and RWD plumes are therefore the primary consideration in terms of eutrophication risk.

KKN WS6 aims to determine appropriate criteria for assessing eutrophication risks by determining the impact of nutrients in surface water on biodiversity and ecosystem health. KKN WS6 was developed to ensure there is a sound understanding of the potential risks to surface water systems from elevated nutrient loads from Ranger, including long term sources associated with groundwater solute movement from Pit 1 and Pit 3.

The following studies relevant to eutrophication have been completed at Ranger:

- Cook (2023): advice related to risk associated with increased nutrient loads into Magela Creek.
- Boland (2023): advice related to risk associated with increased nutrient loads to billabongs, with some additional commentary on risks associated with eutrophication risks in Magela Creek (and in particular, the in-channel billabongs such as Mudginberri Billabong).
- INTERA (2023a): modelled annual loads of nutrients from Pit 3 sources predicted from the realisation representing P10, P50 and P90 predictions in the Pit 3 uncertainty analysis.

Monitoring of background concentrations of nitrate, ammonia, Total N and Total P has also been undertaken by ERA over the 2021/22 and 2022/23 wet seasons to better understand background conditions and nutrient cycling processes. Sampling of algae within Magela Creek and other reference systems is being undertaken by OSS to understand potential nutrient cycling processes with the likely receiving environment and possible effects of increased loads of nitrogen associated with solute movement from tailings and PTF in Pits 1 and 3 and the RWD plume.

A comparison between predicted P50 peak loads and background levels (and the inter-annual variability observed in the 2021/22 and 2022/23 wet seasons) (Holmes, 2023) is shown in Table 7-12.

Table 7-12: Comparison of predicted annual loads and background levels (Holmes, 2023)

CoPC	Predicted Peak Loads – P50 (Kg)		Annual Magela Creek Background Loads (kg)			Pit 3 P50 load as % of max BG	All sources P50 load as % of max BG
	Pit 3 (P50)	All Sources (P90)	2021/22	2022/23	Variability		
Total P	7	14	1,627	3,482	1,855	0%	1%
TAN (NH3-N)	190	3,390	1,108	2,024	916	158%	167%
NOx-N	2	2	5,798	1,260	4,583	0%	0%
Total N	3,192	3,392	14,981	40,900	25,919	8%	8%

Table 7-12 illustrates that P50 TAN loads represent an approximate doubling of background levels of TAN monitored at MCUS relative to 2022/23 wet season and a three-fold increase relative to the 2021/22 wet season. While this is a significant increase relative to background NH3-N levels, it is noted that ammonia is highly bioavailable and loads observed in MCUS monitoring are unlikely to reflect raw background contributions of ammonia to the system. Accordingly, as noted by Cook (2023) comparisons between Total N loads is considered to be a better guide on potential eutrophication risks. Incremental (P50) peak loads of N from Pit 3 sources and all mine sources are predicted to be approximately 3,200 kg and 3,400 kg, respectively. This represents an 8% increase on the loads observed in the 2022/23 wet season at MCUS and just 13% of the variability observed between the 2021/22 and 2022/23 wet seasons. In general, the highest risks presented by increased nitrogen loads are considered to be:

- increased filamentous algae growth in sandy creek sections of Magela Creek; and
- increased phytoplankton growth in Mudginberri Billabong.

The predicted increased loads represent only a small percentage (<15%) of the variability observed in total N loads in the 2021/22 and 2022/23 wet seasons, suggesting that observed conditions in years of higher N loads may be representative of likely eutrophication effects within Magela Creek associated with Ranger related incremental N loads. Observations from the 2022/23 recession flow period in Magela Creek are therefore considered to provide a reasonable indication of what filamentous algae growth under higher nitrogen load conditions may look like given the higher background loads observed during this flow season (Plate 7-1).

Plate 7-1: Algae in Magela Creek – Western Chanel upstream from MG003 (9 May 2023)

7.3.9 Acid Sulfate Soils

Acid sulfate soils (ASS) are a natural and extensive component of the Magela Plain and the general lowland surrounds of the RPA (Willett, 2008). Ranger is predicted to result in elevated levels of sulfate in groundwater that will also contribute to elevated levels of sulfate in surface water. Elevated levels of sulfate in groundwater and surface water have been associated with the formation of ASS under certain conditions, and instances of acidification associated with ASS have been observed in Coonjimba Billabong with associated impacts on dissolved oxygen levels and increased concentrations of some metals including manganese. This indicates that conditions suitable for the formation of ASS are present in at least some locations on the RPA. The extent of the potential impacts from re-wetting of hypersulfidic soils and acidification events will depend on local hydrological factors and are mitigated through significant dilution events as can occur through monsoonal rainfall events and associated flooding. The occurrences of acidification observed in Coonjimba Billabong have been linked to false start wet season events, indicating that the absence of flushing associated with a continuation of rainfall may be a driver of more significant acidification related events (e.g. lower levels of dissolved oxygen and increased concentrations of metals) being observed in these years. Under more consistent wet seasons conditions, flushing of the billabong occurs and these effects of acidification are not observed.

KKN WS5A was developed to provide an understanding of the potential risks of ASS in aquatic sediments, and produce an ASS conceptual model, risk assessment and management options. The assessment of ASS has included both desktop review and sampling programs to assess the potential for, and the risk from, ASS formation on and adjacent to Ranger under current conditions, and with consideration of potential hydrodynamic changes during the transition to closure.

The following studies relevant to ASS have been completed at the Ranger mine:

- Esslemont and Iles (2017): *2016 Billabong Sediment Sampling Program*. Energy Resources of Australia Ltd. August 2017.

- ERM (2020b): site wide conceptual model to identify areas within the RPA that have the potential for ASS to form and are potential source areas.
- ERA (2021a): collection and analysis of sediment samples for ASS and metals from eight locations, including billabongs and retention ponds.
- BMT (2022b): brief literature review about biological responses to acid sulfate soils (ASS) in the context of mine drainage in northern Australia. It forms an input for consideration during the risk assessment processes for the closure of Ranger.
- CDM Smith (2023): collection and analysis of water and sediment samples from targeted remnant pools within Magela Creek.

The site wide conceptual model identified areas within the RPA that have the potential for ASS to form and consequently are potential source areas (see Figure 7-8). It is recognised that some areas of the site can act both as source sediments (location of ASS) and as receptors of acidification products (e.g. Coonjimba Billabong). Additionally, migration of acidification products including sulfate to a receptor where the other key constituents (water-logged conditions and organic matter) are present, introduces the potential for ASS development at that receptor, and for the receptor to, in turn, become a source of ASS (ERM, 2020b). Magela Creek (north-east of Pit 3 near the former Magela LAA) and Indium Billabong have been identified as having the potential for ASS to form (Figure 7-8) and monitoring of sediments in the 2020/21 sampling program indicate Indium Billabong may have ASS present.

FIGURE 7-8

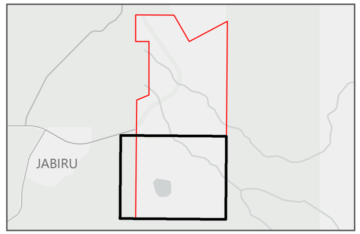
Summary of Preliminary Site Wide ASS Conceptual Model – Potential Source Areas (ERM, 2020a)

LEGEND

- Ranger Project Area
- Extent of Groundwater Data
- No Data Available

Source areas

- ASS Identified - Sediment Sampling
- Potential for ASS - Surface Water
- Potential for ASS - Groundwater
- Potential for ASS - Surface Water



0 0.5 1

Kilometres

Scale 1:31,027 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023), ERM (2020)

7.3.10 Preliminary Human Health Risk Assessment

A preliminary human health risk assessment was undertaken to assess potential risk to human health from predicted CoPC via consumption of water and bush foods from the RPA (Stantec, 2023). It is important to note that any risk to human health associated with solutes moving from Pit 3 (which is a large contributor) would only occur after the entire backfill of the pit was completed and the decant wells were turned off. This is currently planned for year 2034 (noting that the timeframes are subject to the outcomes of further studies being undertaken on water management and bulk material movement). Up until that time, the pit will continue to act as a sink for contaminated water.

The human health risk assessment is primarily a calculation that is undertaken to determine whether predicted contaminant concentrations pose a health risk to exposed populations. The assessment was conducted by Stantec in accordance with Schedule B4 (*Guideline on Site-specific Health Risk Assessment Methodology*) of the NEPM (NEPC, 2013). The main steps in the process are:

- identify the CoPCs;
- identify the population of interest, their occupancy intentions (i.e. planned use of the former mine area and downstream receiving environments) and bush tucker diet (see Chapter 10, Table 10-4 and Table 10-5 for details);
- determine the concentrations at which the CoPCs will be present in drinking water and bush tucker (using established transfer factors);
- review published health documents to identify the provisional tolerable daily intake (PTDI) for each of the relevant CoPCs (this is used to back calculate the safe amount of contaminants that can be present within food or drinking water that can be consumed without presenting a risk to health); and
- calculate the Hazard Index (HI) from the above information for several scenarios. If the HI is >1 there is a potential risk to human health and further action is required.

For the purpose of the preliminary human health risk assessment, eight of the 20 CoPCs have been assessed. The eight CoPCs assessed for human health are: Cd, Cr – as Chromium VI, Cu, Mn, Ni, Se, V and Zn. These eight have been chosen as they are known to bioaccumulate (i.e. accumulate in higher concentrations in bush tucker). Potential health effects of U and radionuclides are considered in the radiation impact assessment provided in Chapter 10. Many of the parameters adopted for the assessment of exposures may be an overestimate of actual exposures. Hence the risk calculations presented in the human health risk assessment are expected to be conservative from an overall exposure point of view.

The results in Table 7-13 and Table 7-14 demonstrate that there is little if any potential for human health risk from Ranger for seven of the eight CoPCs assessed (being Cd, Cr, Cu, Ni, Se, V and Z). Mn is the CoPC that poses a potential risk to human health, being driven by a combination of the modelled manganese concentrations in surface water and the bioaccumulation in older bivalves (i.e. mussels) which is contributing between 20-40% of the HI calculations. Section 7.3.11.6 describes the further work being undertaken to investigate the conservatism in the model and the manganese concentrations.

Table 7-13: Hazard Index results for the assessed scenarios – MG003 and MG009

CoPC	MG003 Peak		MG003 10,000 yrs	
	Child (2–6 yrs)	Adult	Child (2–6 yrs)	Adult
Cadmium	0.00	0.00	0.00	0.00
Chromium	0.01	0.00	0.05	0.00
Copper	0.00	0.00	0.00	0.00
Manganese	**1.77**	0.47	0.31	0.00
Nickel	0.00	0.00	0.00	0.00
Selenium	0.26	0.00	0.25	0.00
Vanadium	0.00	0.00	0.00	0.00
Zinc	0.00	0.00	0.00	0.00
CoPC	**MG009 Peak**		**MG009 10,000 yrs**	
	Child (2–6 yrs)	**Adult**	**Child (2–6 yrs)**	**Adult**
Cadmium	0.00	0.00	0.00	0.00
Chromium	0.18	0.02	0.05	0.00
Copper	0.00	0.00	0.00	0.00
Manganese	**2.82**	0.92	0.50	0.00
Nickel	0.00	0.00	0.00	0.00
Selenium	0.26	0.00	0.25	0.00
Vanadium	0.00	0.00	0.00	0.00
Zinc	0.00	0.00	0.00	0.00

Table 7-14: Hazard Index results for the assessed scenarios – Mudginberri Billabong (MB)

CoPC	MB Peak		MB 10,000 yrs	
	Child (2–6 yrs)	Adult	Child (2–6 yrs)	Adult
Cadmium	0.00	0.00	0.00	0.00
Chromium	0.27	0.06	0.15	0.01
Copper	0.00	0.00	0.00	0.00
Manganese	**6.38**	**2.45**	**1.68**	0.43
Nickel	0.01	0.00	0.00	0.00
Selenium	0.33	0.00	0.32	0.00
Vanadium	0.00	0.00	0.00	0.00
Zinc	0.00	0.00	0.00	0.00

7.3.11 Studies to be completed

There are multiple studies occurring in the water and sediment theme, some of which are still in the scoping and development phase, such as the RWD deconstruction and groundwater modelling; waste rock characterisation; refinement of RSWM for billabongs; update and incorporation of Gulungul Creek into RSWM model; and a manganese study. The studies discussed below are therefore just a subset of the studies that are progressing in the water and sediment theme.

7.3.11.1 Groundwater-Surface Water Interaction and Solute Behaviour

The Ranger Surface Water Model (RSWM) has been developed around the assumption of all Ranger related groundwater solute movement occurring directly from groundwater to creek flow. Additionally, the RSWM assumes all conservation of mass in solute movement from mine related sources and no reactivity within transport pathways. Both of these assumptions oversimplify solute movement and, in the case of the latter assumption, likely overstate the loads of more reactive CoPC such as ammonia and manganese. Having said that, it is acknowledged that the CoPC loads are sensitive to the source term inputs (including variations to tailings conceptualisations) and further refinement to source terms for Ranger will be investigated. It is therefore recognised that additional work is required to improve modelling of likely solute concentrations in surface water, including work to reduce uncertainty in both groundwater and surface water modelling, and to better capture the spatial and temporal aspects of CoPC movement into surface waters.

7.3.11.2 Best Practicable Technology

ERA commits to undertaking BPT assessments of additional remediation concepts aimed at reducing CoPCs, and particularly manganese. BPTs will be undertaken to investigate:

- additional remediation measures for CoPCs leaving Pit 3; and
- remediation measures for CoPCs associated with the RWD groundwater plume and potential impacts on the downstream Coonjimba Billabong.

The findings of these BPTs, and preferred remediation options to reduce CoPCs to achieve agreed guideline values, will be incorporated into the final design for the Ranger closure project.

7.3.11.3 Aquatic Ecosystems / Vulnerability Assessment Framework

The APRA is a screening tool used to assess modelled CoPC predictions in the surface water column against guideline values for toxicity. ARRTC recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of guideline values in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered.

Further targeted field surveys will be undertaken to better understand the sensitivity and response of ecosystem processes to short and long-term manganese exposure. In particular, the effects of manganese on microbial and algae production and processes, and its interactions on ecological components.

7.3.11.4 Eutrophication

The potential for increased levels of nitrogen to cause eutrophication within billabongs and Magela Creek is recognised, however the nature and scale of potential impacts, if any, are difficult to accurately assess.

ERA and the OSS are working collaboratively to address these questions (e.g. KKN WS6 and WS6C). ERA will continue monitoring nitrate, ammonia and Total N and Total P concentrations at MCUS and MG009 over the coming wet season (2023/24) with this monitoring likely to continue to subsequent wet seasons. This monitoring will provide an improved understanding of natural background load variability, both in terms of total load as well as temporal and flow related variability.

As noted above, further work on the RSWM will occur and this refined understanding will continue to inform loads of key CoPCs including ammonia. This work will also investigate the likely denitrification rates associated with this flow path as well as potential for plant uptake in shallow groundwater. These works will also improve the temporal understanding of time-resolved, load estimates, particularly loads to Magela Creek during the recessional flow period for the final landform.

Work being progressed by OSS on a mesocosm in-situ experiment within the Magela sand channel will further improve understanding of the impacts of additional loads of nitrogen into the natural system to understand the effects of increased loads. The design of this experiment will necessarily have regard to likely flow pathways for nitrogen into Magela Creek to ensure simulated conditions are reflective of likely solute flow movement into Magela Creek. This experiment will also likely include additional monitoring and/or linkages to the current ERA monitoring of nitrogen and phosphorus loads in Magela Creek.

7.3.11.5 Acid Sulfate Soils

The development of the site wide conceptual model has provided information on the current extent of ASS at Ranger and areas with potential for sulfidic material formation in the future based on likelihood of saturated soil conditions and historical or likely elevated sulfate exposure. A preliminary assessment of the likelihood of ASS formation/oxidation near Pit 3 has identified that while the conditions for formation of ASS within the Magela Creek sediments and Djalkmarra Sands is unlikely, uncertainties surrounding reducing and oxidising conditions need further investigation before the location specific conceptual model can be finalised. Targeted sample collection and analysis within Magela Creek (adjacent to Pit 3) is being undertaken to provide additional data to further inform development of the ASS conceptual model.

Opportunities to further reduce sulfate loads will be investigated as part of the FLF application. Potential mitigation options being considered for reducing manganese loads in the above-mentioned BPTs will also be beneficial for reducing sulfate loads.

Future investigations to confirm the presence of ASS within Magela Creek sediments and Djalkmarra Sands (adjacent to Pit 3) will be undertaken. The aim of this sampling program is to further characterise the sediments along Magela Creek and gain sufficient quantitative data on ASS. Where possible, these future investigations will draw upon the existing longitudinal groundwater monitoring and studies undertaken by ERA and OSS.

Further investigations and assessment of ASS over the remainder of the RPA will also be undertaken for inclusion in the final landform application. Location specific conceptual models will be developed for aquatic ecosystems downstream of the Pit 3/Magela Creek area and will inform the overall ASS risk profile and management strategy for RPA closure and post-closure phases.

7.3.11.6 Human Health Risk Assessment

The elevated concentrations of manganese reported in the human health risk assessment are consistent with the findings of the surface water assessment and are an area identified as requiring further investigation to reduce modelled manganese loads (from Pit 3 and from the RWD plume).

The following work of relevance to the human health risk assessment will be undertaken:

- The future work related to refining the water quality model.
- A BPT to identify the preferred additional remediation option/s to reduce manganese concentrations entering Magela Creek from Pit 3.
- A BPT to identify the preferred additional remediation option to reduce manganese concentrations entering Magela Creek from the RWD via the Coonjimba catchment.
- An iterative process whereby the modelled manganese concentrations predicted from the preferred remediation option/s are assessed and HI values are determined, creating a feedback loop of remediation and assessment until a HI value <1 is achieved.
- A screening assessment of the remaining 12 CoPCs, PFAS and any relevant emerging contaminants to confirm those eight CoPCs currently assessed are the most appropriate for future human health risk assessment re-runs.
- The current human health risk assessment includes soil contamination inputs derived from 477 samples taken across the RPA. Whilst closure/post-closure dust deposition is unlikely to be a significant contributor to metals in soils, the air dispersion modelling and resulting dust deposition undertaken by SLR (2018) will be included in the re-runs of the human health risk assessment for completeness.
- ERA are currently undertaking another sampling round of contaminant uptake in bush foods (including direct concentrations in flesh/organs/foods) on the RPA. The results of this sampling will be incorporated into future re-runs.
- The current preliminary human health risk assessment calculates HI based on a consumption of 3.6 kg of RPA-sourced bush food per day for an adult and 1.8 kg per day for a child (for each of the 1,040 hours / 43 days of proposed occupancy on the RPA). These inputs to the HI calculation will be investigated further, as will be the concentration factors for manganese.

Beyond the works mentioned above, and if deemed necessary once the re-runs of the assessment including the additional remediation measures is completed, further work may include the site-specific derivation of transfer factors for those bush foods that do not yet have site-specific factors. If not possible, further detailed literature research could be undertaken to confirm the suitability of the standard transfer factors currently used.

7.4 Bow-tie diagrams

As described in Chapter 5, this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. Depending on the theme, there may be multiple bow-ties, representing the relevant aspects being measured for that theme. For water and sediment, three bow-ties have been developed and these are provided as Figure 7-9, Figure 7-10 and Figure 7-11. The bow-ties have been developed based on consideration of groundwater and surface water catchments, and the final landform.

Within each bow-tie diagram, threats and preventative controls are provided on the left side of the diagram, and corrective actions and consequences on the right side. The residual risk ratings reflect the current effectiveness of the controls and corrective actions. Class IV and Class III risks exceed ERA's risk acceptance threshold and will be the subject of further work to reduce uncertainty, strengthen the controls and/or strengthen the corrective actions.

Further details on the preventative controls, monitoring program and corrective actions for the ecosystem theme are provided in Section 7.5, Section 7.6 and Section 7.7 respectively.

Preventative Controls

C7 All tailings deposited into Pits 1 and 3
Marginal - Satisfactory

C10 Low grade material (2s and 3s) buried below vadose zone in Pits 1 and 3
Satisfactory

C11 Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met
Marginal – Strong

C12 Brine injected into Pit 3 underfill
Satisfactory

C13 No water released from mine site unless it meets defined criteria and sufficient creek flow
Satisfactory – Strong

C16 Refuelling and maintenance areas are appropriately bunded
Strong

C22 Containment cell within RP2 for PFAS
Strong

C23 Excavate and dispose contaminated soil/sediments into Pit 3 and RP2
Marginal – Strong

C15 Understanding solute transport pathways, interactions and contaminant behaviour over time
Satisfactory

C14 Understanding source terms, groundwater loads, surface water concentrations
Satisfactory

Corrective Actions

A8 Planned duration of pump and treat extended to further reduce peak contaminant loads
Satisfactory

A9 Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels
Marginal

A10 Short-term restrictions to land access and cultural activities
Marginal

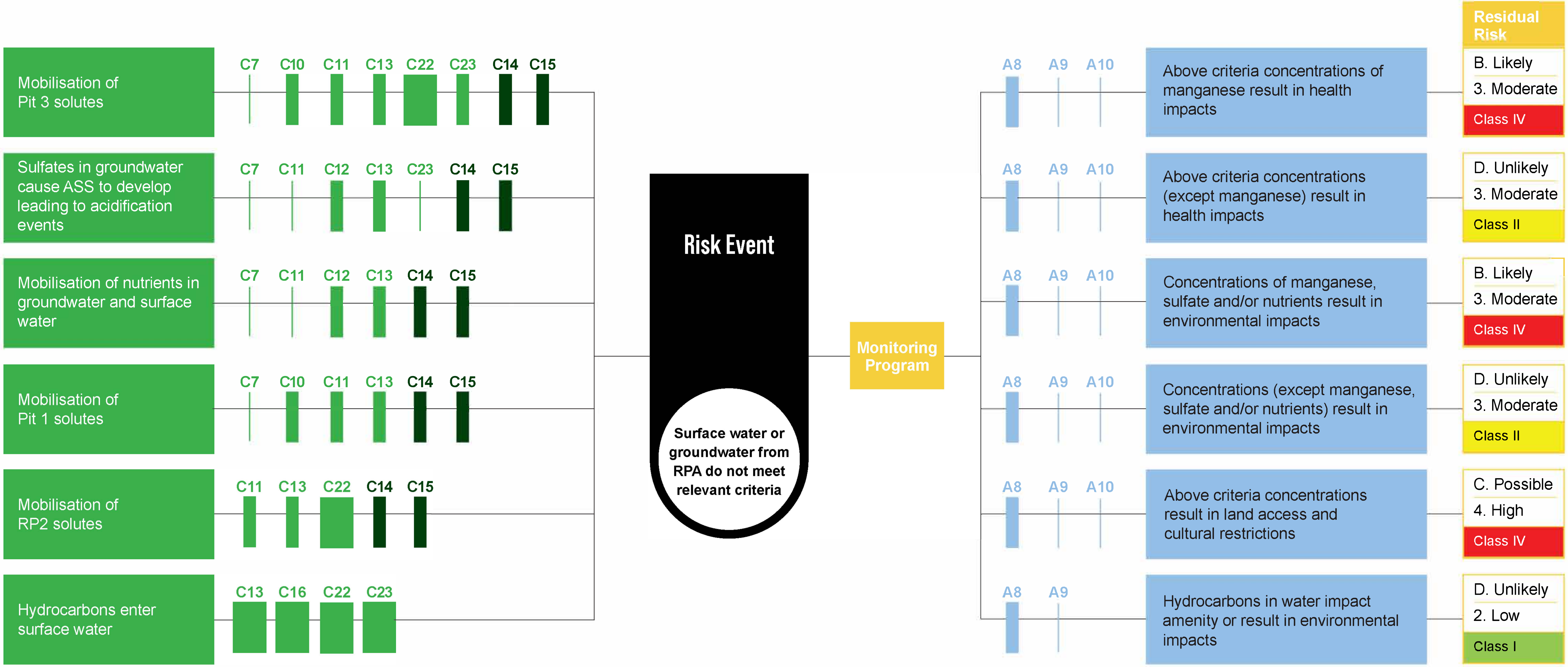


Figure 7-9: Bow-tie diagram for Djalkmarra and Corridor Creek catchments (WS1)

Preventative Controls

C3 Sediment control measures including sediment basins
Marginal - Satisfactory

C5 Revegetation of the final landform surface
Marginal - Satisfactory

C7 All tailings deposited into Pits 1 and 3
Satisfactory - Strong

C10 Low grade material (2s and 3s) buried below vadose zone in Pits 1 and 3
Satisfactory - Strong

C13 No water released from mine site unless it meets defined criteria and sufficient creek flow
Satisfactory - Strong

C17 Clay cap over RWD floor
Satisfactory - Strong

C18 Retain clay core around RWD floor
Satisfactory - Strong

C19 RWD and western stockpile interception trench
Marginal - Satisfactory

C23 Excavate and dispose contaminated soil/sediments into Pit 3 and RP2
Satisfactory - Strong

C14 Understanding source terms, groundwater loads, surface water concentrations
Satisfactory

C15 Understanding solute transport pathways, interactions and contaminant behaviour over time
Satisfactory

NOTE: See also Soils Preventative Controls in Chapter 8

Corrective Actions

A2 Undertaking earthworks to repair significant gullying or eroded areas
Satisfactory

A8 Planned duration of pump and treat extended to further reduce peak contaminant loads
Satisfactory

A9 Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels
Marginal

A10 Short-term restrictions to land access and cultural activities
Marginal

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory – Strong

A12 Additional interception system (e.g. passive reactive barrier)
Marginal

NOTE: See also Soils Preventative Controls in Chapter 8

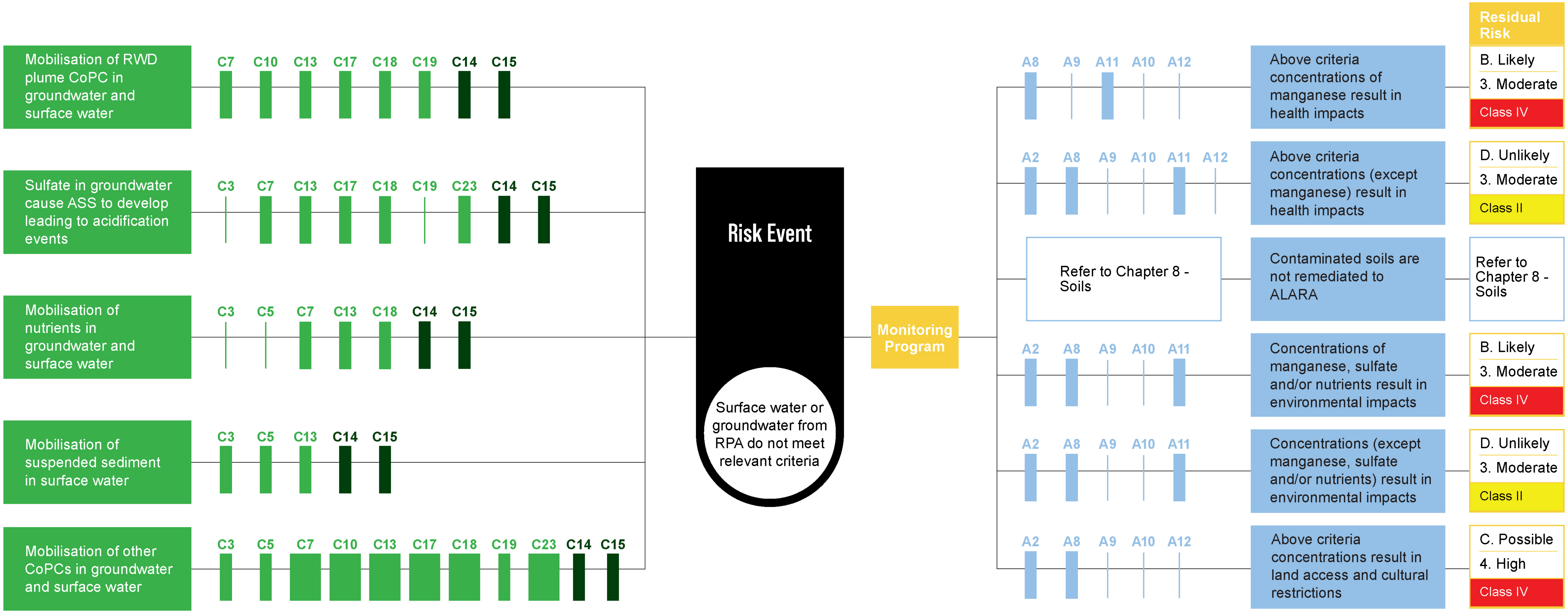


Figure 7-10: Bow-tie diagram for Coonjimba and Gulungul catchments (WS2)

Preventative Controls

- **C1** Final landform design and construction — Marginal - Satisfactory
- **C5** Revegetation of the final landform surface — Marginal – Satisfactory
- **C7** All tailings deposited into Pits 1 and 3 — Marginal – Strong
- **C10** Low grade material (2s and 3s) buried below vadose zone in Pits 1 and 3 — Satisfactory – Strong
- **C11** Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met — Marginal - Strong
- **C12** Brine injected into Pit 3 underfill — Satisfactory – Strong
- **C13** No water released from mine site unless it meets defined criteria and sufficient creek flow — Satisfactory – Strong
- **C16** Refuelling and maintenance areas are appropriately bunded — Strong
- **C19** RWD and western stockpile interception trench — Marginal - Satisfactory
- **C20** Use of approved pesticides as per instruction — Satisfactory
- **C21** Fertiliser use based on identified nutrient need of plants — Satisfactory – Strong
- **C22** Containment cell within RP2 for PFAS — Strong
- **C23** Excavate and dispose contaminated soil/sediments into Pit 3 and RP2 — Marginal - Strong
- **C14** Understanding source terms, groundwater loads, surface water concentrations — Satisfactory
- **C15** Understanding solute transport pathways, interactions and contaminant behaviour over time — Satisfactory

Corrective Actions

- **A1** Maintenance of erosion and sediment control measures — Satisfactory
- **A2** Undertaking earthworks to repair significant gullying or eroded areas — Satisfactory
- **A8** Planned duration of pump and treat extended to further reduce peak contaminant loads — Satisfactory
- **A9** Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels — Marginal
- **A10** Short-term restrictions to land access and cultural activities — Marginal
- **A11** Infill planting and seeding to maintain suitable vegetative cover on final landform — Satisfactory - Strong
- **A13** Discontinue use/change pesticide — Strong
- **A14** Discontinue nutrient use/change fertiliser — Strong
- **A15** Use of approved flocculant / coagulant — Satisfactory

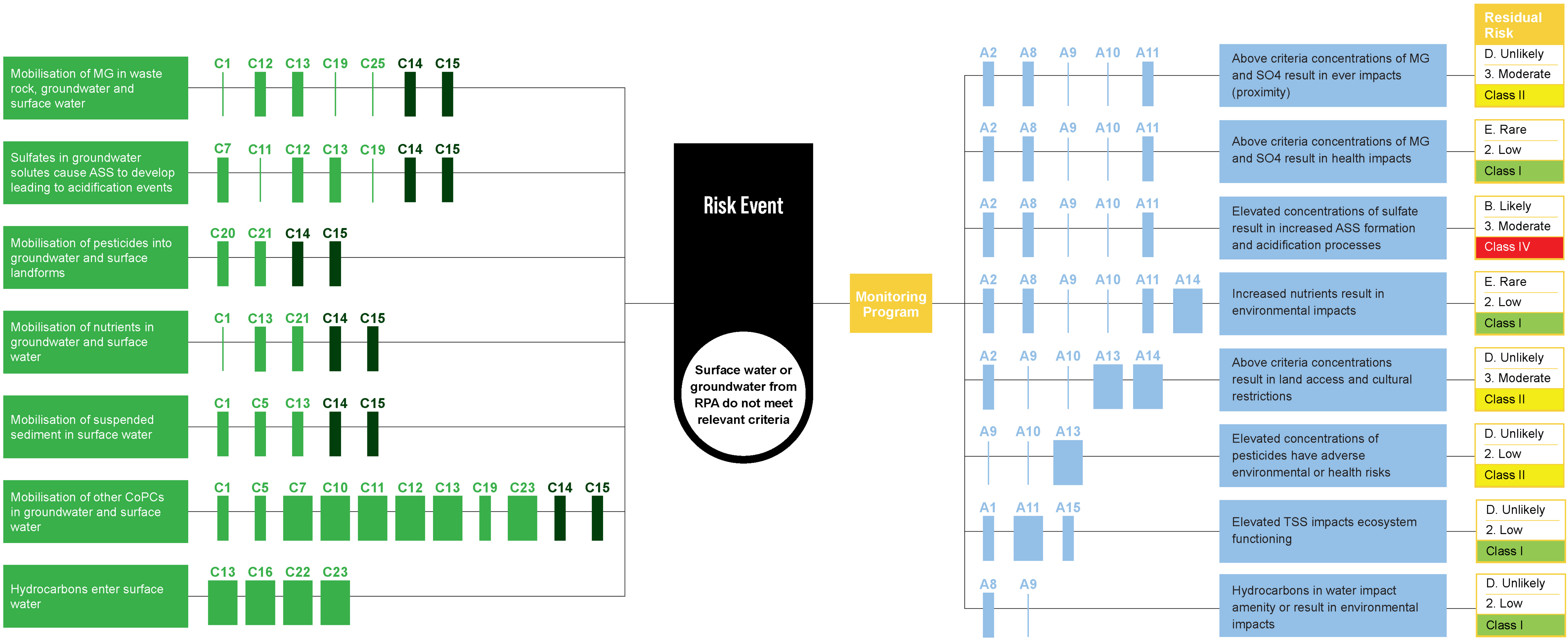


Figure 7-11: Bow-tie diagram for Final Landform and Land Application Areas (WS3)

7.5 Preventative Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well ERA understand and can demonstrate the effectiveness of the controls that will be put in place between now and the creation of the final landform, or shortly thereafter, to ensure that the water and sediment ERs can be achieved or are on the desired trajectory to being achieved. The subjective assessment provided in the spider web diagram at the beginning of this chapter indicates that the current status of progress is 50%.

The threats that relate to the following controls are shown in Table 7-15 and the bow-tie diagrams in Section 7.4.

Table 7-15: Water and Sediment Theme: potential threats

Threat	Djalkmarra and Corridor Creek Catchments (Pit 1, Pit 3, RP2)	Coonjimba and Gulungul Catchments	Final Landform and LAAs
Mobilisation of Pit 1 solutes	✓		
Mobilisation of Pit 3 solutes	✓		
Mobilisation of RP2 solutes	✓		
Mobilisation of RWD plume CoPC in groundwater and surface water		✓	
Mobilisation of nutrients in groundwater and surface water	✓	✓	✓
Mobilisation of suspended sediment in surface water		✓	✓
Mobilisation of Mg in waste rock groundwater and surface water			✓
Mobilisation of other CoPC in groundwater and surface water		✓	✓
Sulfate in groundwater cause ASS to develop leading to acidification events	✓	✓	✓
Mobilisation of pesticides into groundwater and surface landforms			✓
Hydrocarbons enter surface water	✓		✓

With the above threats in mind, the following sub-sections outline the preventative controls that will be implemented to manage the threats. The status and current rating of effectiveness for each preventative control (Table 5-1 describes the parameters used to rate the current effectiveness) is also provided.

7.5.1 Site-wide preventative controls

The preventative controls that are applicable site-wide are listed in Table 7-16 and further discussion is provided below.

Table 7-16: Preventative Controls for Water and Sediment – Site-wide

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C7	All tailings deposited into Pits 1 and 3	Marginal to Strong	'Strong' as all tailings have been deposited at depth into both Pit 1 and Pit 3 and reduces the risk of CoPC to the downstream environment through solute movement and/or mobilisation through erosion. The overall level of control for some CoPC is lower and requires complementary preventative controls to reduce loads and concentrations of these CoPC entering shallow groundwater and surface water systems in receiving catchment.
C10	Low grade material (2s and 3s) buried below vadose zone in Pits 1 and 3	Satisfactory - Strong	This control provides a generally high degree of effectiveness by minimising further oxidation of mineralised material present in this higher-grade material. Risk control effectiveness is higher for uranium however this waste rock/ore material remains a contributing source to predicted elevated levels of magnesium and sulfate, and alone does not achieve a strong level of effectiveness for these CoPC.
C13	No water released from mine site unless it meets defined criteria and sufficient creek flow	Satisfactory - Strong	This is a short to medium term control to manage solute movement risks and its long term application is inconsistent with site relinquishment objectives. The ability to capture surface water runoff on-site provides an effectiveness rating of 'strong' for this control in the short-term, however the 'satisfactory' effectiveness rating is appropriate as it forms only part of the suite of controls necessary to achieve water and sediment objectives in the long-term.
C23	Excavate and dispose contaminated soil/sediments into Pit 3 and RP2	Marginal - Strong	Excavation of contaminated material has strong effectiveness in regards to CoPCs presenting a threat in initial location. Emplacement in Pit 3 and RP2 enables CoPC movement to be controlled. Control effectiveness is rated as Marginal to Strong depending on CoPC as additional controls may be necessary to manage ongoing threats associated with emplacement in Pit 3 or RP2.
'Knowledge-based / Administrative' controls			
C15	Understanding solute transport pathways, interactions and contaminant behaviour over time	Satisfactory	The effectiveness of this control has been rated as 'satisfactory' and is currently considered sufficient to develop predictive models that are appropriate for informing the identification of key CoPC that present potential environmental and health risks.
C14	Understanding source terms, groundwater loads, surface water concentrations	Satisfactory	The current effectiveness of this control has been assessed as being 'satisfactory' as there is a good understanding of the range of CoPC concentrations observed in different source terms and a good understanding of the total volumes of different materials.

All tailings deposited into Pits 1 and 3

The effectiveness of emplacement of tailings within Pits 1 and 3 has been rated as ‘marginal’ to ‘strong’ depending on the particular CoPCs considered. Overall, the emplacement of tailings within the pits is an essential rehabilitation measure and a ‘satisfactory’ control, particularly in terms of preventing direct exposure of tailings to the environment. Coupled with other controls discussed in this section, this control effectiveness is ‘strong’ for most CoPCs as predicted concentrations of all but a few CoPCs will be below the applicable rehabilitation standards (refer Section 7.3.5).

The control effectiveness for burial of tailings is considered to be ‘marginal’ for manganese, sulfate (ASS) and ammonia (eutrophication) and ‘satisfactory’ for magnesium. The ‘marginal’ control effectiveness rating for manganese is associated with the tailings being the primary source for manganese and predicted concentrations remain above the rehabilitation standard for receiving waters based on a 99% species protection level both in the short term and long term.

The ‘marginal’ control effectiveness rating for ammonia relates to the existing uncertainties surrounding potential eutrophication risks from ammonia. Increased understanding of this hazard may result in this risk profile being reduced, particularly given the incremental predicted annual loads are well within observed natural variability of total nitrogen within Magela Creek.

The ‘marginal’ control effectiveness for sulfate relates primarily to uncertainty surrounding risks associated with ASS formation as well as waste rock (and particularly waste rock within the vadose zone) also being a large source of sulfate, and the burial of tailings has no impact on the control of sulfate (and magnesium) from this source. As noted above, magnesium loads from Ranger post-closure are not presently predicted to be above relevant closure criteria. Burial of tailings in Pits 1 and 3 is a key factor in these loads being low, however waste rock remains a significant source of magnesium both in the short term and long-term. For this reason, control effectiveness of tailings burial on magnesium is rated as being ‘satisfactory’.

Low grade ore material buried below vadose zone in Pits 1 and 3

Low grade ore material that was not processed will be (and has been) disposed of in Pits 1 and 3 below the vadose zone. The primary reason for emplacement below the vadose zone is to limit oxidation of the material and potential release of additional CoPCs (primarily uranium and associated radioactive CoPCs as well as other readily oxidised minerals such as sulfides) through geological processes. Emplacement within Pits 1 and 3 also controls the geohydrological transport pathways for these CoPCs to locations where they can be more accurately monitored and effectively controlled (where necessary).

Overall, this preventative control is considered to be ‘strong’ in managing potential risks associated with the CoPCs present within this ore material when used in conjunction with tailings deposition within Pits 1 and 3 (in particular) and the controls currently under investigation for the RWD. However, this control is rated as ‘satisfactory’ only for managing sulfate and magnesium risks given the significant load contributions from other waste rock sources and tailings.

No water released from mine site unless criteria is met

Ongoing active management of water on-site, including operational treatment measures, minimises (and in some cases avoids) potential risks associated with solute movement on the RPA. The ability to capture surface water runoff from the site is a key control in preventing water on the site which contains elevated levels of CoPCs entering downstream water systems. This control is not a permanent control, rather it is designed to be in place (or be re-implemented as a corrective control) where concentrations of CoPCs in surface waters remain at levels where they may present unacceptable environmental or health risks in the receiving environment. This control does not necessarily require treatment of all captured water and may include temporary detention or storage pending suitable flow conditions with Magela Creek to allow discharge of the captured water.

Coupled with the Western Interception System (discussed further in Section 7.5.3 and subject to review as part of the final landform BPT process) and management of groundwater levels in Pits 1 and 3, this control has a 'strong' effectiveness. The 'satisfactory' effectiveness rating relates to the requirement for active management on-site until potential impacts from groundwater solute movement can be demonstrated to meet an acceptable level of risk, and this is inconsistent with long term post-closure management objectives. It will however be a critical part of the control measures implemented during the closure works, particularly during bulk material movements.

Excavate and dispose contaminated soil/sediments into Pit 3 and RP2

Excavation of contaminated material from in situ location removes the source of the contaminant where it presents a higher threat when remaining in that location. This is proven and standard practice for contaminated sites remediation (see Chapter 8) and both Pit 3 and RP2 have ample void space to accommodate this material. Contaminated material to Pit 3 and RP2 is estimated to be 454,910 m^3 and 117,390 m^3 compared to void spaces of 29 M m^3 and 2.5 M m^3, respectively (refer Chapter 4).

Where concentrations and/or loads of CoPC within this material are predicted to present an increased environment risk, they will be further managed through treatment or burial within a containment cell/s.

The effectiveness of this control is 'strong' in relation to management of threats in the original location. Due to the screening processes involved in where and how material is disposed in Pit 3 or RP2, the control effectiveness is also considered to be 'strong', however as additional treatment measures may be required to manage cumulative loads, and/or solute movement may result in ongoing accumulation within sediments, the effectiveness is rated as 'marginal'.

RP1 sediments are known to contain elevated levels of a range of different CoPC and also contain ASS (see Chapter 8). Further work on sampling these sediments and the fate of RP1 (removed of retained) is the subject of a current BPT.

Understanding solute transport pathways

While understanding solute transport pathways is not, in itself, a preventative control, groundwater flow, surface water flow and solute migration within and from the RPA over temporal and spatial scales informs decommissioning and closure decisions and is essential in the development of models designed to predict likely loads and concentrations of different CoPCs well into the future.

Numerous iterative studies and models over the life of the operation have been developed to understand and document these often-complex hydrogeological processes and characteristics (refer Section 7.3).

Ongoing work to improve the confidence in modelling of solutes within surface water flows is also being undertaken. ERA are undertaking further work to improve knowledge regarding the recharge and hydraulic conductivity of waste rock. These studies will improve modelling predictions of solute movement in the waste rock final landform and uncertainty within these parameters can be more accurately captured within the uncertainty analysis undertaken for future applications and presented in future iterations of the MCP.

Understanding source terms and loads

Understanding the source terms and mass within the various source terms is not, in itself, a preventative control, however it is critical in understanding exposure risks associated with different disposal/management options and also the risk control effectiveness of different preventative (and corrective) control measures that have been considered. The current effectiveness of this 'control' has been assessed as being 'satisfactory' in that there is a good understanding of the range of CoPC concentrations observed in different source terms and a good understanding of the total volumes of different materials (refer Section 7.3.2 to Section 7.3.5).

To the extent that there is uncertainty (or variability) in concentrations and or the volume of material that will be present in the rehabilitated landform, the risks presented by this uncertainty are considered through the use of sensitivity analysis or uncertainty analysis which has taken into consideration the known range of variability.

7.5.2 Djalkmarra Catchment and Corridor Creek Catchment

Additional preventative controls for the Djalkmarra Catchment and Corridor Creek Catchment (Pit 1, Pit 3 and RP2) are listed in Table 7-17 and discussed further below.

Table 7-17: Preventative Controls for Djalkmarra Catchment and Corridor Creek Catchment

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C11	Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met	Marginal - Strong	Pumping and treating CoPCs at Ranger is a proven and effective method and is therefore a very 'strong' control for most CoPCs. This control is assessed as having 'marginal' effectiveness for manganese, ammonia and sulfate.
C12	Brine injected into Pit 3 underfill	Satisfactory	'Satisfactory' because the directionally drilled injection wells can be worked-over to unblock if required, and the capacity of the underfill has been calculated at 2.5 GL against the planned production of 1.9–2.1 GL of brine.
C16	Refuelling and maintenance are appropriately bunded	Strong	'Strong' due to it being an engineered control and accepted industry practice.
C22	Containment cell within RP2 for PFAS	Strong	The effectiveness of this control is considered to be 'strong' given that it either removes the threat from the site or utilises well understood and proven containment methodologies.

Pump and treat from Pits 1 and 3

Decant wells and monitoring bores installed in Pits 1 and 3 (and RP2 if required) can be used to remove groundwater from within the backfill material and prevent CoPCs at elevated concentrations relative to the background environment from entering Magela Creek. While groundwater heads within Pits 1 and 3 are maintained below higher hydraulic conductivity HLUs, and the pits can be maintained as a hydraulic sink, movement of solutes associated with tailings and waste rock (and low-grade ore material within the pits) to Corridor Creek and Magela Creek can be very effectively controlled. This pumping will be used initially to remove PTF and other solutes until concentrations within the pits have reached a level where long-term movement is modelled as being unlikely to present a risk of exceeding relevant rehabilitation standards.

The current design of decant wells for Pit 3 (see Chapter 4 for details) envisages removal of all but approximately 65 ML of PTF (within an expected range of 37 ML to 110 ML). This estimate is based on practical constraints associated with PTF extraction and uncertainty regarding the porosity of backfill waste rock. These uncertainties have been considered in the uncertainty analysis undertaken for groundwater solute modelling for Pit 3 sources.

The ability to pump and treat groundwater within Pits 1 and 3 (and RP2 if required), including PTF expressed from consolidating tailings is a ‘strong’ control for most CoPCs within this catchment with the exception of contaminants present in waste rock used to develop the final landform. This control has only ‘marginal’ effect on long term sulfate and magnesium concentrations which are driven by solute movement from the vadose zone waste rock.

Brine injected into Pit 3 underfill

The porous underfill within Pit 3 is the final repository for the concentrated brine waste stream produced by the Brine Concentrator. Due to the higher density of brine material, the brine fills the underfill progressively from the bottom. CoPCs present with the brine are predicted to move downwards in the groundwater system due to its higher density.

The current water model forecasts approximately 1.9–2.1 GL of brine will be generated prior to final site closure. Available void volume is 2.5 GL (Coghill, 2016). The injection of brine into the underfill is considered to be a strong control for the disposal of brine material created through expected water treatment at the Brine Concentrator during the closure process.

Refueling and maintenance areas are appropriately bunded

This is a standard management control to minimise hydrocarbon contamination risks associated with closure (and post closure) management works. Bunding criteria for fuel and liquid storages should have regard to seasonal timing of risks and potential for rainfall during wet season to increase spill risks in the event. The effectiveness of this control is rated as ‘strong’ due to it being an engineered control and accepted industry practice.

Containment cell within RP2 for PFAS

Containment cells developed using low permeability caps and liners can be used to limit movement of higher risk materials and are a well-known and proven method (see Chapter 8, Section 8.5 for details).

7.5.3 Coonjimba Catchment and Gulungul Catchment

Additional preventative controls for the Coonjimba and Gulungul catchments are listed in Table 7-18 and discussed further below (for those controls not discussed above).

Table 7-18: Preventative Controls Coonjimba Catchment and Gulungul Catchment

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C1	Final landform design and construction	Marginal - Satisfactory	This preventative control has been rated as 'marginal' to 'satisfactory'. Modelling has demonstrated effectiveness of the current final landform design. However further work is planned to refine the final landform design.
C5	Revegetation of the final landform surface	Marginal - Satisfactory	Overall, the planting of vegetation will have a 'marginal' to 'satisfactory' impact on solute movement but cumulatively with other controls is expected to contribute to a lower overall risk presented by the rehabilitated landform.
C17	Clay cap over RWD floor	Satisfactory - Strong	Preliminary modelling indicates the clay cap is very effective in mitigating peak loads from the tailings floor sources. Final details of this design feature are under investigation in a future BPT process.
C18	Retain clay core around RWD floor	Satisfactory - Strong	Control effectiveness is similar to that for the clay cap. Final details of this design feature are under investigation in a future BPT process.
C19	RWD and western stockpile interception trench	Marginal - Satisfactory	Existing interception trench has proven effective at intercepting solute movement, however long-term effectiveness is considered to be 'marginal' without pump and treat system.

Final landform design and construction

Elevated turbidity within water can have detrimental effects in terms of impacting energy cycling processes within aquatic ecosystems. Elevated levels of sediments in runoff from constructed landforms can present a risk to downstream environments through deposition of sediments and also through CoPCs present within the suspended sediments. Active water management will be required both during the construction of the final landform and for some years post construction until collected waters are suitable for direct release off-site such that they do not exceed applicable water quality criteria. Sediment basins will be located around the perimeter of the disturbed footprint with the current proposal being a single basin within each sub-catchment (refer Chapter 6). The proposed sediment basins are currently at preliminary design. The location and size of these basins will be determined as part of the *Erosion, Sediment and Water Control Plan* (see Section 6.5.3). This preventative control has been rated as 'marginal' to 'satisfactory'.

Revegetation of the final landform surface

Increased vegetation cover will reduce overall groundwater recharge through increased plant uptake and transpiration. Vegetation cover also plays an active role in managing erosion which reduces potential solute loads associated with CoPCs present within the sediments and reduced turbidity risks to downstream aquatic environments (refer Chapter 6). Vegetation in the final landform can also reduce loads of nitrogen and phosphorus within groundwater through uptake for biological processes.

Individually, the planting of vegetation will have a 'marginal' impact on solute movement in early years when it is still becoming established however control effectiveness increases to a satisfactory level of control once established. Cumulatively with other controls, and in the longer term, it is expected to contribute to a lower overall risk of elevated sediment and solutes presented by the rehabilitated landform.

Clay cap over RWD floor

There is a known plume of contaminated groundwater within the RWD floor and immediately downstream of the RWD associated with tailings and process water storage. Removing this contaminated groundwater and/or slowing the movement of the plume will have significant benefits in reducing loads of some CoPCs present within the plume from entering downstream surface water environments, including Coonjimba Billabong and, if retained, RP1.

Clay material from the clay core in the RWD walls will be emplaced over the tailings floor. This clay material has lower hydraulic conductivity than the overlying waste rock and will reduce vertical groundwater recharge into the underlying floor material which reduces annual solute loads from this source. Final details of this design feature and improved understanding of control effectiveness are under investigation in a future BPT process.

Retain clay core around RWD floor

Used in conjunction with the clay cap, the clay core material below the floor level of the RWD will likely be retained (subject to outcomes of BPT). The retention of this aspect of the clay core would reduce horizontal groundwater flow through the tailings floor material. Control effectiveness is similar to that for the clay cap discussed above.

RWD and western stockpile interception trench

The Western Stockpile Interception trench was installed to intercept solute movement associated with the western stockpile and prevent it from entering RP1 and Coonjimba Creek. A similar interception system was implemented on the western side of the RWD to intercept solute movement from the RWD wall towards Gulungul Creek. This interception system has proven effective at managing this risk and the ongoing use of the western RWD interception system and the extension of the Western Stockpile Interception System along the northern extent of the RWD in the final landform is being considered as part of the RWD BPT process.

While this system is effective in intercepting solute movement from the toe of the waste rock landform, its success would be subject to ongoing pumping and treating of intercepted water. Its effectiveness in managing long-term solute loads from waste rock is therefore limited and is considered to be 'marginal'.

This design feature and its role in solute movement mitigation will be subject to further investigation in the future RWD BPT process and BPTs for the final landform.

7.5.4 Final Landform and Land Application Areas

Additional preventative controls for the Final Landform and LAAs are listed in Table 7-19 and further discussed below (for those controls not discussed above).

Table 7-19: Preventative Controls – Final Landform and LAAs

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C1	Final landform design and construction	Marginal - Satisfactory	This preventative control has been rated as 'marginal' to 'satisfactory'. Modelling has demonstrated effectiveness of the current final landform design. However further work is planned to refine the final landform design. See Section 7.5.3 for discussion.
C5	Revegetation of the final landform surface	Marginal - Satisfactory	Overall, the planting of vegetation will have a 'marginal' to 'satisfactory' impact on solute movement but cumulatively with other controls is expected to contribute to a lower overall risk presented by the rehabilitated landform. See Section 7.5.3 for discussion.
C11	Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met	Marginal - Strong	Pumping and treating CoPCs at Ranger is a proven and effective method and is therefore a very 'strong' control for most CoPCs. This control is assessed as having 'marginal' effectiveness for manganese, ammonia and sulfate. See Section 7.5.2 for discussion.
C12	Brine injected into Pit 3 underfill	Satisfactory	'Satisfactory' because the directionally drilled injection wells can be worked-over to unblock if required, and the capacity of the underfill has been calculated at 2.5 GL against the planned production of 1.9–2.1 GL of brine. See Section 7.5.2 for discussion.
C16	Refuelling and maintenance areas used for closure works or post closure management works are appropriately bunded	Strong	'Strong' due to it being an engineered control and accepted industry practice. See Section 7.5.2 for discussion.
C19	RWD and western stockpile interception trench	Marginal - Satisfactory	Existing interception trench has proven effective at intercepting solute movement, however long-term effectiveness is considered to be 'marginal' without pump and treat system. See Section 7.5.3 for discussion.
C20	Use of approved pesticides as per instruction	Satisfactory	Due to the nature of environmental controls contained in the legislated approval processes for the use of pesticides, the effectiveness of this preventative control is assessed as being 'satisfactory'.
C21	Fertiliser used based on identified nutrient need of plants	Satisfactory - Strong	Current level of effectiveness is satisfactory' to 'strong' based on the ability to target fertiliser application and overall risks considered to be low due to the overall small loads of elements contained in fertilisers relative to other sources.
C22	Containment cell within RP2 for PFAS	Strong	The effectiveness of this control is considered to be 'strong' given that it either removes the threat from the site or utilises well understood and proven containment methodologies. See Section 7.5.2 for discussion.

Use of approved pesticides as per instruction

Pesticides are a potential threat to the environment though their impacts on non-target species and, in some cases, long-term effects where the active ingredients in pesticides remain biologically active well after the initial application period. These risks are managed through legally binding restrictions on the use of the pesticides in the form of the instructions for use. Further, the approval of pesticides for use in Australia also has regard to the potential environmental risks associated with the use of the specific pesticide and this is reflected in the instructions for use where such use is approved for specific pests (fungal, animal or plant). Due to the nature of environmental controls contained in the legislated approval processes for the use of pesticides, the effectiveness of this preventative control is assessed as being ‘satisfactory’.

Fertiliser used based on identified nutrient need of plants

Fertiliser use is required as part of the revegetation program due to the relatively low nutrient status of the waste rock material (see Chapter 9). Mobilisation of nutrients in fertilisers presents potential (but likely low) of elevated nutrients entering downstream waterways that may contribute to eutrophication risks and elevated levels of some other CoPCs, particularly when considered in a cumulative context with existing predicted CoPCs loads from other sources. The effectiveness of this control has been rated as ‘satisfactory’ to ‘strong’ based on the ability to target fertiliser application and overall risks associated with this threat is considered to be low due to the overall small loads of elements contained in fertilisers relative to other sources.

7.6 Monitoring Program

A series of comprehensive monitoring events will be undertaken throughout the closure and post-closure periods to track the progress and achievement of the closure criteria, and to trigger adaptive management and corrective actions if required. The closure and post-closure phase allow an adaptive management approach to site rehabilitation and closure, whereby the monitoring program will provide ongoing feedback on the performance of the site rehabilitation to identify any issues and inform maintenance activities. The monitoring program will also assist in testing the accuracy and validating impact predictions (typically obtained from computer models) and to guide future decisions with regards to closure activities. The monitoring programs specific to groundwater and surface water are discussed below.

Groundwater and surface water

ERA undertakes groundwater and surface water monitoring at Ranger and reports the findings annually in the Ranger Water Management Plan (RWMP), Ranger Water Monitoring Strategy (RWMS), the Annual Groundwater Report, through provision of monitoring data (including routine water quality reports weekly during flow and monthly at all other times), and the Surface Water Wet Season Report.

This section does not seek to duplicate the monitoring described or listed in these plans and reports, but rather provide a summary of additional monitoring that will be undertaken during the closure phase. Table 7-20 describes this monitoring.

Table 7-20: Groundwater and surface water monitoring additional to monitoring requirements in the Ranger Water Monitoring Strategy

Objective	Parameter	Location	Frequency
Groundwater Monitoring			
Ultimately, this program is to demonstrate that solute transport velocities and concentrations are consistent with solute transport modelling predictions and that the receiving environment will remain protected from defined CoPC	Surface water level (SWL), in-situ EC, pH, temperature, Redox Al, As, B, Ca, Cd, Cl, CO_3, Cr, Cu, Fe, HCO_3, K, Mg, Mn, Na, Ni, NH_3-N, NH_4, NOx-N, NO_3, Pb, Po (annually), PO_4, PO_4-P, Ra (annually), Se, Si, SO_4, U, V, Zn	Existing groundwater bores downgradient of known contaminant sources	Bi-annually.
Out of Pit Surface Water Monitoring			
Ultimately, to validate and assess the predictive solute transport models (including exfiltration) and confirm that the receiving environment will remain protected from defined CoPC	Turbidity (MCUS & MG009 only) and EC	MCUS, MG001, MG003, MG009	Continuous.
	Mn, U, SO_4, Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N, NO_3, NO_2	MCUS, MG009, Indium Billabong	Fortnightly during the wet season, reducing to monthly during the dry season (when water is available for sampling).
In Pit Surface Water Monitoring			
To determine the quality of water being pumped to RP2 (from the capped surface)	In-situ EC, pH, temperature Mn, U, SO_4, Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N, NO_3, NO_2	Localised low points where surface water pooling is identified	Weekly when pumping from the capped surface to RP2.
PTF and Process Water Removal Monitoring			
To determine the rate and volume of PTF extracted via the decant structures	Flow meters on the discharge pipeline from each decant pump.	Decant structures in Pit 1 and Pit 3	Ongoing for Pit 1. Following the commissioning of Pit 3 decant pumps. Monitoring will be continuous whilst pumping is occurring. Pumping will continue until the targeted volume of PTF has been removed from the deposited tailings.
To determine the rate and volume of process water removed via the underdrain bore	A flow meter installed on the underdrain bore pump measuring the volume of water expressed via the underdrain bore.	Flow meter on the underdrain bore pump	Monitoring will be continuous whilst pumping is occurring.

7.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subject 60% progress status for ‘corrective actions’. This reflects uncertainty around solute concentrations of particular CoPC and the effectiveness and practicability of treatment options.

The monitoring program described in Section 7.6 will be used to detect potential deviations or threats, which will trigger further investigation. Clear deviations in trajectory may trigger a number of corrective actions. These are described in Table 7-21, along with status and effectiveness. The table is followed by a discussion of each.

Table 7-21: Corrective Actions for Water and Sediment (all ‘Active’ Corrective Actions)

Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
A1	Maintenance of erosion and sediment control measures	Satisfactory	This control is considered ‘satisfactory’ due to the residual need to manage water collected in sediment control structures and associated impacts.
A2	Undertaking earthworks to repair significant gullying	Satisfactory	Due to this control being unlikely to require implementation beyond the relinquishment phases, this is considered to have a ‘satisfactory’ level of control effectiveness.
A8	Planned duration of pump and treat extended to further reduce peak contaminant loads	Satisfactory	The base case prediction is that active pump and treat will finish in 2034. Should monitoring determine the agreed water and sediment guideline values would not be met, pump and treat would be extended.
A9	Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels	Marginal	The effectiveness of this control is currently rated as ‘marginal’ based on uncertainties around requirements, potential impacts associated with implementation of these controls and uncertainty around the success of such interventions.
A10	Short term restrictions to land access and cultural activities	Marginal	The effectiveness of this control is considered ‘marginal’ due to reliance on human behaviour to comply with restrictions and potential secondary impacts on biodiversity values associated with hard controls.
A11	Infill planting and seeding to maintain vegetative cover on final landform	Satisfactory - Strong	Infill planting may be required if unexpected impacts on vegetation associated with solutes in groundwater are observed. Control effectiveness for this corrective action is assessed as being ‘satisfactory’ due to some uncertainty regarding impacts associated with solute transport in the shallow groundwater.
A12	Additional interception systems (e.g. passive reactive barrier)	Marginal	As these controls are still under investigation, they are rated as having a ‘marginal’ effectiveness.
A13	Discontinue use / change pesticide	Strong	The effectiveness of this control is rated as ‘strong’ given its ability to avoid ongoing impacts.
A14	Discontinue use / change fertiliser	Strong	The effectiveness of this control is rated as ‘strong’ given its ability to avoid ongoing impacts.
A15	Use of approved flocculant / coagulant	Satisfactory	Flocculants are effective at reducing suspended sediment prior to discharge.

Maintenance of erosion and sediment control measures

Erosion and sediment control measures will be maintained and operated to design specifications throughout the closure and post-closure periods up until relinquishment (refer Chapter 6). As sediment movement risks reduce over time, it is anticipated the use of sediment dams will be phased out as runoff from the landform meets quality levels that will not result in an exceedance of relevant closure criteria.

Overall, the effectiveness of this as a corrective action is assessed as 'satisfactory' with the rating not considered to be strong only due to the residual need to manage water collected in sediment control structures and associated impacts (including extended presence of management activities on-site).

Undertaking earthworks to repair significant gullying

These activities will occur prior to relinquishment if greater than predicted gullying is observed as erosion risks will be highest during the early years after landform establishment with risks expected to reduce as vegetation becomes established. Material erosion and gullying that occurs throughout the closure and post-closure periods will be actively managed (refer Chapter 6).

Planned duration of pump and treat extended to further reduce peak contaminant loads

In the event that further modelling or monitoring indicates proposed control measures are unlikely to be adequate to enable relevant water quality closure criteria to be met, lower groundwater heads via additional pump and treat within the Pits 1 and 3 and surrounding landform can be maintained at a level that slows or prevents solute movement from these areas to surface water systems.

Similarly, extending and or recommencing pumping from the RWD and western interception systems can be used to intercept solute movement in shallow groundwater and surface flows.

While in operation, this control is rated as having 'strong' effectiveness.

The major limitation on this control is that it requires ongoing site access, and water storage and treatment facilities.

Additional remediation if sediments at Coonjimba or Gulungul Billabongs do not achieve target levels

Sediments within Coonjimba and Georgetown Billabong are known to contain elevated levels of some CoPCs and contain ASS. The sampling program described in Chapter 8 will advance this understanding. Chapter 8 also describes the remediation measures and corrective actions associated with contaminated soils/sediments on the RPA including billabongs.

The effectiveness of this control is currently rated as 'marginal' based on uncertainties around requirements, potential impacts associated with implementation of these controls and uncertainty around the success of such interventions.

Short-term restrictions to land access and cultural activities

This corrective action whilst effective in the short-term is not preferred and is rated as having a ‘marginal’ effectiveness. The implementation of this corrective action is considered to be inconsistent with the achievement of other mine closure objectives and would be implemented only as a temporary measure or where alternate controls are not sufficiently effective in managing human health risks.

Infill planting and seeding to maintain vegetative cover on final landform

Infill planting and/or seeding is likely to be required in some areas of the landform where vegetation development is less successful (see Chapter 9).

Monitoring of vegetation in areas downslope of expected groundwater exfiltration points and areas of shallow groundwater with higher concentrations of CoPC that may affect plant growth will also be undertaken. Infill planting will be required in these areas if unexpected impacts on vegetation associated with solutes in groundwater are observed.

Control effectiveness for this corrective action is assessed as being ‘satisfactory’ due to some uncertainty regarding impacts associated with solute transport in the shallow groundwater. The effectiveness of infill planting in the final landform as a control measure for sediment related risks is well understood and is assessed as ‘strong’.

Additional interception systems (e.g. passive reactive barrier)

Additional controls that have potential to reduce higher than expected solute loads are under investigation and will be considered as part of BPT processes planned in 2024. These additional controls could include wetland filters or passive reactive barriers that would reduce CoPC loads through geochemical and/or biogeochemical processes; interception bores with associated treatment options and use of low permeability barriers.

Effectiveness of these potential intervention measures is currently rated as ‘marginal’ due to them being under investigation, however it is noted that their use has been demonstrated to be effective in other circumstances. It is also noted that such systems, if required, would likely be installed prior to the creation of the final landform (i.e. a preventative control) and therefore is only included here as a corrective action for completeness in the event that monitoring deems them to be necessary where pre-closure modelling predictions did not.

Discontinue use / change pesticide

If a particular pesticide is identified as having significant adverse impacts, its use would be modified or stopped. The effectiveness of this corrective action is rated as ‘strong’ given its ability to avoid ongoing impacts. Additional remediation options may need to be considered if the concerns associated with a specific chemicals use are associated with it continued bioavailability long after use has ceased.

Discontinue use / change fertiliser

If fertiliser use is identified as a material contributor to adverse nutrient or ecotoxicological risks the use of the fertiliser would be modified or stopped. The effectiveness of this corrective action is rated as ‘strong’ given its ability to avoid ongoing impacts.

Fertiliser use is not expected to be required beyond the initial establishment period for vegetation and therefore long-term risks associated with fertiliser use are considered to be low.

Use of approved flocculants

Flocculants are effective in removing suspended sediments from water enabling release water to meet turbidity criteria. Risks presented by flocculants usually relate to potentially elevated levels of some metals used in the flocculants or released from suspended sediments associated with geochemical reactions triggered by flocculant addition. The use of flocculants on-site is currently subject to regulatory review by the OSS. This review processes includes consideration of unintended environmental impacts associated with metal concentrations in treated water. The effectiveness of this corrective action is rated as ‘satisfactory’ given the review processes associated with approval for use at RPA and the controls applicable to the discharge of water from site.

7.8 Trigger, Action, Response Plan

Table 7-22 consolidates the monitoring and adaptive management programs described above into the form of a trigger, action, response plan. The triggers and action/response presented in this TARP are indicative and may change as further information becomes available. This TARP will be updated as required in future iterations of the MCP.

Table 7-22: Trigger, Action, Response Plan for Water and Sediment

Groundwater – to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions (within documented uncertainties)			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Samples results below specific screening criteria defined in closure criteria. Analysis indicates that groundwater is tracking according to model predictions.	Samples exceed specific screening criteria defined in closure criteria. Analysis indicates that groundwater is tracking according to model predictions.	Samples exceed specific screening criteria defined in closure criteria. Analysis indicates that groundwater is not tracking according to model predictions.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Site Environmental Officer (or delegate)	Continue routine monitoring as per Table 7-20.	Monitor trends and develop site specific action plan as required.	Review model assumptions and outputs. Remediate as per relevant corrective action e.g. extend pump and treat, install additional interception systems.
Surface water – to validate and assess the predictive solute transport models (including exfiltration) and confirm that the receiving environment will remain protected from defined CoPC			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Samples results below specific screening criteria defined in closure criteria. Analysis indicates that surface water is tracking according to model predictions.	Samples exceed specific screening criteria defined in closure criteria. Analysis indicates that surface water is tracking according to model predictions.	Samples exceed specific screening criteria defined in closure criteria. Analysis indicates that surface water is not tracking according to model predictions.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Site Environmental Officer (or delegate)	Continue routine monitoring as per Table 7-20.	Monitor trends, identify cause and develop site specific action plan as required.	Remediate as per relevant corrective action. Review model assumptions and outputs.

PTF removal – to determine the rate and volume of PTF extracted via the decant structures Process Water Removal – to determine the rate and volume of process water removed via the underdrain bore			
	Normal State	**Level 1 Triggers**	**Level 2 Triggers**
Trigger Action Response Plan	Decant structures and underdrain bore performing as expected.	Flow meters indicate moderate variance from predicted flow rate.	Flow meters indicate significant variance from predicted flow rate
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Pit 3 Area Owner	Continue routine monitoring as per Table 7-20.	Undertake an investigation to identify potential causes of variance. Update models if necessary.	Undertake an investigation to identify potential causes of variance. Update model and reassess performance.

7.9 Future Work

The spider web diagram at the beginning of this chapter provided a subjective progress status for the water and sediment theme. Where <100% is indicated, future work is occurring, planned and/or required. The following outlines the future work for each of the metrics shown in the spider web diagram (noting that other chapters in this MCP describe future studies that are related to water and sediment and therefore they are not repeated here):

Closure criteria approved (70%):

- Continue to apply the WQMF approach to develop water and sediment quality objectives for management goals.

Relevant studies completed (70%):

- Section 7.3.11 details the future work for this theme.

Preventative controls (50%):

- Ongoing work on understanding reactive transport processes applicable to manganese, nitrogen (predominately ammonia) and sulfates (associated with ASS formation and related sulfur cycle processes) continues to be undertaken to understand potential risks associated with elevated concentrations of these CoPCs moving from Ranger into the surrounding environment.
- The high loads of manganese within groundwater remains under review in terms of reactivity within the transport pathways.
- Further work to improve the understanding of seasonal changes in solute transport is proposed to inform the consideration and design of additional preventative control factors that may be necessary to further reduce loads of CoPCs identified as presenting a potential ongoing risk, including, manganese, ammonia and sulfate.
- ERA commits to undertaking a BPT assessment of additional remediation concepts for Pit 3 and the RWD plume.

Monitoring program developed and operational (80%):

- Detailed monitoring programs will be prepared as part of the RWD and FLF application processes. These programs will adapt the existing operational monitoring programs and include (where necessary) additional surface and groundwater monitoring to assess solute movement from the site and the effectiveness of preventive controls implemented.

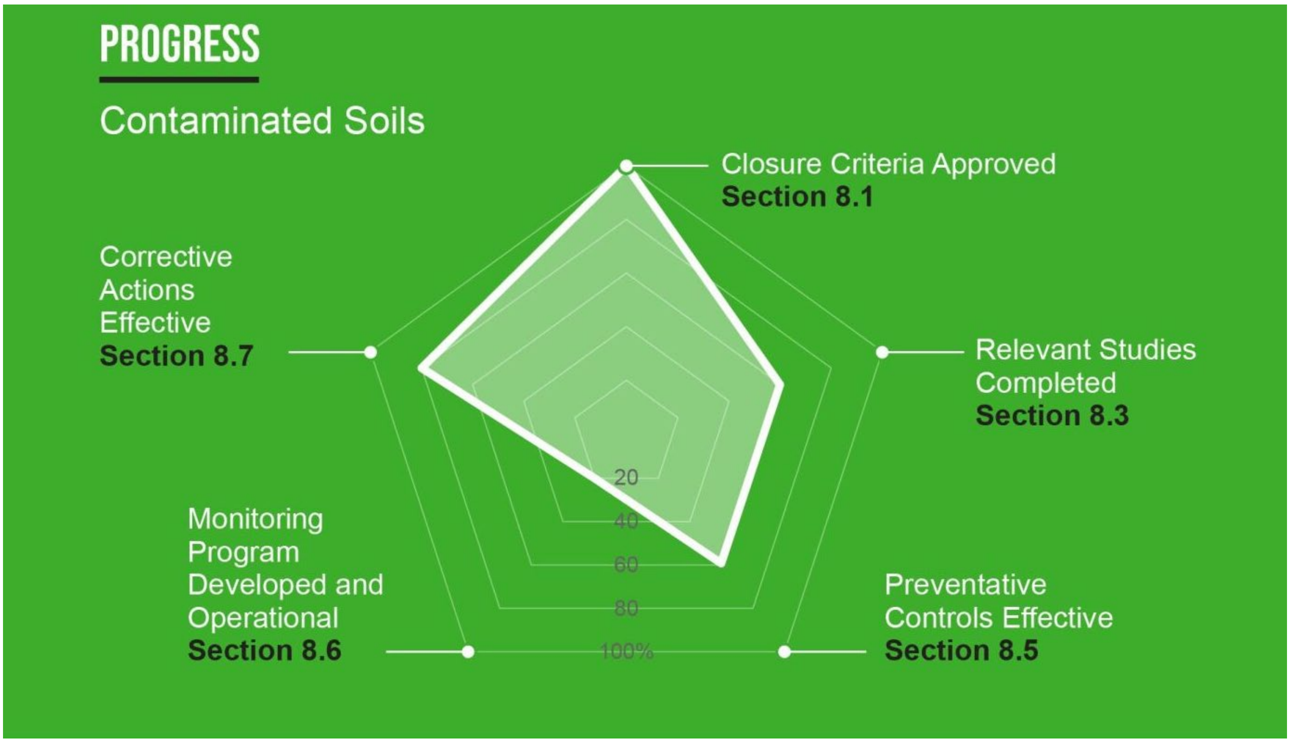
Corrective actions effective (60%):

- Further investigation of potential measures for treatment of water over the long-term to ensure water quality closure criteria can be met.
- Additional controls that have potential to reduce higher than expected solute loads are under investigation and will be considered as part of future BPT processes and discussed in future iterations of the MCP.

8 SOILS

The purpose of this chapter is to consolidate information relevant to contamination of surface and near-surface land on the RPA. One closure objective has been derived from the soils related ERs, which requires that soils are remediated to a level that demonstrates ALARA and residual contamination does not present an unacceptable risk to human health or the environment. An indication of progress against key metrics for soil contamination is summarised in the spider web diagram below. It shows:

- All relevant Closure Criteria are approved (100%, Section 8.1).
- Twenty-five studies have been completed to inform the level and spatial extent of contamination on the RPA, collectively these form Phase 1 of the planned studies. Further sampling and the development of Remediation Action Plans (Phase 2) and remediation activities (Phase 3) are planned future work (60%, Section 8.3).
- Preventative controls to manage soil contamination have been described and will be further developed during Phases 2 and 3. Sufficiently large and deep voids (Pit 3 and RP2) are available to dispose contaminated soils (60%, Section 8.5).
- A high-level framework for monitoring the success of remediation activities is included in the MCP but considerable future work is planned to develop detailed plans (20%, Section 8.6).
- Corrective actions for the treatment of contaminated soils, should they be detected during the validation sampling, are well understood and common practice (80%, Section 8.7).



For the purpose of the MCP, the theme of 'soils' is referring to surface or near-surface land that may have been contaminated during the operation of the mine. It includes land on the RPA that has become contaminated through treatment of pond water in wetlands and bunds, irrigation of pond water in the LAAs, and seeps and spills in areas such as the processing plant. It does not include acid sulfate soils (addressed in Chapter 7), or the nutrient cycling aspect of soils that contribute to plant health (addressed in Chapter 9), or any long-term accumulation in sediments caused by post-closure water movement (addressed in Chapter 7).

8.1 Closure Objectives and Criteria

Table 8-1 lists the ER relevant to the soils theme.

Table 8-1: Soils Theme: Environmental Requirements

Environmental Requirement	ER Reference
1 Environmental Protection *1.2 The company must ensure that operations at Ranger Mine do not result in:* *(e) environmental impacts within the RPA which are not ALARA, during mining excavation, mineral processing, and subsequently during and after rehabilitation.*	1.2 (e)

As shown in Table 8-2, one closure outcome and corresponding closure criteria has been derived from the ERs related to the soils theme. The closure criteria received Ministerial approval on 30 September 2021 and no changes are proposed.

Table 8-2: Soils – Approved Closure Criteria

Closure Objective	Closure Outcome	Parameter	Summary of Criteria
The company must ensure that operations at Ranger do not result in environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation	Impacted soils are remediated to as low as reasonably achievable to protect the environment	Contaminated soil assessment for uranium and manganese in LAA	Demonstrate risk is ALARA
		Contaminated assessment of identified CoPCs for other soils identified as not being part of the larger decommissioning works	Demonstrate risk is ALARA

8.2 Design elements

Chapter 4 describes the closure activities completed and yet to occur at Ranger. Of most relevance to the soils theme is Section 4.4, where it is noted that:

- The general principle with regards to the disposal of demolished and contaminated material is to maximise the amount of material disposed into Pit 3, where:
  - Approximately 455,000 m^3 of demolished and/or contaminated material is to be disposed to Pit 3. The total void space available in Pit 3 is approximately 29 M m^3.
  - Approximately 117,400 m^3 of demolished and/or contaminated material is to be disposed to RP2. The total void space available in RP2 is approximately 2.5 M m^3.

- The bulk of this material is contaminated soils, representing approximately 405,000 m^3 (or 81%) and 35,000 m^3 (or 42%) to Pit 3 and RP2 respectively. The bulk of contaminated soils will come from beneath the processing plant, wetland filters and from within the retention ponds (RP1, RP3 and RP6).

8.3 Relevant Studies / Knowledge Base

The spider web diagram at the beginning of this chapter assigns a subjective 60% complete for the progress status relating to 'relevant studies'. Section 8.3.1 describes the studies that have been completed to date. Section 8.3.2 describes the studies that have not yet been completed, and once completed would progress the status to fully complete (100%).

8.3.1 Studies completed to date

The following studies relevant to contaminated soils have been completed at Ranger:

- Hollingsworth (2006): an investigation of contamination via sampling of 52 groundwater bores and 198 soil samples collected across the site to determine the spatial extent of contamination.
- Alarcon and others (2007): a further investigation of contamination in the deep soil profile and shallow groundwater.
- Gellert and Jones (2008): a status of contamination on-site, including further sampling of previously sampled sites, and the initial development of a regular monitoring program.
- Gellert (2009a): installation of an additional nine groundwater monitoring bores downstream of areas previously identified as contaminated and targeted sampling at selected bores.
- Gellert (2009b): additional groundwater sampling to clarify the source of hydrocarbon contamination from the bulk diesel tower.
- ERA (2010): assessment of the material within four cells of the hydrocarbon bioremediation facility.
- ERM (2015): Ranger groundwater report, which summarised amongst other things, the groundwater conditions in the context of contaminants (i.e. CoPCs) (note: this is an annual report and discussed in Chapter 7 of this MCP).
- Golder (2016): groundwater contamination assessment of the processing plant area.
- Paulka (2016): understanding of the post-closure occupancy intentions for the RPA to enable the calculation of post-closure radiation doses and to assist in the development of post-closure closure criteria.
- ERA (2016): characterisation and assessment of existing underground pipelines and tanks.
- INTERA (2016): development of conceptual models to understand the migration of soluble contaminants resulting from mine-related activities (noting that this modelling has been updated regularly, most recently in 2023, and is discussed in Chapter 7).
- BMT WBM (2017): characterisation of magnesium concentrations in creeks and billabongs to inform impact assessments on aquatic ecosystems.

- BMT (2017): development of a management framework to assess the effects of CoPCs on receiving environments.
- Hatch (2018): an updated Contaminated Sites Register (CSR), identifying potentially contaminated sites and groundwater plumes.
- Skinner (2019): review of the CSR and recommendations for future studies.
- ERA (2020b): contaminated sites drilling and sampling PFAS investigation, and update of the CSR.
- ERA (2020c): Ranger wet season report, which summarised the water quality in creeks and billabongs relevant to the RPA (note: this is an annual report and discussed in Chapter 7 of this MCP).
- ERA (2020d): Ranger PFAS, soil and water contamination assessment report, including recommendations for future studies.
- ERM (2020c): soil assessment of the LAAs, including an assessment to determine if the CoPCs in soil would mobilise into groundwater.
- ERM (2020a): establishment of the full list of CoPCs for the site and the background threshold values for CoPCs and other analytes.
- ERA (2021b): soil and groundwater contaminated sites investigation, including the installation of an additional 15 groundwater monitoring bores.
- Supervising Scientist (2021c): PFAS results from a sampling program undertaken in Magela and Gulungul Creeks, waterbodies located close to Jabiru township and Ranger, and reference sites in Kakadu National Park to the south of Jabiru and Ranger during the 2020/21 wet season.
- Cardno (2021): detailed site investigation of PFAS, including field sampling of soils, sediment, concrete, surface water and groundwater.
- ERA (2022a): collection and analysis of 48 sediment samples for metals from eight locations, including billabongs and retention ponds.
- Stantec (2023): report prepared for the 2022 Feasibility Study that summarises the current status and understanding of contaminated soils from all of the above reports.

The following sections of this chapter draw from the last study listed above, the Stantec (2023) report that summarises the current status of contaminated soils on the RPA.

The Ranger Contaminated Sites Register (CSR) identifies all sites where activities occurred that had the potential, or caused actual, contamination of land. As part of the Stantec review, an updated CSR has been developed. This is a 'live' document used to track specific risks, data gaps, planning and management, remediation and/or closure assessment with regards to Areas of Potential Concern (AoPC) within the RPA. Table 8-3 lists the potential contaminants associated with the various sources on the RPA.

Table 8-3: Sources of contamination and potential contaminants

Source	Potential Contaminant
Ranger Water Dam (RWD), Process Water Storages	• Total Recoverable Hydrocarbons (TRH), Polycyclic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOCs) including BTEXN, phenols and Semi-volatile Organic Compounds (SVOC). • Inorganics: Ammonical nitrogen (NH_3-N), phosphorus (Total P/PO_4-P), total mono-nitrogen oxides (NOx), Ammonia, total ammonia nitrogen (TAN), Nitrate-nitrogen (NO_3-N), total suspended solids (TSS), turbidity, Sulfate (SO_4), total dissolved solids (TDS), pH and electrical conductivity (EC). • Polychlorinated biphenyls (PCBs) and Chlorinated Hydrocarbons (CHC). • Per- and polyfluoroalkyl substances (PFAS). • Metals: aluminium (Al), arsenic (As), boron (Br), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), magnesium (Mg), nickel (Ni), selenium (Se), uranium (U), vanadium (V) and zinc (Zn). • Radionuclides: Polonium (Po) 210, Radium (Ra) 226, Radium (Ra) 228. • Acid Sulfate Soils (ASS): Suspension Peroxide Oxidation Combined Acidity and Sulfur (SPOCAS) suite, sulfate indicator.
Pits 1 and 3 • Tailings • Leachate from waste rock • Sludges • Brine.	• TRH, PAH, VOC, BTEXN, Phenols and SVOC • NH_3-N, TP, PO_4-P, NOx, NH_4-N, TAN, NO_3-N, TSS, turbidity, SO_4, TDS, pH and EC • PCBs and CHCs • PFAS • Metals: Al, As, Br, Ca, Cd, Cr, Cu, Fe, Pb, Mn, Mg, Ni, Se, U, V, Zn • Radionuclides: Po-210, Ra-226, Ra-228 • ASS: SPOCAS suite and sulfate indicator.
Processing Plant Area • Power Station • Shellsol Tank • CCD Circuit • Various tanks and storage vessels.	• TRH, PAH, VOC, BTEXN, Phenols & SVOC • NH_3-N, TP, PO_4-P, NOx, NH_4-N, TAN, NO_3-N, TSS, turbidity, SO_4, TDS, pH and EC • PCBs and CHC • PFAS • Metals: Al, As, Br, Ca, Cd, Cr, Cu, Fe, Pb, Mn, Mg, Ni, Se, U, V, Zn • Radionuclides: Po-210, Ra-226, Ra-228 • ASS: SPOCAS suite and sulfate indicator.
Ore and Waste Rock Stockpiles	• TRH, PAH, VOC, BTEXN, Phenols & SVOC • NH_3-N, TP, PO_4-P, NOx, NH_4-N, TAN, NO_3-N, TSS, turbidity, SO_4, TDS, pH and EC • PCBs and CHCs • PFAS • Metals: Al, As, Br, Ca, Cd, Cr, Cu, Fe, Pb, Mn, Mg, Ni, Se, U, V, Zn • Radionuclides: Po-210, Ra-226, Ra-228 • ASS: SPOCAS suite and sulfate indicator.
Jabiru Airport • Refuelling facility • Historical use of pesticides / herbicides for weed control.	• TRH, PAH, VOC, BTEXN, Phenols & SVOC • NH_3-N, TP, PO_4-P, NOx, NH_4-N, TAN, NO_3-N, TSS, turbidity, SO_4, TDS, pH and EC • PCBs and CHCs • PFAS • Metals: Al, As, Br, Ca, Cd, Cr, Cu, Fe, Pb, Mn, Mg, Ni, Se, U, V, Zn • Radionuclides: Po-210, Ra-226, Ra-228 • ASS: SPOCAS suite and sulfate indicator • Organochlorine and Organophosphate Pesticides (OC/OP).

Source	Potential Contaminant
Retention Ponds and Wetland Filters Potential impacts from upgradient mine process area (i.e. sediment, surface, and groundwater), waste rock seeps and mine dewatering discharge	• TRH, PAH, VOC, BTEXN, Phenols and SVOC • NH_3-N, TP, PO_4-P, NOx, NH_4-N, TAN, NO_3-N, TSS, turbidity, SO_4, TDS, pH and EC • PCBs and CHCs • PFAS • Metals: Al, As, Br, Ca, Cd, Cr, Cu, Fe, Pb, Mn, Mg, Ni, Se, U, V, Zn • Radionuclides: Po-210, Ra-226, Ra-228 • ASS: SPOCAS suite and sulfate indicator.
Land Application Areas (LAAs)	• TRH, PAH, VOC, BTEXN, Phenols & SVOC • NH_3-N, TP, PO_4-P, NOx, NH_4-N, TAN, NO_3-N, TSS, turbidity, SO_4, TDS, pH and EC • PCBs and CHCs • PFAS • Metals: Al, As, Br, Ca, Cd, Cr, Cu, Fe, Pb, Mn, Mg, Ni, Se, U, V, Zn • Radionuclides: Po-210, Ra-226, Ra-228 • ASS: SPOCAS suite and sulfate indicator.

The list of potential contaminants and quantity estimate provided from the 2023 assessment will be further reviewed and updated as part of the Phase 2 contaminated soils studies.

The AoPC have been classified as follows (Figure 8-1):

- Clear – no potential for land contamination;
- Green – confirmation sampling required, unlikely to be contaminated or require ex-situ remediation;
- Orange – sampling required in these areas to inform remediation;
- Red – remediation required; and
- Blue – active closure areas not subject to the contaminated soils assessment.

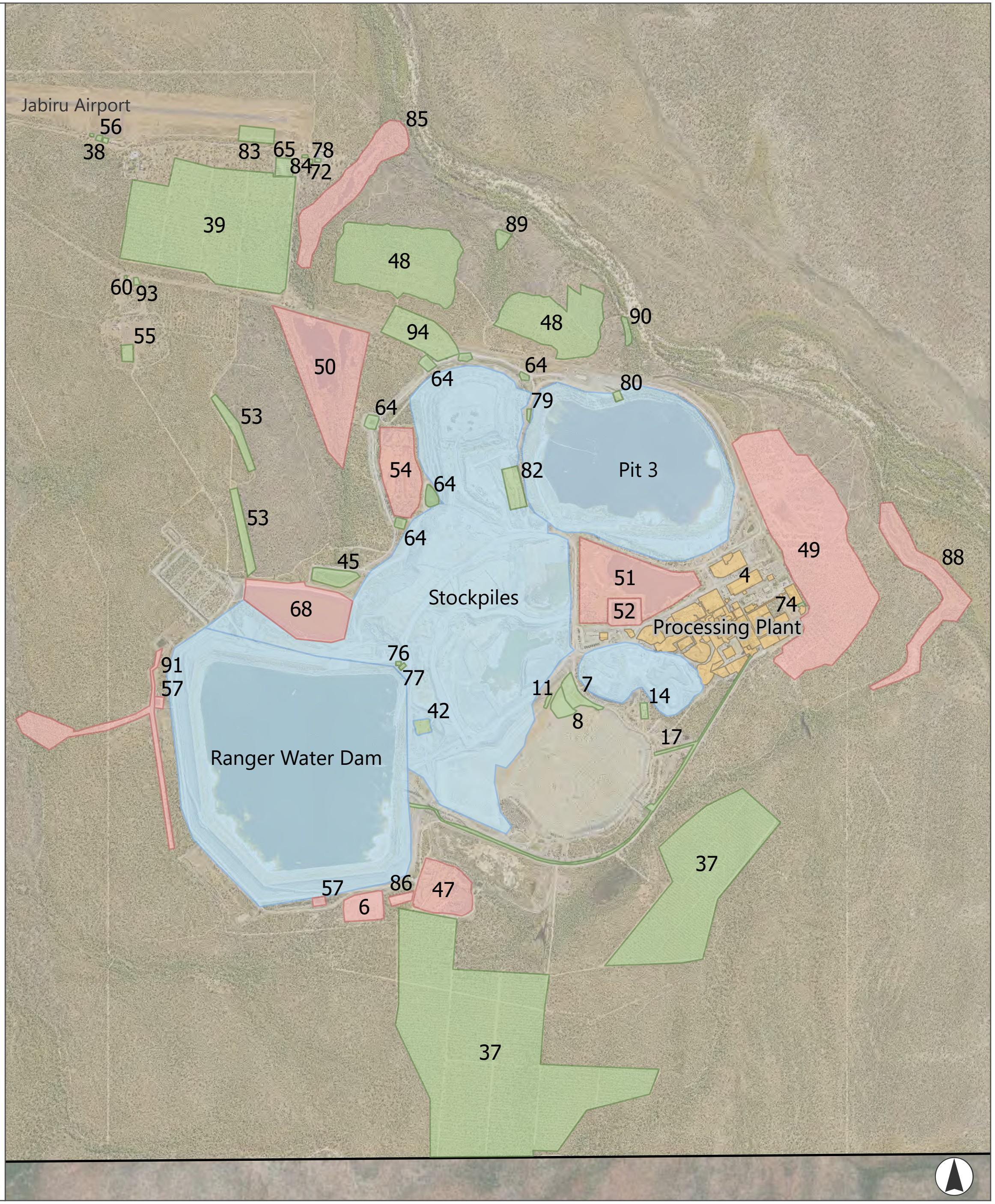
The colour coded areas on Figure 8-1 were generated from a review of the CSR, and a screening of the previous sampling results against ‘Focus’ level criteria (i.e. values that if exceeded would trigger an investigation). It is important to note that these levels are not ‘Action’ values (i.e. values that would trigger a correction action) or ‘Limit/Guideline’ values (i.e. values that are not to be exceeded). These three types of values are described further in the TARP in Section 8.8.

The Focus level criteria used for the current screening exercise are listed in Table 8-4 and Table 8-5. These tables provide an indication of the contaminants that would be sampled, however this is preliminary only and not an exhaustive list. Additional CoPCs (e.g. PFAS, Uranium) will be added as the Phase 2 investigations are undertaken and appropriate criteria are established.

The AoPC shown on Figure 8-1 were derived from an assessment of sampling results from groundwater (33 bores), surface water (63 sites), sediment (134 sites) and soil (115 sites) against the screening criteria. The implications of disposing this contaminated material into Pit 3 is described in Chapter 7 because this material is a potential source term to be considered in the groundwater and ultimately surface water modelling.

AOPC AREAS

11:Bioremediation Pad
14:Orica Yard
17:Corridor Road
37:Corridor Creek Irrigation
38:Jabiru Airport
39:Jabiru East Irrigation
42:Snake Pit (Southern Stockpile Seepage Sump)
45:SED2B
47:Corridor Wetland Filter Network
48:Djalkmarra Flood Irrigation Area
49:Magela Land Application Area
4:Supply Waste Oil Tanks
50:Retention Pond (RP1)
51:Retention Pond 2 (RP2)
52:Retention Pond 3 (RP3)
53:RP1 Flood Irrigation
54:RP1 Wetland Filter
55:Septic Tanks
56:Jabiru Airport
57:TSF Western Sumps
60:Gagudju Workshop
64:RP1WLF
65:New Core Yard
68:RP6
6:Historical Landfill
72:Exploration Wash Bay
74:Shellsol Underground and above ground tanks
76:Dredge diesel unloading, storage and pumping facility
77:TSF/Dredge Maintenance Workshop
78:Exploration Core Sorting Shed
79:New Pit 3 Power Station
7:Current Domestic Landfill
80:Pit 3 Controlled Waste Sludge Disposal
82:Pit 3 controlled waste landfill
83:Jab Airport Aviation Emergency Response exercsise
84:Nursery ERT Training Demountable
85:Coonjimba Billabong
86:General Waste Landfill
88:Georgetown Billabong
89:Djalkmarra Release Point
8:Current Industrial Landfill at Pit 1
90:Indium Billabong
91:GCT2IS
93:Fomer Jabiru East Fuel Station
94:Former Industrial Area (partial)



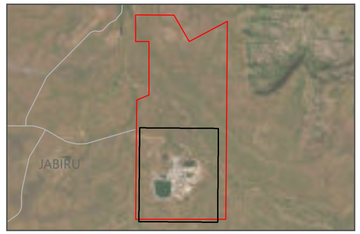
ERA Energy Resources Of Australia

FIGURE 8-1

Areas of Potential Concern for Contaminated Soils on the RPA

LEGEND

- Ranger Project Area
- Confirmation sampling required, unlikely to be contaminated or require ex-situ remediation
- Sampling required in these areas to inform remediation
- Remediation required
- Active closure areas not subject to contaminated soils assessment



0 0.5 1
Kilometres

Scale 1:35,000 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

8.3.2 Studies to be completed

The Stantec (2023) report completes Phase 1 of the soil contamination studies, that being to develop an understanding of the scale and location of land contamination at Ranger from a review of available information. Phase 2 will undertake further sampling in AoPC to further this understanding, particularly in the areas where previous sampling has not occurred (e.g. areas shown as orange on Figure 8-1) and to close out AoPC where remediation is not required. Phase 2 will also include the development of detailed Remediation Action Plans. Specific to contaminated soils, Phase 2 will:

- engage stakeholders to develop and agree on the Focus, Action and Limit/Guideline criteria for relevant CoPCs;
- conduct further soil / sediment sampling (e.g. within Coonjimba Billabong, RP1, beneath the processing plant);
- conduct further characterisation of the final landform waste rock;
- assess the extent of organic compound contamination from hydrocarbon storage and usage; and
- conduct a BPT to establish preferred remediation options, and develop Remediation Action Plans for the preferred remediation options across relevant areas of the RPA.

Phase 3 will then be the on-ground execution of the Remediation Action Plans, the validation sampling, and the reporting of performance at each of the AoPC against the agreed criteria.

Table 8-4: Soil assessment screening criteria (Focus values) – heavy metals

Scenario	Analyte (mg/kg) Source	Arsenic(III)	Boron	Cadmium	Chromium (III-VI)	Chromium (VI)	Copper	Lead	Manganese	Nickel	Selenium (Total)	Zinc
Human health screening values - Residential	NEPM (2013)	100	4,500	20	100	-	6,000	300	3,800	400	200	7,400
Human health screening values - Open Space	NEPM (2013	300	20,000	90	300	-	17,000	600	19,000	1,200	700	30,000
Terrestrial Ecosystem - Ecological Investigation Levels	NEPM (2013)	40	-	-	-	60	20	470	-	5	-	15
Sediment Quality Values	ANZG (2018)	20	-	1.5	80	-	65	50	-	21	-	200

Table 8-5: Soil assessment screening criteria (Focus values) – Total Recoverable Hydrocarbons (TRH), Total Petroleum Hydrocarbons (TPH) and BTEXNTRH)

Scenario	Analyte (mg/kg) Source	F1 – TRH C6-C10 (minus BETX)	F2 – TRH >C10-C16 (minus naphthalene)	F3 – TRH >C16-C34	F4 – TRH >C34-C40	TPH C6-C9	Benzene	Toluene	Ethylbenzene	Xylene	Napthalene
Human health screening values – Residential	CRC CARE (2011)	4,400	3,300	4,500	6,300	-	0.7/1/2/3	480	-	110/310	-
Human health screening values – Open Space	CRC CARE (2011)	5,100	3,800	5,300	7,400	-	120	18,000	5,300	1,900	-
Terrestrial Ecosystem – Ecological Investigation Levels	NEPM (2013)	-	-	-	-	-	-	-	-	-	10
Sediment Quality Values (Management Limit)	NEPM (2013)	800	1,000	3,500	10,000	800	-	-	-	-	-

8.4 Bow-tie diagram

As described in Chapter 5, this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. One bow-tie has been developed for the soils theme and this is provided as Figure 8-2. Within this bow-tie diagram, threats and preventative controls are provided on the left side of the diagram, and corrective actions and consequences on the right side. The residual risk ratings reflect the current effectiveness of the controls and corrective actions.

Further details on the preventative controls, monitoring program and corrective actions for the soils theme are provided in Section 8.5, Section 8.6 and Section 8.7 respectively.

The bow-tie diagram identifies the level of risk for five potential undesired outcomes. It is noted that additional threats and outcomes may occur because of contaminated soils, but these are described in other sections as follows:

- soil contaminants are transported into groundwater and/or surface water impacting downstream receiving environments (see Chapter 7 for details);
- soil contaminants are transported into groundwater and/or surface water impacting human health (see Chapter 7 for details); and
- the soils contain elevated uranium and/or radionuclides, which result in radiation dose exceedances for humans and/or non-human biota (see Chapter 10, Section 10.3 for details).

Preventative Controls

C22 Containment cell within RP2 for PFAS
Satisfactory

C23 Excavate and dispose contaminated soil/sediments into Pit 3 and RP2
Strong

C26 In situ treatment of mildly contaminated, or culturally sensitive, sites
Marginal

C27 Tilling
Satisfactory

C24 Detailed understanding of soil contamination levels and location
Satisfactory

C25 Validation sampling
Satisfactory

C28 Post-closure monitoring
Marginal

Corrective Actions

A9 Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels
Marginal

A16 Contaminated soils detected after the validation sampling will be excavated and disposed below the 2s cap in Pit 3 or into RP2
Strong

A17 Tilled soils on the Magela LAA that do not reach target levels will be disposed to RP2 (or Pit 3 depending on timing) and the area will be replanted
Strong

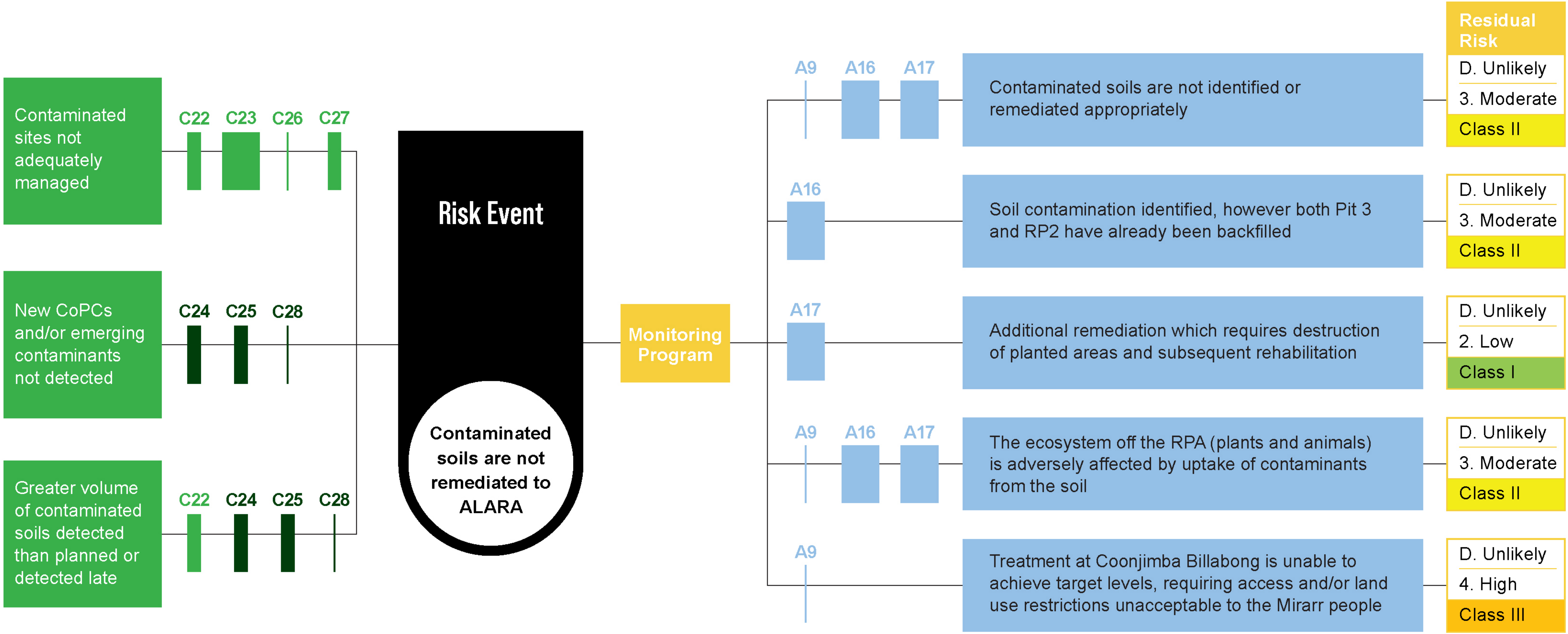


Figure 8-2: Bow-tie diagram for contaminated soils (S1)

8.5 Preventative Controls and their Effectiveness

The basis of design for contaminated land management is to ensure that residual contamination does not present an unacceptable risk to agreed post-closure land uses and associated receptors. The primary preventative control to achieve this objective is to remediate on-site contamination.

The spider web diagram at the beginning of this chapter assigns a subjective 60% complete for the progress status relating to 'preventative controls'. This progress status reflects that most controls shown in Figure 8-2 have an effectiveness rating of 'satisfactory', but further development to strengthen the controls is required.

It is likely that some of the AoPC (i.e. green areas on Figure 8-1) will not require remediation (this will be confirmed during the Phase 2 sampling). For the remainder of the AoPC (orange and red areas on Figure 8-1) remediation will likely be required. Detailed remediation plans will be developed for each of the areas subject to remediation. Table 8-6 outlines each preventative control and their status and current effectiveness rating. The table is followed by a discussion of each preventative control. The effectiveness rating and status is drawn from the information provided in Table 5-1 of Chapter 5.

Table 8-6: Preventative Controls for Soil Contamination

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C22	Containment cell within RP2 for PFAS	Satisfactory	Currently 'Satisfactory' because considerable data is available, well established and proven method, but uncertainty remains until Phases 2 and 3 are completed.
C23	Excavate and dispose contaminated soil into Pit 3 and RP2	Strong	'Strong' because considerable data is available, well established and proven method, more than sufficient void space is available, and the validation sampling to identify all contaminated soils will be completed well before Pit 3 is backfilled up to the predicted long term average water level (the 2s cap).
C26	In-situ treatment of mildly contaminated, or culturally sensitive, sites	Marginal	Currently 'Marginal' until sampling occurs and the Remediation Action Plan demonstrates that target criteria can be achieved.
C27	Tilling	Satisfactory	Well established and proven process, but uncertainty remains on the full extent required until Phase 2 is completed.
'Knowledge-based / Administrative' controls			
C24	Detailed understanding of soil contamination levels and location	Satisfactory	'Satisfactory' because considerable data is available from the studies already completed and this will be strengthened by the Phase 2 sampling.
C25	Validation sampling	Satisfactory	Well established and proven contaminated sites process but not rated as 'Strong' because in of itself will not affect the ability to achieve the ER.
C28	Post-closure monitoring	Marginal	Monitoring requirements to be developed, and in of itself will not affect the ability to achieve the ER.

8.5.1 Containment cell within RP2 for PFAS

PFAS (polyfluoralkyl substances) are used in a large range of products because of their non-stick properties (e.g. waterproof clothing, furniture, cookware, paint). Most relevant to Ranger, they are used in firefighting foams and are therefore present throughout the operational site and airport where fire extinguishers have been used. They are highly mobile in water and persistent, and the environmental and human health impacts are not well understood.

As such, the precautionary approach is proposed, whereby these materials would be excavated and placed within a containment cell in RP2 (this disposal method will be further investigated as part of the Remediation Action Plans). As noted in the PFAS NEMP (2020), the remediation and treatment of PFAS impacted soils can be impeded by:

- the resistance of PFAS to common physical, chemical and biological processes;
- the solubility and mobility of PFAS in the environment;
- the potential for production of other PFAS during the treatment process; and
- the generation of additional contaminated by-products and wastes if appropriate precautions are not implemented.

The preferred hierarchy of treatment and remediation is:

- separation, treatment and destruction;
- on-site encapsulation; and
- off-site removal to a specific landfill.

Based on the quantity of soil and the limitations of destruction technologies, encapsulation is considered the preferred approach in view of the available storage area and additionally managing the commingling of contaminants. Likewise, other available immobilisation technologies are yet to be proven for long-term immobilisation.

Approximately 35,000 m^3 of PFAS contaminated material would be contained within this cell. Containment cells are a standard and proven practice in waste management. The PFAS containment cell in RP2 would generally consist of:

- a compacted floor in RP2;
- a geosynthetic clay liner (GCL) across the walls and floor of the cell;
- a HDPE liner installed on top of the GCL base layer and lining the walls;
- a cushion geotextile layer, typically made from polyester or polypropylene;
- the PFAS material placed into the lined cell;
- a HDPE and GCL liner on top of the PFAS material to act as a ceiling to the containment cell; and
- backfill of waste rock to cap and cover the containment cell, with the top of the cell to be at least 10 m below the final landform height.

As mentioned above, RP2 has an available void space of 2.5 M m^3 and therefore the inclusion and burial of a containment cell for 35,000 m^3 of contaminated material is readily achievable. This preventative control has been rated as 'satisfactory' in Table 8-6 because containment cells are a common and proven technology for waste management and an effective means of isolating contaminants.

8.5.2 Excavate and dispose contaminated soil/sediments into Pit 3 and RP2

Approximately 405,000 m^3 and 35,000 m^3 of contaminated soils would be excavated and buried in Pit 3 and RP2 respectively. Soil sampling to date has identified numerous locations across the RPA that contain soils with contaminant levels that exceed human health and environmental Focus level screening values. The Phase 2 sampling program will confirm the areas and volumes for disposal. The disposal into Pit 3 would occur concurrent to the bulk backfill activities and burial of the demolition waste.

As mentioned above, Pit 3 has an available void space of 29 M m^3 and therefore the inclusion and burial of these contaminated soils is readily achievable. This preventative control has been rated as 'strong' in Table 8-6 because this control is a common and proven waste management practice, and burial below the conservative long-term average water level (the 2s cap) is readily achievable (void space below this level is 20 M m^3), and therefore below the permanent water table that will develop in Pit 3 after the decant wells cease to extract water from the pit.

8.5.3 In situ treatment of mildly contaminated, or culturally sensitive, sites

The cultural sensitivity of on-site billabongs, particularly Coonjimba Billabong, is acknowledged by ERA and as such contaminated soils from this area may not necessarily be included in the excavate and dispose activity described above, rather, an element of in-situ treatment may be preferred by the Mirarr Traditional Owners (this preference is yet to be confirmed).

Sampling indicates that the soils in Coonjimba Billabong are acidic, and treatment with lime would be required for in-situ treatment.

This preventative control has been rated as 'marginal' in Table 8-6 because the treatment method is proven and common practice, but the option for remediation is not yet decided and in-situ treatment may only be a one-off treatment of the soils in the billabong. It is recognised that further studies and stakeholder engagement of acceptable remediation measures are required to determine an appropriate treatment of contaminants in the soils of Coonjimba Billabong.

8.5.4 Tilling

Sampling to date in the LAAs has established elevated uranium concentrations exist in the first 10 cm of the soil profile at the Magela LAA (Akber *et al*., 2011). Tilling is deemed to be an appropriate and effective practice because 80% of the contaminants are within the top 10 cm (Akber *et al*., 2011), and soil mixing down to 30–40 cm depth would significantly reduce radiation levels and bring concentrations down to ambient levels. Tilling involves clearing and grubbing of vegetation, stockpiling this material, tilling/ripping the soils to a depth of 50 cm, respreading the cleared vegetation and/or revegetating the area.

This preventative control has been rated as ‘satisfactory’ in Table 8-6. It is a common and proven practice, however it is not removing contaminants from the system, rather it is blending them on-site to achieve an acceptable level. This is not appropriate in areas with higher concentrations of contaminants but is considered appropriate at the Magela LAA.

8.6 Monitoring Program

The spider web diagram at the beginning of this chapter assigns a subjective 20% complete for the progress status relating to ‘monitoring program’. As noted above, the studies undertaken to date have provided an understanding of the scale and location of soil contamination within the RPA. However, it is also recognised that further sampling will be undertaken, and data gaps will be filled prior to the development of the detailed monitoring programs that will be included in the Remediation Action Plans. New CoPCs not currently listed in the screening criteria will be added and emerging contaminants will be considered. The Focus level values, together with Action and Limit values, will be developed in consultation with key stakeholders.

The monitoring program for contaminated soils will follow the standard validation process of evaluating the effectiveness of the remediation activities. The Remediation Action Plans will document the sampling requirements and validation criteria required to demonstrate successful remediation and management of contaminated sites and include the following components:

- remediation goals and objectives;
- roles and responsibilities;
- site description and contamination status;
- remediation goals, objectives and targets;
- remediation options analysis;
- remediation design;
- regulatory compliance and requirements;
- remediation health and safety management;
- stakeholder engagement;
- remediation validation clean-up targets; and
- records, documentation and reporting.

It is anticipated that for the key periods of infrastructure removal and soil remediation works, that full time on-site supervision will be provided. The supervision tasks will include:

- Field supervision to ensure that the remediation contractor adheres to the requirements endorsed in the Remediation Action Plans (i.e. design details) and seeks prior approval for any material changes to the Remediation Action Plans as may be required depending on actual ground conditions.
- Detailed tracking of remediation and validation progress (as part of reporting works).

- Provide technical advice and support associated with the management of contaminated sites.
- Undertake the required sampling, assessment, remediation and validation, and associated reporting, to achieve site reclassification(s) compatible with agreed post-mining land use.
- Review and confirm the findings of the remediation contractor's weekly reports.
- Support ERA by ensuring that the remediation contractor does not conduct any unnecessary remedial activities without written approval to do so.
- Timely verification for the completion of remediation and validation to allow the backfill and/or reshaping of remediated areas.
- To ensure that field work is completed in a manner that is transparent, thorough, methodical and consistent.

The on-site supervision will continue throughout the remediation activities and the validation sampling. Validation sampling and 'sign-off' that remediation targets have been achieved is typically a one-off process undertaken at the completion of the remediation works. However, ERA will undertake annual sampling for a further five years after the final landform has been created in the areas of the Magela LAA and Coonjimba Billabong to ensure levels remain within acceptable limits.

Beyond the validation sampling program noted above, groundwater and surface water monitoring as described in Chapter 7 will be implemented to test the effectiveness of the containment cell and in-pit disposal.

8.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subjective 80% complete for the progress status relating to 'corrective actions'. The successful execution of the preventative controls described in Section 8.5 are expected to result in the management of contaminated soils to a level that achieves the closure criteria. That is, soils will be remediated where required, or buried at depth in Pit 3 or RP2, to a level that demonstrates ALARA and where residual contamination does not present an unacceptable risk to human health or the environment.

The validation sampling and additional post-closure monitoring discussed above will be undertaken to demonstrate the success of these actions. The following corrective actions will be implemented if the Phase 2 sampling, validation sampling or post-closure monitoring identify elevated contamination levels:

- The Phase 2 sampling will be completed well before the Pit 3 backfill reaches the height of the predicted long term average water level, therefore any additional contaminated soils identified during that sampling will be excavated and disposed into Pit 3.
- The backfill of RP2 will be one of the last activities to occur on-site in the process of creating the final landform. If the validation sampling in any areas subject to tilling establishes that target levels have not been achieved, and that additional tilling is not likely to achieve target levels, the material will be excavated and disposed into Pit 3 or RP2 (depending on the timing that the sampling detects the exceedance).

- If validation sampling or monitoring in Coonjimba Billabong establishes that target levels have not been achieved, engagement with key stakeholders (GAC, NLC, OSS, DITT) will occur to determine an appropriate path forward. This may include additional on-site treatment, excavation and disposal of material to Pit 3 or RP2, and/or restricted use of the billabong for certain activities at particular times.

Table 8-7 outlines a number of corrective actions, along with their status and effectiveness.

Table 8-7: Corrective Actions for Soil Contamination (all 'Active' Corrective Actions)

Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
A9	Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels	Marginal	Considerable uncertainty about what additional remediation would be appropriate and the preference by the Mirarr people.
A16	Contaminated soils detected after the validation sampling will be excavated and disposed below the 2s cap in Pit 3 or into RP2	Strong	Well established and proven method and sufficient void space will be available below the conservative long-term average water level in Pit 3 at the time validation sampling is conducted and RP2 in the event of late unplanned finds of contaminated soils.
A17	Tilled soils on the Magela LAA that do not reach target levels will be disposed to RP2 (or Pit 3 depending on timing) and the area will be replanted	Strong	As per above.

8.8 Trigger, Action, Response Plan

Table 8-4 and Table 8-5 presented the human health and environmental Focus values that surface and near-surface soil sampling will be screened against. Table 8-8 consolidates the monitoring and adaptive management programs described above into the form of a TARP. The triggers and action/response presented in this TARP are indicative and may change as further information becomes available. This TARP will be updated as required in future iterations of the MCP as the Phase 2 and 3 works are undertaken.

Table 8-8: Trigger, Action, Response Plan for Soil

	Normal State	Level 1 Trigger	Level 2 Trigger
Trigger Action Response Plan	Validation sampling (one-off after remediation works) and post-closure monitoring (annual for five years after final landform created in Magela LAA and Coonjimba Billabong) confirms that no surface or near surface soils have contamination levels that exceed the human health or environmental Focus values.	Validation sampling detects contamination that exceeds the Focus level criteria, but is below the Action and/or Limit criteria.	Validation sampling and/or post-closure monitoring detects contamination above Action level criteria.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Site Environmental Officer (or delegate)	Cease soil sampling after remediation validation and five years of post-closure monitoring.	Investigate the spatial extent and CoPCs with contamination levels that exceed the Focus criteria. Increase the sampling frequency to ensure contamination levels are remaining below the Action values.	Implement additional remediation (corrective actions) as per Section 8.7.

8.9 Future work

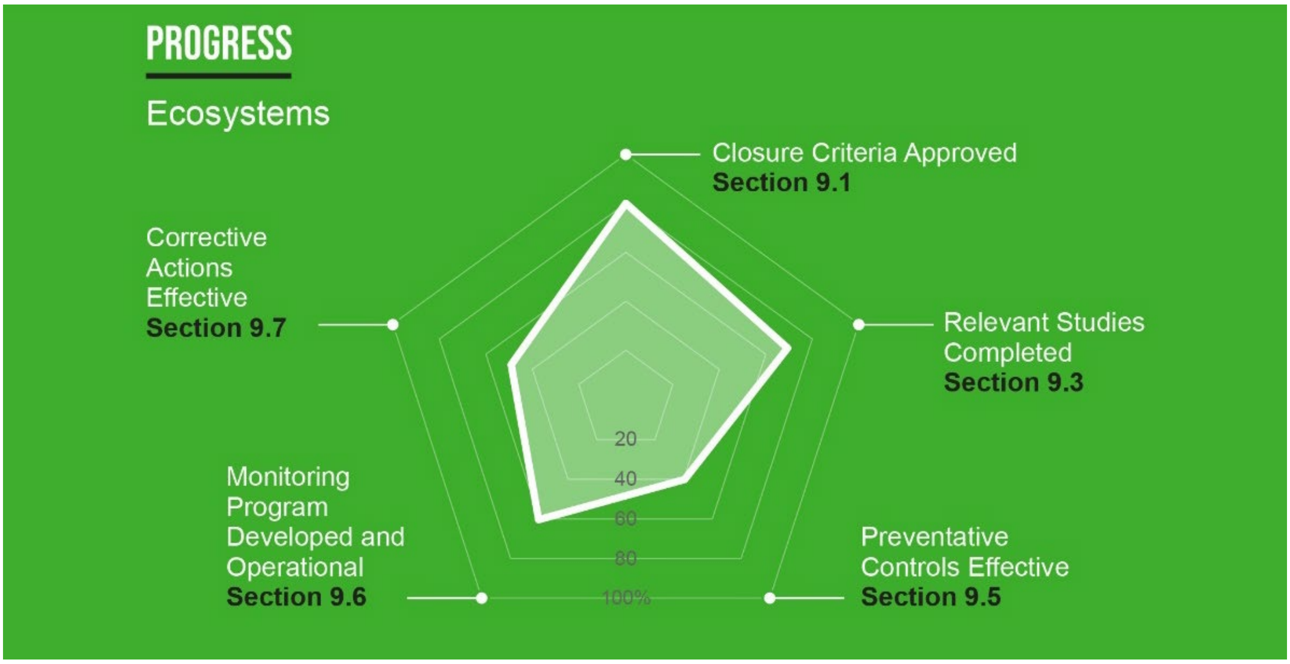
This chapter presented the current knowledge base and bow-tie diagram for contaminated soils. In consideration of this information, the following future work (subject to change) has been identified:

- Phase 2 of the soil contamination studies: this phase will build upon and address data gaps identified in the Phase 1 study. Specific to contaminated soils, it will:
    - engage stakeholders to develop and agree on the Focus, Action and Limit criteria for relevant CoPCs;
    - conduct further soil / sediment sampling (e.g. within Coonjimba Billabong, RP1, beneath the processing plant);
    - conduct further characterisation of the final landform waste rock;
    - assess the extent of organic compound contamination from hydrocarbon storage and usage; and
    - conduct a BPT to establish preferred remediation options and develop Remediation Action Plans for the preferred remediation options across relevant areas of the RPA.
- Phase 3 of the soil contamination studies: this phase is the on-ground execution of the Remediation Action Plans, the validation sampling, and the reporting of performance at each of the AoPC against the agreed criteria.
- Review of the bow-tie diagram indicates that further work is required to strengthen the effectiveness of preventative controls related to:
    - ensuring that the validation sampling is sufficiently broad to detect contaminants not currently included in the Table 8-4 and Table 8-5;
    - the remediation (e.g. containment cell) for PFAS, particularly the long-term ability to manage migration of PFAS; and
    - the remediation required at Coonjimba Billabong.
- The spider web diagram assigns a subjective 20% complete for the monitoring program. This reflects the considerable future work that is planned to better inform the validation sampling and five year post final landform monitoring program; and
- Review of the bow-tie diagram indicates that further work is required to strengthen the effectiveness of corrective actions related to remediation activities at Coonjimba Billabong. In particular, to find an acceptable balance with the Mirarr people between the level of disturbance activities that could be undertaken (e.g. excavate and dispose contaminated material into Pit 3) and the potential for reduced cultural uses if monitoring detects elevated levels of contaminants after in-situ treatment has occurred.

9 ECOSYSTEMS

The theme of ‘ecosystems’ in this MCP refers to the establishment and maintenance of vegetation, habitat and faunal communities on both waste rock of the constructed final landform and areas within the RPA that have experienced considerably less mine-related disturbance. An indication of progress against key metrics is summarised in the spider web diagram below. It shows:

- Closure criteria and measurable indicators of performance have been agreed, however further work is occurring to refine these indictors in the areas of conceptual reference ecosystems (CRE) and indicators for sustainability criteria. All criteria have been revised recently in consultation with stakeholders and require Ministerial approval (80%, Section 9.1).
- Decades of relevant studies and ongoing revegetation trials have provided a substantial knowledge base for Ranger. Areas planned for further work include the development of appropriate CREs, defining expected trajectories, and developing site-specific establishment programs for the final landform drainage lines (70%, Section 9.3 and Section 9.9).
- Several preventative controls for this theme are well understood and considered to have a satisfactory or strong effectiveness. However, uncertainties remain around some key areas and further studies are underway (40%, Section 9.5).
- A thorough monitoring program has been established on the back of several ongoing, and in some cases long-term, revegetation trials. The current program will be further refined and expanded (60%, Section 9.6).
- Corrective actions for ecosystems are relatively well understood but not yet implemented on a constructed waste rock landform nor demonstrated to recover a deviated trajectory in a short period a time. Further work is planned (50%, Section 9.7).



9.1 Closure Objectives and Criteria

There are two objectives derived from the ERs relating to the ecosystem theme (previously termed flora and fauna), as presented in Table 9-1.

Table 9-1: Ecosystems Theme: Environmental Requirements

Environmental Requirement	ER Reference
2 Rehabilitation *2.2 The major objectives of rehabilitation are:* *(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.*	2.2 (a)

ER 2.2(a) is one of the primary rehabilitation objectives, and comprises two aspects. The first, referred to as 'ecosystem similarity', requires the flora and fauna species composition, abundance and community structure of rehabilitated areas within the RPA to be similar to Kakadu National Park. The second, referred to as 'ecosystem sustainability', requires rehabilitated areas to contain functioning ecosystems that are long-term viable and require a maintenance regime similar to those in adjacent areas of Kakadu National Park.

The development of similarity and sustainability closure criteria are the focus of KKNs ESR1B and ESR5A. Several criteria relating to ecosystem similarity and sustainability received Ministerial approval on 30 September 2021. Following this, a revised set of qualitative closure criteria were developed collaboratively with support from OSS and NLC, and guided by:

- ecosystem dynamics in northern Australia;
- knowledge gained through extensive studies, trials and research on the RPA and surrounding areas; and
- international principles and standards for the ecological restoration and recovery of mine sites as described by the Society for Ecological Restoration (Young *et al.,* 2022).

The revised criteria were finalised in August 2022, and are presented in Table 9-2 for Ministerial approval. These closure criteria require further quantification and this will continue to be developed in consultation with stakeholders.

In addition, reference ecosystems for similarity criteria and expected trajectories towards these are not yet fully defined. It is recognised that the rehabilitated landform will not be directly analogous with the pre-existing ecosystems, or adjacent areas. Further complexity regarding existing fire management practices in direct reference sites suggests that conceptual reference ecosystems, also referred to as CREs, are most appropriate. These are likely to change over time, and should consider reference sites, variations in substrate and topography, cultural values and species suitability. The current status of CRE development is described in Section 9.3.1.1.

Table 9-2: Ecosystems – Closure Criteria for Minister approval in the 2023 MCP

<table>
<tr><th>Attribute</th><th>Sub-attribute</th><th>Goal</th><th>Summary of Criteria</th></tr>
<tr><td colspan="4">Ecosystem Similarity</td></tr>
<tr><td rowspan="4">Species composition and relative abundance</td><td rowspan="2">Species composition of vegetation</td><td rowspan="2">The assemblage of overstorey species and understorey functional species are similar to, or on a trajectory towards, that of the reference ecosystem(s).</td><td>The contribution in relative abundance of species in overstorey assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).</td></tr>
<tr><td>Functional composition of understorey species refers to the following lifeforms:
Legumes: Minimum number of legume species and variety of lifeforms.
Perennial grasses: Minimum number of perennial grass species, including specified species.
Annual grasses: Minimum number of annual grass species. Forbs: Minimum number of forb species from a minimum number of families.
Climbers and vines: Minimum number of climber and vine species used as a food source.
Non-legume woody species (shrubs): Minimum number of non-legume woody species and specified species (including woody ground cover species).</td></tr>
<tr><td>Species richness of vegetation</td><td>Species richness of overstorey and understorey are similar to, or on a trajectory towards, that of the reference ecosystem(s).</td><td>The total number of (i) overstorey species, and (ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).</td></tr>
<tr><td>Species abundance of vegetation</td><td>Abundance of overstorey and understorey species are similar to, or on a trajectory towards, that of the reference ecosystem(s).</td><td>The total abundance of (i) overstorey species, and (ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).</td></tr>
<tr><td rowspan="3">Community structure</td><td>Structure</td><td>Vegetation structure similar to, or on a trajectory towards that of the reference ecosystem(s).</td><td>Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).</td></tr>
<tr><td rowspan="2">Vegetation strata</td><td>Overstorey and midstorey cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).</td><td>The distribution of percentage canopy cover is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).</td></tr>
<tr><td>Understorey vegetation cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).</td><td>Percentage cover of understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).</td></tr>
</table>

Attribute	Sub-attribute	Goal	Summary of Criteria
Composition and abundance of native vertebrate species	Species composition of native vertebrate species	The assemblages of mammal, bird and reptile species, are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Species richness of native vertebrate species (number of species)	Species richness of: mammals, birds and reptiles is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of: i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of native vertebrate species	Abundances of mammal, bird and reptile species, are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total abundance of: i) mammals (including bats); ii) birds; and iii) reptiles are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of threatened species	Species composition of threatened native vertebrate species	The assemblage of threatened vertebrate species is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of targeted threatened fauna species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of threatened vertebrate species	Abundance of threatened vertebrate species is similar to, or on a trajectory towards, that of the reference ecosystem.	Total abundance of targeted threatened vertebrate species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of ants	Species composition of native ant species	The assemblages of native ant species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of species in native ant assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Species richness of native ant species	Species richness of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of native ant species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of native ant species	Abundance of native ant species is similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	The total number of individuals of native ant species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Ecosystem Sustainability			
External exchanges	Key vegetation-dispersing fauna	Abundances of nectivorous and frugivorous bird species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	Total number of individuals of: i) nectivorous; and ii) frugivorous bird species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Ecosystem function	Habitat availability for fauna	Habitat for fauna is present, or is forming.	Habitat for fauna is, or indicators of habitat formation are, present.

Attribute	Sub-attribute	Goal	Summary of Criteria
	Nutrient cycling	Chemical, physical and biological indicators provide evidence that nutrient cycling will sustain ecological processes.	Litter decomposition rates necessary for supporting ecological processes are consistent with, and within the ranges of, those reported for northern savanna ecosystems.
			Appropriate soil microbial community functions that support nutrient cycling are present.
			Soil organic carbon and nitrogen are accumulating at a rate necessary for supporting ecological processes.
			Soil mineral nitrogen and soluble organic nitrogen stocks and rates of mobilisation are at a level necessary to support ecological processes.
	Resilience to fire	Ecosystem resilience to the appropriate fire regime.	Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.
			Post-fire mortality rates of juvenile and adult overstorey species do not exceed those of the reference ecosystem.
	Resilience to extreme weather events, pests and disease	Ecosystem resilience to natural disturbances (wind, drought, disease) is similar to the reference ecosystem.	In the event of natural disturbances (e.g. wind, drought, or disease), all other closure criteria must be shown to have been met, demonstrating recovery.
Threats	Weeds	No Class A weeds or Weeds of National Significance (WoNS).	Class A and/or Weeds of National Significance are either absent from the Ranger Project Area (RPA) or have been eradicated from within the RPA for a period of time that exceeds the seed bank longevity of any given species.
		Abundance of Class B weeds no greater than the reference ecosystem(s).	The incidence and abundance of all Class B weeds within the RPA is no greater than the reference ecosystem, at a landscape-scale.
		Abundance of other introduced flora species would not require a maintenance regime different from that appropriate to adjacent areas of Kakadu National Park.	The presence and abundance of other introduced flora within the RPA is no greater than those in adjacent areas of Kakadu National Park.
	Abundance of exotic fauna species	Abundances of buffalo, horses, pigs, cats and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.	The total abundance of: i) buffalo; ii) horses; iii) pigs; iv) cats; and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.

9.2 Design elements

The primary rehabilitation objective for Ranger is to revegetate the disturbed sites of the RPA using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park. The purpose of rehabilitation activities is to form a viable, long-term ecosystem that would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park.

Chapter 4 describes the closure activities at Ranger. Of most relevance to ecosystems, it is noted that:

- There is approximately 1,065 ha of land to rehabilitate on the RPA, including approximately 800 ha of reconstructed waste rock on the final landform area. Section 4.8 describes the bulk material movement and the waste rock discrimination plan that will facilitate the placement of non-mineralised (grade 1) waste rock within the upper layer of the final landform, ideally to a depth of at least 6 m. Section 4.8 also describes the predicted timing of the final landform development and therefore the likely sequence of progressive rehabilitation as the various areas reach final landform.
- Section 4.8.3.2, and in particular Figure 4-19 (reproduced here as Figure 9-3), shows the areas on the final landform that will receive varying depths of waste rock and the difference between current landform and the final landform.
- Section 4.4 describes the areas of the RPA that will be treated for contaminated soils (particularly RP1, Coonjimba Billabong and the Magela LAA). These areas will be subject to varying levels of revegetation.
- Section 4.4.3.1 describes the infrastructure that will be retained for several years after the creation of the final landform to ensure a continuity of services required for water treatment, monitoring and maintenance activities. This is important to understand as these areas will be replanted last in the project sequence.
- As described in Section 4.8.4, the surface of the final landform will be planted with a density of approximately 1,000 stems per hectare to create a self-sustaining ecosystem. Section 4.4.3.8 describes the plant nursery and the capacity of this nursery to provide local provenance seed and infrastructure required to propagate this seed.
- Section 4.8.4 describes the planned irrigation for newly planted seedlings to promote high plant survival rates.

9.3 Relevant Studies / Knowledge Base

The spider web diagram at the beginning of this chapter assigns a subjective 70% complete for the progress status relating to ‘relevant studies and knowledge base’. This acknowledges the substantial understanding gained from research studies and through several ongoing revegetation trials, while recognising that further work is required.

This section describes the relevant studies that have been undertaken and the knowledge base obtained to inform the achievement of the closure criteria and thus the ERs. As noted above, there are two aspects to the ecosystem ERs:

- Ecosystem similarity – which requires the flora and fauna species composition, abundance and community structure of rehabilitated areas within the RPA to be similar to Kakadu National Park. Relevant information on this aspect is provided under the section headings:
    - Vegetation composition, abundance and community structure (Section 9.3.1); and
    - Habitat formation, composition and abundance of fauna (Section 9.3.2 where related to composition and abundance of fauna).
- Ecosystem sustainability – which requires rehabilitated areas to contain functioning ecosystems that are viable in the long-term and similar to those in adjacent areas of Kakadu National Park. Relevant information on this aspect is provided under the section headings:
    - Habitat formation, composition and abundance of fauna (Section 9.3.2, where related to key vegetation dispersing fauna and habitat availability);
    - Nutrient cycling (Section 9.3.3);
    - Resilience to an appropriate fire regime (Section 9.3.4);
    - Resilience to extreme weather events, pests and disease (Section 9.3.5);
    - Declared weeds and other introduced flora (Section 9.3.6); and
    - Abundance of exotic fauna (Section 9.3.7).

Figure 9-1 shows the locations of current vegetation trials, many of which are discussed directly in the following sections.

FIGURE 9-1

Existing Revegetation Areas

LEGEND

- Ranger Project Area
- Revegtation area (internal sub-areas displayed inset)
- Watercourses

Planting/construction dates

Trial Landform – initially constructed and planted 2009/2010

Magazine Laydown Area - planted 2018/2019

Ranger Mine Village - planted 2020

Pit 1 - planted 2021/2022

Stage 13 - planted 2020/2021

Area 52 - planted 2023

0 0.5 1
Kilometres

Scale 1:25,000 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

9.3.1 Vegetation composition, abundance and community structure

9.3.1.1 Appropriate vegetation reference ecosystems

Reddell and Meek (2004) highlighted the importance of identifying and describing vegetation types that are ecologically, culturally and technically realistic target endpoints, for different facets of the final landform. The development of appropriate reference ecosystems begins with a thorough understanding of the natural surrounding ecosystems, which is the focus of KKN ESR1A (see Appendix 5.1). Schodde and others (1987) describe four vegetation types that occur across the RPA and surrounds, which are described in Table 9-3.

Table 9-3: Vegetation community descriptions in undisturbed areas of the RPA (Schodde *et al.*, 1987)

Vegetation Community	Proportion across RPA	Description
Open Forest	~42%	Tall (12 to 20 m) open forest dominated by *Eucalyptus miniata* and *Eucalyptus tetrodonta* and with other species of eucalypts present in the canopy. The only frequent non-eucalypt that occurs in the canopy is *Erythrophleum chlorostachys*. The shrub layer consists of *Acacia spp.*, *Calytrix exstipulata*, *Gardenia spp.*, *Livistona humilis*, *Petalostigma quadriloculare*, *Planchonia careya, Terminalia spp.* and *Xanthostemon paradoxus*. Ground cover is usually sparse, inconspicuous and comprises mostly annual grasses of *Sorghum spp.* and other herbaceous plants.
Woodland	~26%	This habitat typically lacks a distinct canopy and is more stunted (usually less than 12 m) than open forest, being dominated by bloodwoods (*Corymbia spp.*), but also contains eucalypts such as *E. miniata, E. tetrodonta* and *E. tectifica*. However, it is quite variable in structure and can be tall on slopes to the point where it grades into open forest. The shrub layer is the same as in open forest but much sparser. The palm *L. humilis* is common and pockets of *Pandanus spiralis* may also be present. The ground cover is much denser than in open forest, containing mainly annual grasses, e.g. *Sorghum spp.* In stunted woodlands perennial grasses *Heteropogon triticeus* and *Sehima sp. dominate*.
Myrtle-Pandanus Savanna	~26%	Consists of grassland with small open pockets of woodland, mixed shrubland and rainforest trees, interspersed with strips of *Pandanus spiralis* along the edges of floodplains and with paperbarks (*Melaleuca spp.*) along creeks and streams. Tall trees from genera such as Corymbia and Eucalyptus are sparingly present. A very patchy shrub layer of *Melaleuca viridiflora, M. nervosa* and *P. spiralis* occur. Common grasses include annuals from genera such as *Digitaria, Ectrosia, Panicum, Schizachyrium* and *Sorghum* and perennial grasses including those from genera such as *Eriachne* and *Themeda*. Sedges (Cyperaceae) are also a common component of the ground cover.
Myrtle-Pandanus Savanna/ Paperbark Forest	~6%	Paperbark forests line freshwater creek systems and the edges of billabongs and are dominated by *Melaleuca spp.* The canopy can be 15 to 20 m in height and can vary greatly from open to almost closed. The shrub layer varies from sparse to dense and comprises *Acacia spp., Ficus spp.* on marginal areas and the ubiquitous freshwater mangrove *Barringtonia acutangula*. *Pandanus aquaticus* and *B. acutangula* line streams and channels. In zones edging woodland, the trees are wider spaced and often form an ecotone with myrtle-pandanus savanna. In this ecotone area eucalypts, bloodwoods and other savanna trees co-dominate with the paperbarks.

Within areas with similar climate and fire regime, geomorphology plays a major role in determining the vegetation communities described above. This geomorphology is applicable to disturbed, non-waste rock areas that will be rehabilitated as part of the final landform, however it is recognised that the waste rock landform will not restore the pre-mining landscape with an identical geomorphological system.

The proposed waste rock substrate is composed of metamorphic, Cahill-formation schists, whereas adjacent substrates and vegetation communities are derived from a geologically unrelated entity known as the Koolpinyah surface (Needham *et al*., 1973). Although every effort is being made to recreate an ecosystem on the final landform that is analogous to surrounds, it seems reasonable to suggest that there may be some constraints with regards to the suitability of substrate for some species. It is important that the CREs can be adapted to reflect these constraints as they are realised.

Proposed CREs are outlined below, including related studies. These are representative of the vegetation types described by Schodde and others (1987).

Savannah Woodland CRE

This CRE is representative of the *Eucalyptus tetrodonta* and *Eucalyptus miniata* dominated open forest and woodland communities. The following studies investigated the most appropriate and representative reference ecosystem for this CRE:

- Hollingsworth and Meek (2003): Ecosystem Reconstruction for the Ranger Mine Final Landform– Phase 2 Target Ecosystem Closure Criteria.
- Brennan (2005): Quantitative descriptions of native plant communities with potential for use in revegetation at Ranger uranium mine.
- Hollingsworth and others (2007a): Revegetation at Ranger: An analysis of vegetation types and environmental trends in analogue areas.
- Hollingsworth and others (2007b): Planning for closure at Ranger Mine – Landscape reconstruction using natural analogues.
- Humphrey and others (2009). Use of vegetation analogues to guide planning for rehabilitation of the Ranger Minesite.
- Humphrey (2013): Use of vegetation analogues to guide planning for rehabilitation of the Ranger Mine site.
- Supervising Scientist (2019c): Technical Advice #006: Species richness and composition indicator values for assessing ecosystem similarity for savanna woodland.
- Supervising Scientist (2019d): Technical Advice #007: Vegetation strata, woody plant species size class distribution and total basal area data for use as indicator values.
- Supervising Scientist (2020c): Technical Advice #028: Functional diversity of savanna surrounding Ranger 2020.
- Mattiske and Meek (2020): Review of Reference Site Selection for ERA Ranger Mine.
- Supervising Scientist (2021d): Technical Advice #041: Updated Conceptual Reference Ecosystem data.

The latter Technical Advice #041 (Supervising Scientist 2021d) provides data for 10 relatively undisturbed and accessible one-hectare vegetation reference sites. These sites were surveyed between 2018 and 2021 and represent the framework for the *E. tetrodonta and E. miniate* Savanna Woodland CRE. Locations of the sites are presented as S1-S3 and S6-S12 on Figure 9-2, noting that sites S4 and S5 were removed due to their apparent disturbance history. Further detail regarding the Savanna Woodland CRE is provided in Appendix 9.1.

Seasonally Inundated Savanna CRE

In 2019 and 2020, OSS surveyed four sites within the Myrtle-Pandanus Savanna community (Supervising Scientist, 2020d). The locations of these are presented as F1-F4 on Figure 9-2. Relevant additional information is currently being reviewed for other historic surveys, and will support the development of an appropriate seasonally inundated savanna CRE with consideration of the modelled and/or constructed characteristics of the final topography and the underlying substrate. Depending on the outcomes, this CRE may also require differentiation between waste rock and non-waste rock areas.

Riparian CRE

It is recognised that a distinct CRE is required for the planned drainage lines on the final landform, and the surrounding Myrtle-Pandanus Savanna / Paperbark Forest vegetation community may be used as a basis for this. The development of a revegetation plan and a CRE for these areas will be completed in consultation with the Traditional Owners through the Cultural Reconnection Steering Committee.

Potential RWD alternative CRE

Further work is required to understand the final landform and depth to the clay layer proposed for the RWD, and whether this may inhibit deep rooting trees and present a constraint to the establishment of the CREs described above. If the BPT currently being conducted for the RWD confirms that the clay layer is a preferred inclusion, and this BPT is supported by the MTC, additional work will be required to create an alternative CRE for the RWD catchment area in consultation with stakeholders.

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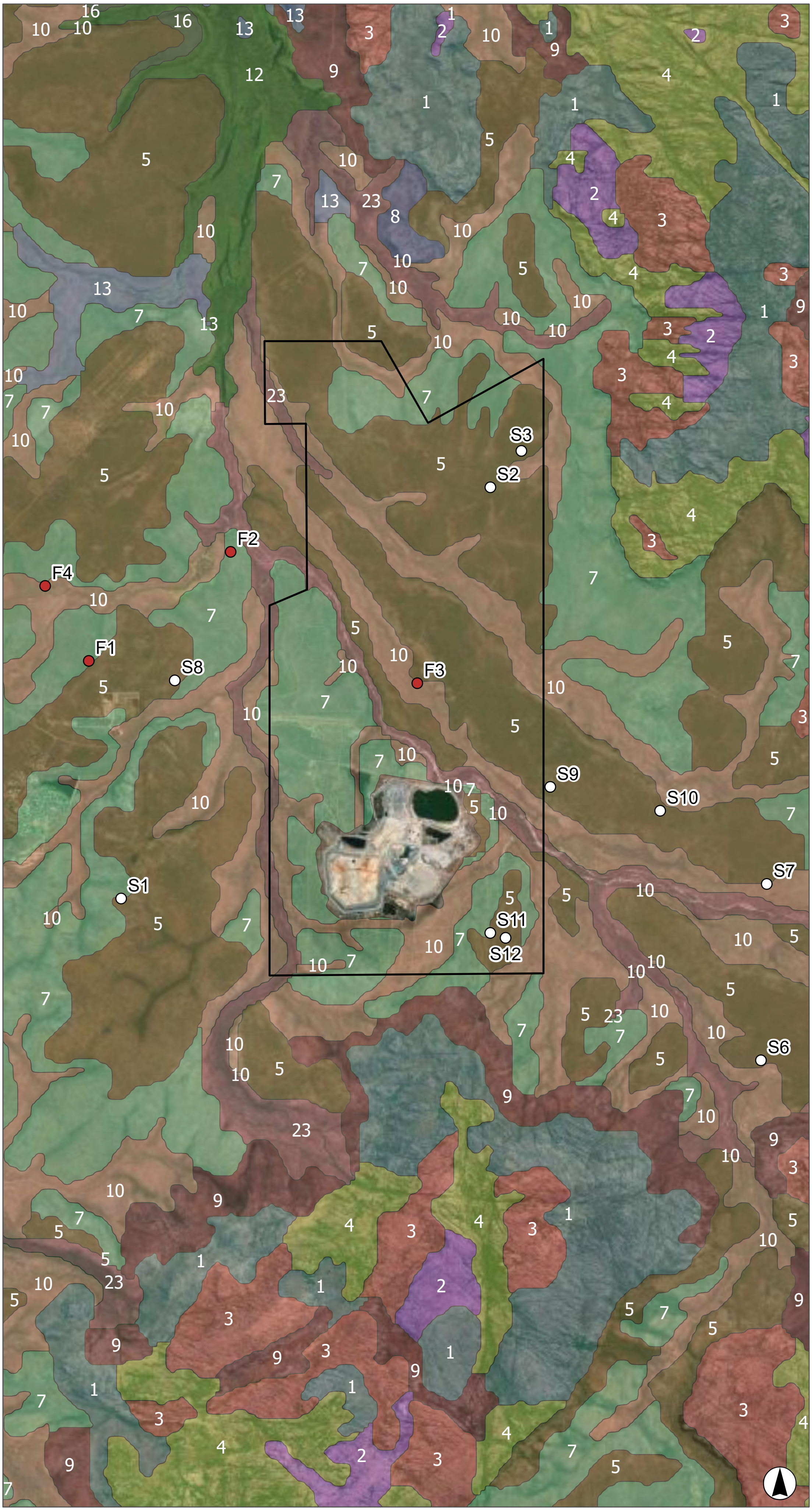
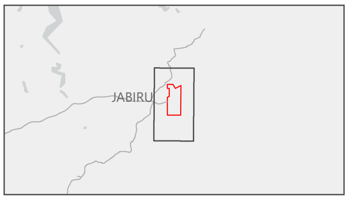
FIGURE 9-2

OSS 2018-2021 Surveyed Reference Sites, with Vegetation Types Mapped by Schodde and others (1987)



LEGEND

- Ranger Project Area
- Vegetation reference sites
  - Intermittently Flooded Savanna reference site
  - Savanna Woodland reference site
- Vegetation Communities (after Schodde 1987)
  - 1: Sandstone Woodland
  - 2: Sandstone Spinifex
  - 3: Broadleaf Shrubbery
  - 4: Sandstone Rainforest
  - 5: Open Forest
  - 7: Woodland
  - 8: Hill Woodland
  - 9: Mixed Shrubland
  - 10: Myrtle-Pandanus Savanna
  - 12: Paperbark Forest
  - 13: Floodplain Sedgeland
  - 16: Coast Rainforest/Myrt-Pand Savanna
  - 23: M-Pand Sav/Paperbark/ Coast Rainforest



0 1 2
Kilometres

Scale 1:123,817 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

9.3.1.2 Final landform growth substrate

Reddell and Meek (2004) highlighted the importance of a suitable waste rock landform and growth substrate for initial establishment, long-term growth, development and functioning of revegetated plant communities. The relevant studies and knowledge base are discussed below under the following headings:

- waste rock backfill;
- waste rock plant available water;
- sub-stockpile compaction;
- surface preparation; and
- chemical characteristics.

Waste rock backfill

For up to 75% of the waste rock landform, the earliest stage of ecosystem re-establishment is the placement of waste rock to achieve an appropriate landform surface. Chapter 4 describes how this occurred for Pit 1 and how it is planned to occur for Pit 3 and other final landform areas. Chapter 6 describes the approach of developing the final landform surface to reduce erosion and the resulting deposition of sediment.

The surface layer of the waste rock landform is required to support the establishment of the vegetation communities described above, of which the Savanna Woodland CRE is most widespread. This CRE is characterised by a dominant overstorey of larger *Eucalyptus* trees. In natural systems, the root systems of these trees extend to at least 5 or 6 m below the surface, enabling access to water over the prolonged dry season (Hutley *et al.,* 2000).

Figure 9-3 shows the planned depth of waste rock across the final landform. To facilitate root development as described above, for areas of the waste rock landform that that will be filled, a ‘vegetation growth layer’ will be constructed to a depth of up to 6 m. Like the methodology used in the construction of the TLF, the vegetation growth layer at Pit 1 was placed in two relatively thick layers, to a depth of 6 m, using techniques known as tip-head and paddock dumping (Daws and Poole, 2010). These methods minimise compaction and support the preferential flow of surface water to optimise water holding capacity.

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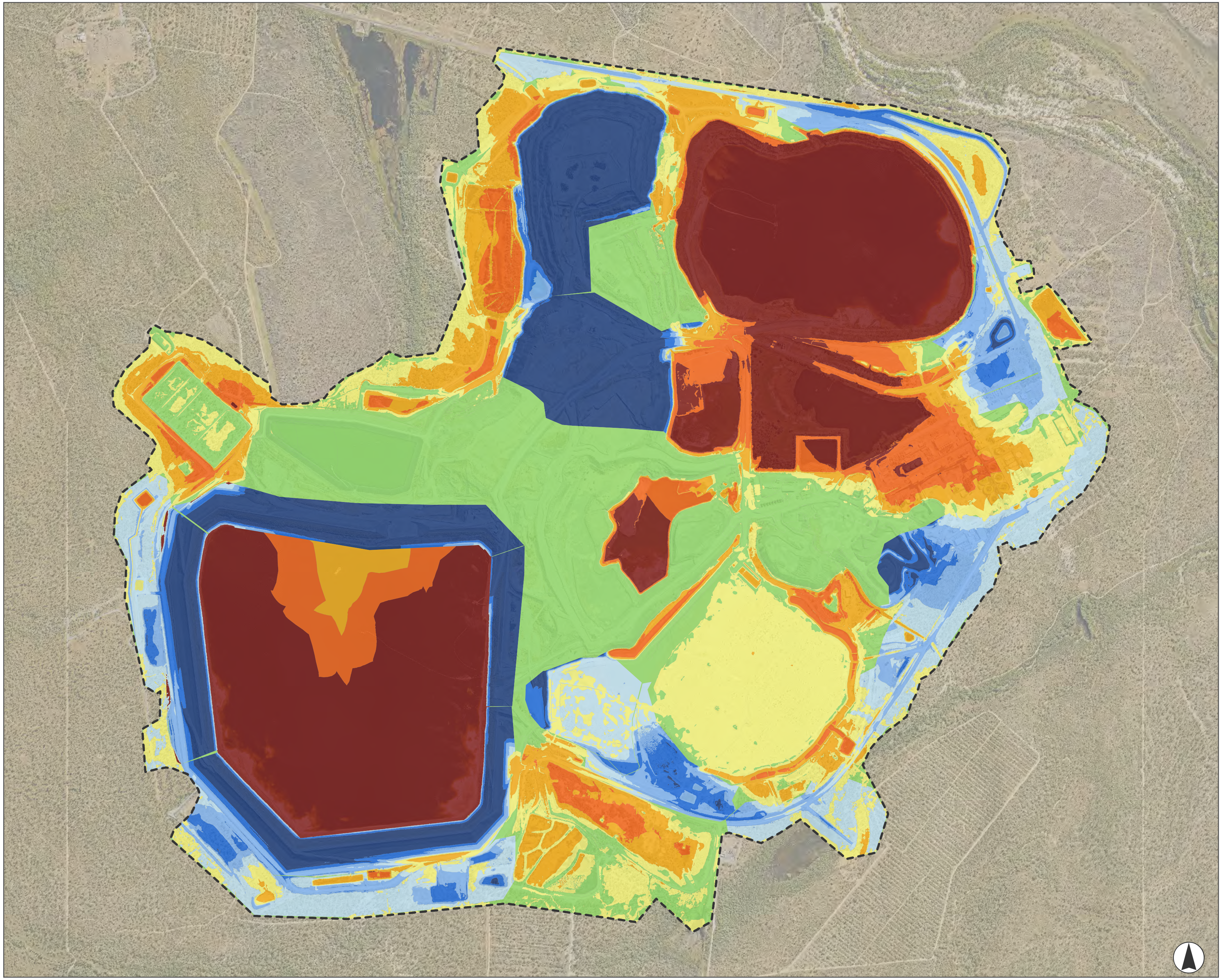
FIGURE 9-3

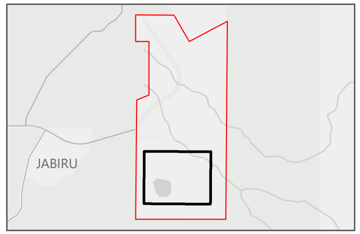
Difference Between Current and Final Landform (FLv7)



LEGEND

Height difference (existing ground level)

- >6m cut
- 3m - 6m cut
- 1m - 3m cut
- 0m - 1m cut
- Cut-to and then backfilled
- 0m - 1m fill
- 1m - 3m fill
- 3m - 6m fill
- >6m fill



0 250 500
Metres

Scale 1:19,548 at A4
GDA 1994 MGA Zone 53

Image Source: ESRI Basemap (2022); Aerometrex (2023) **Data source:** NT Government Data (2023)

Further backfilling and contouring of Pit 1 ensured that the final landform surface aligned with the latest final landform design (FLv6.2 at that time), with an acceptable construction tolerance in the order of +/- 1 m. Following construction (completed in 2020) and initial planting, differential settlement of waste rock and the consolidation of tailings have contributed to localised depressions and variations across the Pit 1 surface, which was expected. During a Cultural Reconnection Steering Committee visit in March 2023, Traditional Owners indicated that the areas of subsidence on Pit 1 are not a major concern at their current size and depth, and suggested certain flora species that may perform better in such conditions. It was noted however that large areas of subsidence across the landform would not be desirable. During another Cultural Reconnection Steering Committee visit held in September 2023, there was further consultation with Traditional Owners around the acceptability of potential co-occurrence of *Melaleuca sp.* and *Eucalyptus sp.* on the final landform in some areas. A natural occurring ecotonal community in adjacent areas on the RPA was also visited as a potential reference.

The final landform surface and the development of such localised depressions and variations will be monitored and will influence the composition of any required infill planting. ERA are developing a strategy on the most appropriate species to be established under such conditions.

Waste rock plant available water

It is necessary for ERA to determine if sufficient plant available water will be available in the final landform to support a mature vegetation community (this is the focus of KKN ESR7B, Appendix 5.1). In waste rock, plant available water is typically a concern due to the increased presence of large rock fragments and macropores when compared with natural soils.

Within the proposed 6 m waste rock vegetation growth layer, it is essential that the plant available water capacity of the substrate is suitable for the establishment of the relevant CRE. Plant available water capacity is influenced by:

- the proportion of fine sediments (<2 mm), referred to below as 'fines'; and
- the total depth of the waste rock.

Studies and modelling conducted on the TLF, Pit 1 and established reference sites surrounding the disturbance area have indicated that for a waste-rock depth of at least 6 m, a minimum of 25% fines is sufficient to sustain the proposed Savanna Woodland CRE (Lu *et al.,* 2019; Okane, 2021). Conversely, a proportion of fines that is too great may impede drainage and require a different vegetation community type.

Particle size distribution sampling conducted by Douglas Partners during the construction of the Pit 1 vegetation growth layer verified that the waste rock substrate contained approximately 30%–40% fines (Miller, 2020). A study conducted on the TLF by Hancock and others (2020) suggested similar proportions of fines, however the larger rocks included in the TLF waste rock appear to have been excluded from analyses. For subsequent areas of the final landform, particle size analysis of waste-rock stockpiles indicates a general range of between 20%–45% fines (Douglas Partners, 2019a, however rocks larger than 150 mm were excluded, meaning that actual proportions of fines may be less). Where possible, bulk material movement planning and implementation will be designed and managed to ensure that the vegetation growth layer, on average, contains at least 25% fines.

To support decision-making on the ground, a visual guide of ‘desirable’ and ‘undesirable’ waste rock will be created to help with selection of growth layer material. This should help minimise the extent of areas with excessively coarse or fine waste rock.

Further investigation into substrate constraints and implications on ecosystem establishment is planned for 2024.

Sub-stockpile compaction (cut-to areas)

The area known as Stage 13, is a 4 ha section of final landform that became available for revegetation at the beginning of 2020. The area was cut down from a waste rock stockpile to the designed final landform surface level (i.e. cut-to), leaving an average 3.1 m thick layer of waste rock overlying natural ground.

Generally, the revegetation at Stage 13 has performed relatively poorly. Besides compaction, this was attributed to a range of factors as described by Wright and others (2021).

To investigate concerns with compaction of cut-to stockpile areas, dynamic cone penetrometer (DCP) testing was conducted prior to revegetation activities at two locations at Stage 13, where the total waste-rock depth measured at 1.7 m and 2.5 m over natural ground (Douglas Partners, 2019b). Similar DCP testing was also conducted on equivalent natural soils during geotechnical investigations for the Jabiru power station (Construction Sciences, 2020). A comparison between the two studies suggests that:

- DCP testing in waste rock is highly variable due to the presence of rocks and may not be the most accurate indicator for compaction; and
- cut-to waste rock may potentially be more compacted than natural ground for the first 0.6 m.

Figure 9-3 illustrates that almost one-third (28%) of the final landform will be cut-to areas (noting that an additional 19% will be cut-to and then backfilled). As such, further investigation into the characteristics of these areas and the treatment that can be applied to maximise plant performance (e.g. deep ripping followed by contouring to create a surface easily traversed on foot) are planned.

Surface preparation

Ripping is a common industry practice used in mine site rehabilitation to aid vegetation establishment. The process improves the success of re-vegetation by promoting infiltration of surface water and assisting in capture of organic material and finer sediments locally.

The entire TLF was ripped at 2 m intervals along the contours to a depth of approximately 50 cm (Daws and Poole, 2010, Plate 9-1). Over a decade later, the surface has a similar appearance now to what it did immediately after ripping. This has contributed to concerns by Traditional Owners around traversability and they have indicated a preference to minimise ripping wherever possible across the final landform.

As part of a trial, a similar approach was applied at Stage 13. This resulted in larger boulders catching the grader tynes, leaving deep linear gouges across the surface (Wright *et al.,* 2021).

With lessons learnt from the TLF and Stage 13, a different approach was trialled on the surface of Pit 1. A grader blade was used to apply a light scarification (i.e. shallow 'ripping' using a grader blade with teeth 10 cm deep). Recent inspections suggest that the surface scarification is no longer visible and the surface is easily traversed on foot (Plate 9-2). At this early stage, the lesser degree of surface preparation has not had a noticeable impact on ecosystem establishment, with the average plant survival across the three Pit 1 research trial areas being approximately 70% at two years post planting.

As described in Chapter 6, ERA will assess the need to deep rip steeper slopes of the final landform to reduce erosion.

Plate 9-1: Contour ripping on trial landform trial of 2 m interval (2010)

Plate 9-2: Scarification of the Pit 1 surface as seen in October 2023

Chemical characteristics

The non-mineralised (grade 1) waste rock material proposed for the vegetation growth layer differs from natural soils by having higher pH, electrical conductivity, cation exchange capacity, magnesium, Total phosphorus and sulfate concentrations (Ashwath *et al.,* 1993).

Efflorescence (confirmed as mostly magnesium sulfate ($MgSO_4$) salts) has been observed on the Pit 1 surface, with further investigation into the effect on revegetation planned for 2024. Hutley and others (2021) suggest that elevated levels of $MgSO_4$ can be reasonably classified as a low risk to vegetation growth, however this study is focussed on riparian species only.

Earlier studies by Malden and others (1994) did indicate a potential impact of $MgSO_4$ to germination from seed, which may have implications for species proposed for initial direct seeding, or ongoing recruitment. Further investigation is needed to identify any constraints this may pose to long-term ecosystem development.

For non-waste rock areas, and particularly LAAs that have been irrigated with mildly contaminated pond water for decades, no noticeable impacts to vegetation health have been observed (EcOz, 2022).

9.3.1.3 Revegetation strategy

An early Ranger Revegetation Strategy was developed by Reddell and Meek (2004) and provided a solid theoretical foundation for the establishment of terrestrial vegetation, which is the focus of KKN ESR3A (Appendix 5.1). The 2004 strategy is still largely relevant, however a number of elements have since been further developed.

Most notably, active introduction of understorey within the first year has been explored further in recent years. The Reddell and Meek (2004) strategy proposed to avoid the use of understory species in the early years due to concerns of competition with establishing trees and risk of wildfire spread. Confidence in fire management and the prevention of early wildfire has improved more recently (as described in Section 9.5.7), and considering the ecological and stability benefits, recent trials at Stage 13.1 and Pit 1 (2020 to 2021) have included the introduction of understorey species in initial stages. Outcomes to date have been positive and the revegetation strategy is currently being developed to include relatively non-aggressive, low biomass grasses and herbaceous species for initial establishment.

To build on learnings from historical revegetation trials and test many of the elements described by Reddell and Meek (2004), the TLF was constructed in 2009. The TLF is an 8 ha area, constructed of waste-rock material and available laterite. A range of species were planted from tubestock and/or direct seeded across different treatments, and ongoing monitoring of these has provided an opportunity to assess revegetation performance on the proposed waste rock substrate. Particular sections of the TLF are shown on Figure 9-1. Plate 9-3 illustrates the progress of vegetation establishment on the TLF over time.

Plate 9-3: Trial landform (permanent monitoring plot 2) in 2009 (top left), 2016 (top right) and 2023

The methodology and monitoring outcomes of vegetation establishment related trials conducted at the TLF are documented within:

- Daws and Poole (2010): Construction, revegetation and instrumentation of the Ranger Uranium Mine trial landform: Initial outcomes.
- Daws and Gellert (2010): Initial (2009) revegetation monitoring on the trial landform.
- Daws and Gellert (2011): Ongoing (2010) revegetation monitoring on the trial landform.
- Gellert (2012): Ongoing revegetation monitoring on the trial landform 2011.
- Gellert (2013): Ongoing revegetation monitoring on the trial landform 2012.
- Gellert (2014): Ongoing revegetation monitoring on the trial landform 2013.
- Gellert and Lu (2015): Revegetation monitoring on the trial landform in 2014.
- Wright (2019a): Effects of the 2016 prescribed fire on revegetation at the trial landform (2016 and 2018 surveys).
- Parry and others (2022): Improved native understorey establishment in mine waste rock in Australia's wet-dry tropics'.

The current revegetation strategy also considers data from the following (unreported) studies that have been conducted on the TLF:

- monthly adaptive management monitoring since September 2018: noting vegetation health and evidence of flowering, fruiting, recruitment and weed spread;
- survey of every woody stem in 2019 and 2022, including established permanent plots;
- ongoing monitoring of understorey tubestock from a previous trial (Parry *et al.,* 2022) that were planted into 'islands' on Sections 1A and 1B and mulched with leaf litter collected from surrounds, in January 2019;
- ongoing monitoring of several understorey and woody species, established via tubestock and/or direct seeding, in selected plots with and without litter cover, in February 2020;
- ongoing monitoring of direct seeded *Xanthostemon paradoxus*, spread over 40 sites across Sections 1A and 1B in December 2021; and
- survey of understorey cover on the TLF in 2022, using a quantitative point intercept method.

Between 2020 and 2023, revegetation trials were also established on waste rock at Stage 13, Pit 1 and Stage 52 (Figure 9-1), including several small-scale direct seeding trials for identified suitable species. These studies, designed around refining the ecosystem establishment strategy include:

- Stage 13 ecosystem establishment research trials 2020–2022;
- Pit 1 ecosystem establishment research trials 2021–2023: exploring year-round revegetation and specific methods and materials to optimise initial seedling survival;
- Pit 1 direct seeding trials: small scale trial consisting of five understory and 2 midstory species;

- Stage 52 *Xanthostemon paradoxus* trial 2023; and
- Ongoing adaptive management monitoring of Pit 1, Stage 13 and Stage 52 since February 2023: noting vegetation health, evidence of flowering, fruiting, recruitment and weed spread.

Ongoing monitoring has and will continue to be used to inform best practice nursery propagation, establishment methods, seasonal effects, irrigation and individual species suitability and performance. Although data from various trials are specific to the substrate in which the trial occurs, they may be reasonably applied to alternative substrates with some allowance for uncertainty and have been interpreted for consideration in the current revegetation strategy.

Non-waste-rock areas of the RPA have been subject to varying degrees of disturbance, including for the purpose of water disposal via evapotranspiration (i.e. on the LAAs). Many of these areas will be subject to revegetation activities over the coming years, subject to the removal of irrigation infrastructure and the development and execution of contamination assessment/remediation plans (described in Chapter 8). Various non-waste rock areas have been progressively rehabilitated including at the Magazine Laydown Area in 2018/2019 and Ranger Mine Village in 2020 (Figure 9-1). Building on this and recent broadscale investigations conducted by EcOz (2022) and Dendra Systems in 2022, specific revegetation requirements for each unique non-waste rock area will be developed.

ERA continues to partner with Kakadu Native Plant Supplies Pty Ltd (KNPS), a local Indigenous business owned and managed by Peter Christophersen. KNPS specialises in cultural-led land management and propagates a deep understanding of local ecology and environmental conditions. KNPS have been engaged by ERA to undertake land management activities on the RPA and the adjacent Jabiluka mining lease since 2005, extending to seed collection, tubestock propagation, planting and irrigation management. KNPS also regularly provides advice on ecosystem establishment and assists with stakeholder consultations.

Species Establishment Research Program

Based on the CRE described in Section 9.3.1.1, ERA have developed a Species Establishment Research Program (SERP) database. The SERP is vital to the revegetation strategy and includes information on:

- seed management – including species phenology and seed collection, storage longevity, viability and germinability;
- propagation – including seed treatments, inoculation, nursery germination rates, plant growth, seasonality of propagation and alternative propagation methods; and
- establishment methods – including relevant substrates, initial tubestock planting, direct seeding, secondary introduction, natural colonisation, persistence, expected growth and development at key stages, flowering, fruiting and recruitment.

A comprehensive research project on local flora seed biology by Bellairs and McDowell (2012) provided a foundation for the SERP, which has been continuously updated with available information from published literature, ongoing revegetation trials and traditional knowledge.

Based on information recorded in the SERP, Appendix 9.1 includes a description of the current revegetation strategy for the Savanna Woodland CRE, including information on seed provenance, propagation, establishment methods and proposed initial planting/seeding density for target species.

Seed Collection and Storage

Seed availability may be influenced by various environmental factors, including repeated 'poor' wet seasons, herbivory by fauna (e.g. cockatoos) or inappropriate fire regimes. For this reason, the collection program is designed with a degree of flexibility and allows for and encourages early collection for species with adequate storage life. Regular reconnaissance, field testing and knowledge of the landscape ensures that seed is collected at maximum viability. After collection, vegetative material is carefully processed according to industry standards and traditional knowledge for individual species, with relatively pure seed lots dried to maintain viability for long-term storage.

Seed storage principles are based on minimising temperature, moisture content and oxygen. To achieve these conditions, ERA vacuum-pack the dried seed lots and manage long-term storage. Vacuum-packing minimises exposure to oxygen, humidity and limits the impacts from pests. A consistent temperature of 21°C minimises the effects of condensation when seed lots are exposed to ambient temperatures in a tropical climate. Unprocessed plant material and bulk grass seed is stored separately to avoid transfer of pests.

This process has so far proven to be effective. In 2019, ERA engaged CDU to conduct seed viability and germination testing for 80 selected seed lots across 49 species with a range of collection dates. The results were used to validate the storage process and facilities, whilst determining acceptable storage timeframes for various species and groups. ERA is in the processes of setting up an ongoing, periodical seed testing campaign, which will further inform collection and storage requirements.

Propagation and Establishment

Although year-round planting may be required to complement scheduling and resourcing requirements, planting in the early dry season with provision of suitable irrigation will be prioritised for a number of reasons, including:

- maximum availability of species with perishable seed, allowing propagation of a greater species richness;
- avoidance of dormancy issues with some species that occurs when propagated over the dry season and planted during the build-up;
- optimal access to planting areas by heavy machinery and vehicles;
- minimal impacts from wind, heavy rain and erosion;
- minimal early impacts from weeds, pests and disease in cooler weather;
- controlled conditions for irrigation; and
- cooler temperatures more favourable for planters and for reducing planting shock.

For planting in other seasons, trials have indicated that variations in germination and growth for most species can be accounted for with particular techniques, including the use of a naturally heated greenhouse, longer propagation periods and increased initial planting densities.

The Ranger nursery has capacity for approximately 100,000 tubestock at any one time, with an average tubestock growth time for most species of around two to three months. Although not preferred due to the above reasons, if scheduling requires year round planting then it may be feasible to produce three rounds of propagation annually, with an annual capacity of around 300,000 tubestock.

Appropriate planting zones will be clearly defined across the final landform, including a network of access tracks to support initial planting, irrigation, monitoring and maintenance. As with previous revegetation trials at Pit 1, for 1,000 tubestock per hectare, these will be planted at a spacing of approximately 2–4 m in a non-uniform pattern.

Where they require specific environmental conditions (e.g. accumulation of organic matter, surface cover and canopy cover), identified species may be established entirely via secondary introductions. An early study included in Gellert (2014) indicated that *Xanthostemon paradoxus*, a common local tree species, may fall into this category, however more recent investigations on Stage 52 have so far indicated that this limitation may be overcome with suitable initial irrigation and improved quality of tubestock. Remaining species that fall into this category are more likely to include herbaceous understorey legumes and vines, of which the specific methods and optimal timing will be determined with ongoing monitoring and further trials on more mature revegetation (e.g. TLF).

Sustainability processes and recruitment

Of the woody species originally established on the TLF, over three-quarters have been observed to flower, fruit and self-recruit, either via seed or vegetative reproduction (suckering), of which the latter for some species appear to be influenced by fire (Wright, 2019b). The persistence of recruits from seed is variable and further investigation into influential factors is required.

Several understorey species that have been established more recently on the TLF, Stage 13.1 and Pit 1 have indicated high early rates of self-recruitment and/or spread.

Additional species, including weeds, are expected to naturally colonise through external pathways including fauna and wind. Monitoring on the TLF has recorded close to 100 naturally recruited native species. Some of these are woody species, however the majority are herbs and grasses, including an increasing number of perennials, which have substantially improved ground cover.

Documentation of recruitment, and early indicators such as flowering and fruiting, is important, particularly for species that experience senescence (e.g. *Acacia* with generally shorter life span). Accounting for senescence and recruitment ensures the sustainability of target populations densities and has been considered in the calculation of initial planting/seeding densities for the proposed Savanna Woodland CRE (Appendix 9.1).

9.3.2 Habitat formation and composition and abundance of fauna

As described in Section 9.3.1.1, the final vegetation communities established at Ranger will reflect conceptual reference ecosystems that are based on, but not identical to, that of natural reference sites. Therefore, the faunal populations that are expected to return to the rehabilitated site may vary slightly from those in surrounding areas. In order for ERA to set expectations in regard to faunal recolonisation, it is important that natural reference populations, habitat characteristics and key population drivers are well understood (this is the focus of KKN ESR2A, see Appendix 5.1).

9.3.2.1 Appropriate Fauna Reference Populations

Vertebrates

In 2021, SLR Consulting (SLR) were engaged by ERA to identify vertebrate fauna species that have the potential to recolonise the rehabilitated site, based on the results of relatively recent and appropriate fauna studies conducted at savanna woodland sites.

Identified native mammal, bird, reptile and amphibian species from 35 savanna woodland survey sites are listed in Appendix 9.2. Of these, species listed as threatened under the relevant Commonwealth and NT legislation included:

- Black-footed Tree-rat (*Mesembriomys gouldii*);
- Fawn Antechinus (*Antechinus bellus*);
- Northern Brown Bandicoot (*Isoodon macrourus*);
- Northern Quoll (*Dasyurus hallucatus*); and
- Partridge Pigeon (*Geophaps smithii*).

Frugivorous and nectivorous birds are specifically referenced in closure criteria due to their role in external exchanges and vegetation dispersal. To account for this, relevant species were identified by Dr John Woinarski and included in Appendix 9.2.

It is also noted that the listed species in Appendix 9.2 are not exhaustive and may be expanded with further survey efforts and more recently developed monitoring techniques. For example, several bat species are not included, however were not targeted in the subject surveys.

Invertebrates

Ants were identified by Oberprieler and others (2020) to be broadly representative of the total invertebrate diversity for the area and have also been included in closure criteria. This study included a preliminary characterisation of reference populations for ants, comparing four sites on the TLF with seven natural reference sites surrounding the RPA. As to be expected, ant species richness and composition on the TLF was not similar to that in the surrounding Kakadu National Park, given the young age of the rehabilitated areas, however overall ant abundance was similarly high.

9.3.2.2 Establishment of Suitable Fauna habitat

It is recognised that surrounding fauna communities will be the main source for fauna recolonisation of the rehabilitated landform. Much of the vertebrate fauna is expected to recolonise later in the recovery trajectory of the site, in response to the development of invertebrate and vegetation resources. Assuming healthy surrounding fauna populations and appropriate migration corridors, successful fauna recolonisation is reliant on the presence of suitable habitat.

ERA conducted a literature review in 2023 to identify opportunities to artificially or naturally enhance Ranger's rehabilitation areas to ensure that sufficient habitat resources exist (the focus of KKN ESR2B, Appendix 5.1).

The key findings included:

- fire regimes and exotic fauna pose the biggest threats to native fauna populations;
- important habitat components comprise species rich overstorey and understorey vegetation, with a degree of landscape level heterogeneity;
- appropriate understorey should be established as early as possible, maximising available habitat, resources and refuge from predators;
- successional fauna return is expected as vegetation is established, which may be influenced by artificial habitat structures; and
- caution should be exercised with early establishment of artificial habitat structures prior to development of a mature vegetation structure (15–20 years), which may contribute to an ecological trap for returning species, where foraging resources are lacking and/or predation is favoured.

Habitat features such as leaf litter, stag trees, coarse woody debris and hollows are expected to form naturally over varying timeframes. Of these, hollows are the slowest, with studies suggesting that it may take up to 100 years or more before the formation of tree hollows provides suitable habitat for some species (Taylor *et al.,* 2003; Goldingay, 2009; Goldingay, 2011). To aid relatively short-term recruitment of fauna, several feasible options for artificial habitat enhancement have been identified. The knowledge base for each of these is described below.

Artificial nest boxes or chainsaw hollows

A large-scale nest box trial is currently active on the RPA. This includes the installation of approximately 90 nest boxes using five distinct designs to accommodate different faunal groups (small mammals, medium-sized mammals, small birds, medium-sized birds, micro-bats). The boxes are fixed to trees on the TLF, disturbed remnant vegetation on-site and natural reference sites. The trial design is documented in an implementation plan (SLR, 2022) which was endorsed by stakeholders at ARRTC 50. Monitoring will be conducted for a minimum period of 12 months with outcomes to be presented to stakeholders for further discussion and inclusion in future iterations of the MCP.

Rockpiles

Excess large rocks that are recovered during bulk material movement have been proposed for use in the creation of rocky habitat structures, which may provide some benefit in an alternative habitat type for suited flora and fauna. Previous discussions have sparked interest from the Traditional Owners and a series of rock pile structures were installed on the Pit 1 surface in 2021 (Brady *et al.*, 2021). As the established ecosystem on Pit 1 develops, infill planting of culturally significant species will be undertaken around these rock structures, and the ongoing monitoring of fauna response will provide a valuable learning opportunity for future landform design and planning.

Transplantation of leaf litter and humus from surrounds

This is currently listed as a preventative control for ecosystem establishment and has multiple benefits including habitat for invertebrates and foraging resources for vertebrates. However, as described previously, the practical feasibility for a site wide strategy requires further consideration.

9.3.3 Nutrient cycling

Natural reference ecosystems

Natural nutrient cycling processes in savanna ecosystems include litter decomposition and mineralisation of nutrients for uptake by plants. These processes are essential for the ongoing sustainability of ecosystems and are driven by functional microbial communities in leaf litter, surface soil and the rhizosphere, or rootzone.

The rehabilitated landform at Ranger will have certain physical, chemical and biological characteristics that differ to that of surrounding undisturbed natural soils. Therefore, relevant indicators will not be assessed against reference site values, however knowledge of typical litter decomposition rates, soil microbial communities, chemistry and plant uptake of nutrients in reference ecosystems will help to make sense of how these processes might behave in a developing ecosystem on a novel substrate.

Studies undertaken by Huang and You (2018), and Huang and others (2020), included an assessment of some of these elements at relevant reference sites, which indicated the following attributes could be considered as natural reference ecosystems:

- healthy microbial communities (which are described in detail in the reports);
- an average of 4.5% soil organic carbon;
- more than 20 mg/kg soil nitrogen; and
- sufficient plant available mineral and soluble organic nitrogen.

In natural reference ecosystems, fire regime plays a major part in the sustainability of nutrient cycling processes and carbon sequestration (Scheiter *et al.,* 2015), which are driven by the presence of leaf litter and organic materials (Tongway and Hindley, 2004). Fire creates a short-term spike of available nutrients (Frost and Robertson, 1987), however frequent burning over extended timeframes contributes to losses of nutrients through atmospheric transfers and erosion of deposited ash (Hutley and Setterfield, 2008; Cook, 2021).

Nutrient cycling on waste rock

The key processes that encourage nutrient cycling in a developing ecosystem include deep ripping and topsoil return. Deep ripping encourages accumulation of litter and nutrients, while topsoil return conserves existing microbial communities and encourages nutrient cycling (Grant *et al.,* 2007). Unfortunately, the conservation of topsoil was not encouraged during initial operations at Ranger, and deep ripping will be avoided wherever practical due to concerns around traversability and cultural use. Understandably, this leads to the question of whether nutrient cycling processes will support ecosystem sustainability on the Ranger waste-rock substrate (this is the focus of KKN's ESR7A and ESR7C, Appendix 5.1).

Early assessment of the waste-rock substrate by Ashwath and others (1993) and Gellert (2014) indicated relatively low levels of inherent organic carbon and nitrogen. After ten years, the TLF had demonstrated sustained growth of overstorey vegetation, however understorey had not been actively established and was still sparse at this stage. Huang and You (2018), and Huang and others (2020), found that after ten years of ecosystem development at the TLF, soil nitrogen remained very low. Microbial communities in surface soils were active and highly diverse, however with a reduced potential capacity for organic matter decomposition.

The studies further suggest that microbial communities, soil chemistry and litter decomposition will all be improved with increased presence of understory vegetation, and particularly nitrogen fixing leguminous species. This recommendation was considered and has contributed to a shift in the revegetation strategy to introduce understorey and a diversity of leguminous species in the initial stages (see Section 9.3.1).

The addition of fertiliser at initial stages (i.e. first two years) is part of the revegetation strategy for Savanna Woodland (Appendix 9.1) and was applied during the establishment of trials at the TLF, Stage 13, Pit 1 and Stage 52. No additional nutrient additives have been applied to these areas since establishment, with demonstrated sustained vegetation growth. This suggests that the chemistry of the waste-rock substrate does not present any limitations to vegetation growth and is compatible with the development of nutrient cycling processes.

9.3.4 Resilience to an appropriate fire regime

9.3.4.1 Appropriate fire regimes

Fire regimes are characterised by the frequency and intensity of fires in an area, which is influenced by weather, vegetation and seasonal variability. Both naturally occurring and anthropogenic fires are common in Australia's tropical savannas and the surrounding Kakadu National Park, where it remains a major force in shaping and altering the natural landscape, and impacting vegetation, flora and fauna communities, and cultural use of the land by Traditional Owners.

Management of fire in the surrounding Kakadu National Park, and expected/observed changes in climate, will be used to progressively update the current understanding of fire regimes in surrounds. Some recent preliminary studies have been conducted at Paradise Farm, an outstation within Kakadu National Park approximately 45 km south west of the RPA. The Traditional Owners of this area have been documenting the effect of various fire regimes on different parts of the landscape, which may be used to better understand appropriate fire regimes.

Fire frequency in the regional surrounds

Publications of fire frequencies between 1980 and 2019 indicate that Kakadu National Park experienced a relatively high fire frequency, with three to seven fires per decade, of which one to three are considered late dry season fires (Cook, 2021). This correlates with fire occurring over 50% of Kakadu National Park annually (Andersen, 2020).

A high fire frequency has been found to lead to a simplification of vegetation structure, comprising only large trees, an understorey of grasses, and eucalypt resprouts (Cook, 2021; Freeman *et al.,* 2018; Scott *et al.,* 2012). This effect has been observed in major research projects in the NT (at Munmarlary and Kapalga) where long unburnt sites have developed substantially less grass cover than sites that had been burned annually (Bowman and Panton, 1995; Andersen *et al.,* 1998, 2003, 2005). Discussions with Traditional Owners during cultural reconnection visits to the RPA are in alignment with this research, with suggested concerns around the impact of frequent fire on *Sorghum* density, as well as particular bush food species.

By contrast, a regime of less frequent fires has been found to provide greater opportunities for recruited saplings to escape the flame zone and for a mid-stratum to persist (Freeman *et al.,* 2017; Setterfield, 2002).

Fire intensity in the regional surrounds

Regarding the intensity of fires, this is primarily driven by seasonal conditions. In Kakadu National Park and the area surrounding the RPA, high annual wet season rainfall promotes extensive vegetation growth, particularly from annual grasses dominated by *Sorghum*. With subsequent curing of the vegetation over the long dry season the risk of intense fire increases, peaking in September to November due to a combination of low humidity, higher temperatures (above 35°C) and low soil moisture (Gill *et al.,* 1996). Generally, fires occurring in the early dry season with cooler weather and less fuel load have a reduced intensity, and therefore, less impact.

The fire management plan for Kakadu National Park from 2016 to 2026 (Director of National Parks, 2016) aims to reduce the area impacted by large fires and the risk of wildfires entering, spreading, or leaving the park. The plan recognises the importance of maintaining long-unburnt patches for vegetation regeneration and wildlife habitat and acknowledges that reduced frequency, intensity and extent of fires will contribute to this.

The future of fire in Kakadu

Understanding of longer-term scenarios is essential. A Ranger Uranium Mine Climate Change Risk Assessment was prepared following the Intergovernmental Panel on Climate Change 6th Assessment (BMT, 2023d), which identified a number of risks relevant to the rehabilitation of Ranger. The report predicts increases in frequency and intensity of hot periods up to the year 2100, and changes in rainfall seasonality (i.e. growing seasons). These changes may contribute to increased fuel loads and/or fire intensity, however the proposed revegetation species compositions to be used at Ranger are expected to be the most resilient to these changes.

9.3.4.2 Resilience to fire

To be considered sustainable, the rehabilitated ecosystem needs to demonstrate resilience to an appropriate fire regime and suitable recovery (this is the focus of KKN ESR8A, Appendix 5.1).

Reddell and Meek (2004) suggested to exclude fire for the first three years following establishment. This has more recently been challenged, considering remaining uncertainty with resilience and the impact that a fire would have on ecosystem establishment and nutrient cycling on a waste rock substrate, with 10–15 years a more likely timeframe. Therefore, exclusion of fire will be prioritised until such time that monitoring indicates appropriate resilience characteristics. In general, this and a strategy based on the re-establishment of vegetation with similar composition, abundance and structure to that of surrounds will ensure that resilience is achieved over time.

To support this concept in a project specific context, ERA engaged Dr Gary Cook, a renowned expert in fire ecology, to identify typical resilience mechanisms that are common to the rehabilitation strategy and specific planting compositions (Cook, 2021). These are listed in Table 9-4, along with typical establishment timeframes (Cook, 2021), learnings from trial burns at the TLF (Wright, 2019a; Wright, 2019b) and general observation. Understanding of this will be significantly improved when the re-established ecosystems are mature and an appropriate fire regime is gradually introduced, however the importance of excluding fire until resilience mechanisms have developed is clear, particularly for larger framework tree species.

Table 9-4: Fire resilience mechanisms for Ranger rehabilitation

Growth form	Mechanism for fire resilience	Relevant species	Mechanism establishment timeframe
Trees	Some species with rapid vertical growth to escape flame zone.	*Eucalyptus tetrodonta* *Eucalyptus miniata*	3–8 years (TBC) In general, trees taller than 2.5 m were more likely to survive trial burns at TLF
	Many species have deeply embedded epicormic sprouts (above ground growing points) protected by thick bark (Lawes *et al.* 2011).	*Eucalyptus spp.* *Melaleuca spp.*	3–8 years (TBC) In general, trees with DBH greater than 4 cm were more likely to survive trial burns at TLF
	Many species have underground lignotubers that can avoid heat and contain resources for rapid post-fire regrowth (Freeman *et al.* 2017), which encourages further growth and capability of lignotubers (Fensham and Bowman 1992). While large lignotubers in natural systems may be decades to centuries old (Fensham and Bowman 1992), seeded Eucalypts in southern Australia have been shown to develop suitable lignotubers within one to two years of germinating (Gill 1997).	*Acacia hemignosta* *Corymbia disjuncta* *Eucalyptus tetrodonta* *Eucalyptus spp.* *Erythrophleum chlorostachys* *Melaleuca spp.* *Wrightia saligna*	3–8 years (TBC)
Shrubs and trees (non-Eucalypt)	Many develop flowers and fruits at an immature stage between fire events, enabling persistence in the flame zone.	*Buchanania obovata* *Brachychiton spp.* *Planchonia careya* *Petalostigma quadriloculare* *Planchonia careya* *Terminalia ferdinandiana*	2–5 years (TBC)

Growth form	Mechanism for fire resilience	Relevant species	Mechanism establishment timeframe
Palms	Growing point protected by thick leaf bases and thick trunk.	*Livistona spp.* *Pandanas spiralis*	3–5 years (TBC)
Shrubs	Acacia seed is particularly fire resistant, and germination is triggered following fire. Observations from TLF trial burns suggest this may also be the case for *Owenia vernicosa* and *Petalostigma pubescens.*	*Acacia spp.* *Owenia vernicosa* *Petalostigma pubescens*	2–4 years (TBC)
Dense shrub stands	Some species will exclude grasses and fuel loads, reducing risk of fire and allowing further colonisation and persistence of dense stands. This process may also limit development of nutrient cycling processes.	*Calytrix exstipulata* *Dodonaea hispidula*	2–4 years (TBC)
Shrubs (Grevillea)	Some with an ability to resprout rapidly from lignotubers and reproduce in one season.	*Grevillea dryandra* *Grevillea goodii*	2–3 years (TBC)
Herbs	Many species have underground tubers that can avoid heat and resprout following fire.	*Galactia tenuiflora* *Haemodorum spp.*	1–2 years
Perennial grasses	Many species have relatively deep, robust growing points which can avoid heat and resprout following fire.	*Chysopogon fallax* *Alloteropsis semialata* *Heteropogon triticeus*	1–2 years
Annual grasses	Many species have seed that buries into soil, protecting from fire prior to germination.	*Sorghum intrans* *Aristida spp.*	Within 1 year

9.3.5 Resilience to extreme weather events, pests and disease

A resilient ecosystem can experience the range of reasonably anticipated, natural disturbance events, or stressors, and maintain integrity, or trajectory (in regard to establishing rehabilitation areas). The potential influence of climate change should also be considered, with likely increases in drought and storm intensity, and prevalence of pests and disease in surrounds (BMT, 2023d). Regional ecosystems are exposed to periods of prolonged drought (due to distinct but variable wet and dry seasons) and destructive wind events including powerful storms and cyclones. They may also be exposed to pests and disease, both native and exotic, and therefore need to demonstrate resilience and recovery to be considered sustainable.

Since establishment, revegetation areas on the TLF have been subject to several disturbance events, including:

- Widespread damage observed on two to three year old trees (likely to be caused by a species of native wood moth, *Maroga melanostigma* or longicorn beetle, *Acalolepta mixtus*) prompting treatment with a systemic insecticide (Gellert, 2012; Gellert, 2013).
- A major wind event in 2019 that felled several trees, most of which have since re-shooted.
- Widespread infestation in late 2022 by the subterranean termite (*Mastotermes darwiniensis*), again prompting treatment with a targeted application of insecticide at the base of impacted trees. Although a formal follow-up survey of the treated plants has not been performed, observations during the regular adaptive management walk-throughs has indicated some recovery and reshooting.

Pit 1 and Stage 13 have also experienced widespread insect damage on some young shrubs and trees throughout 2023. The damage is believed to be caused by the tree boring larvae of a native moth (possibly *Maroga melanostigma*, however field staff have been unable to locate/collect larvae to date) and this is generally contained to a handful of species with *Acacia dimidiata*, *Acacia oncinocarpa* and *Grevillea decurrens* being the most severely affected.

Further work is planned to strengthen the revegetation strategy with regards to when and if to actively intervene in the event of pest and/or disease outbreaks.

9.3.6 Declared weeds and other introduced flora

Weeds are a material risk at Ranger and are part of the focus of KKN ESR4A (Appendix 5.1).

9.3.6.1 Mechanisms for spread and local weed species of concern

Weeds may be defined as plants (native or exotic) that colonise and persist in an ecosystem where they did not previously exist or are not compatible with the subject land-use. Particular adaptations (e.g. production of large numbers of seeds) enable weeds to colonise, thrive and reproduce in hostile environments, and particularly bare areas without competition from established vegetation. Mechanisms for spread, most commonly via seed, include:

- wind, surface water and fire;
- animal movement;
- vehicles and machinery; and
- human movement.

Decades of disturbance at the RPA and surrounds have contributed to the presence and abundance of a range of weed species, which require ongoing management. ERA has established a positive and collaborative relationship with the NT government weeds branch and herbicide suppliers Macspred and Adama, which has contributed to knowledge sharing and improved methods. Further collaboration with these organisations, as well as Kakadu National Park (regarding their own weed management programs) may generate further opportunities for:

- improved weed management programs;
- reduction of threats both from and to the immediate surrounds; and
- understanding the presence and abundance of listed and other potentially threatening weed species in:
    - reference ecosystems at a landscape scale; and
    - adjacent areas of Kakadu National Park.

The latter points above are particularly important and will be used to add definition to closure criteria and assessment of monitoring outcomes.

Closure criteria are based on three categories of weeds (namely Class A, Class B and other introduced flora). Previously detected and/or currently managed species that fall within each of these categories are listed in Table 9-5.

Table 9-5: Weed categories and currently relevant species of concern

Class A (NT Weeds Act 2001) and/or Weeds of National Significance (Federal Environment Protection and Biodiversity Conservation (EPBC) Act 1999)		
Andropogon gayanus		
Class B (NT Weeds Act 2001)		
Cenchrus polystachios	*Mesosphaerum suaveolens*	*Senna obtusifolia*
Sida acuta	*Themeda quadrivalvis*	
Other introduced flora		
Acacia holosericea[1]	*Alysicarpus vaginalis*	*Calopogonium mucunoides*
Cenchrus pedicellatus	*Chamaecrista rotundifolia*	*Chloris barbata*
Cleome viscosa[1]	*Crotalaria goreensis*	*Dactyloctenium aegyptium*
Echinochloa colona	*Euphorbia hirta*	*Hibiscus sabdariffa*
Hymenachne amplexicaulis	*Ipomoea quamoclit*	*Macroptilium atropurpureum*
Melinis repens	*Passiflora foetida*	*Sesamum indicum*
Sida cordifolia	*Sorghum spp.* [2]	*Spigelia anthelmia*
Stylosanthes spp.	*Tridax procumbens*	*Urochloa mutica*
Urochloa pubigera		

[1] The local native/introduced status of these species is uncertain, however they are managed similarly to other introduced flora.

[2] The local *Sorghum spp*. are native but are managed as weeds (mainly by fire) due to their transformative potential.

Class A (NT *Weeds Management Act 2001*) and/or Weeds of National Significance (Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*)

The *Weeds Management Act 2001* (NT) states that Class A weeds must be eradicated, aligning with closure criteria. *Andropogon gayanus* (commonly known as Gamba Grass) is the only Class A weed that has been recorded in the RPA, which is also classed as a Weed of National Significance under the EPBC Act. Isolated plants have previously been recorded at the Jabiru Airport and road verges, and immediately removed, as well as the management of any resulting seed bank. In 2022, there was a reported potential sighting of one individual plant on a ramp entering Pit 1, however this plant was removed before identification could be confirmed. It is most likely that all of these occurrences were caused by transport of seed on vehicles and machinery from other areas, highlighting the importance of regular vehicle inspection, wash-downs and cleaning.

Class B (NT Weeds Act 2001)

The *Weeds Management Act 2001* (NT) states that Class B weeds must be controlled. Five species that fall within this category occur within the RPA and are actively managed.

Other introduced flora

Although not declared under legislation, a number of other introduced flora have been identified as having the potential to threaten the sustainability of ongoing management regimes and/or impact the development of revegetated ecosystems on the final landform. Competition with native species for resources has the potential to:

- impact vegetation establishment in new revegetation areas;
- transform existing or developing composition and structure, and/or
- encourage the presence of exotic fauna, pest, disease and/or an inappropriate fire regime.
- It is for these reasons that 'other introduced flora' are actively managed to control further spread.

9.3.6.2 Management methodologies

A wealth of knowledge has been developed around the ecology of the species listed in Table 9-6 and the effective control of these.

Commonly implemented control methods include:

- application of short acting herbicides;
- application of pre-emergent herbicides;
- seed head cutting;
- manual removal; and
- burning during the appropriate season.

Herbicides and their application on the RPA are summarised in Table 9-6.

Table 9-6: Commonly used herbicides and target species

Herbicide and active ingredient	Label description and relevant recommended genera/species	Target species
Glymac (glyphosate)	Non-selective, water-soluble herbicide for the control of a wide range of Annual and Perennial Weeds (including *Cenchrus*, *Chloris*, *Echinochloa, Urochloa, Sorghum* and *Melinis)*	All
Sulfomac (sulfometuron methyl)	For the control of certain annual and perennial grasses and broadleaf weeds (including *Echinochloa*)	*Cenchrus polystachios* *Cenchrus pedicellatus*
Clomac (Clopyralid)	Control of a wide range of broadleaf weeds (including *Acacia* and other volunteer legumes)	*Alysicarpus vaginalis* *Calopogonium mucunoides* *Stylosanthes spp.*
Picoflex (picloram)	A wide range of annual, perennial, noxious and woody weeds (including *Senna obtusifolia, Acacia*)	*Crotalaria goreensis*
Cavalier (Oxyfluorfen)	For selective weed control of broadleaf weeds and some grasses (*Cenchrus, Echinochloa, Urochloa*)	All (pre-emergent)

Herbicide and active ingredient	Label description and relevant recommended genera/species	Target species
Starane (Fluroxypyr)	For the control of a wide range of broadleaf weeds and woody weeds (including *Sida spp. Passiflora foetida*, *Acacia, Ipomoea quamoclit*)	*Acacia holosericea*

9.3.7 Abundance of exotic fauna

Studies are planned to gain an understanding of the incidence and abundance of exotic fauna in adjacent areas of Kakadu National Park, their ecology (part of the focus of KKN ESR4A, Appendix 5.1), and how this may translate to Ranger (focus of KKN ESR2C, Appendix 5.1). This work may involve a collaborative process with Kakadu National Park, which will improve the confidence of exotic fauna risks and management.

9.4 Bow-tie diagrams

As described in Chapter 5, this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. For ecosystems, there are seven bow-ties, representing the relevant aspects that are described in Section 9.1. These are provided as Figure 9-4 through to Figure 9-10. Within each bow-tie diagram, threats and preventative controls are represented on the left side of the diagram, and corrective actions and consequences on the right side. The residual risk ratings reflect the current understanding and effectiveness of the controls and corrective actions. Class IV and Class III risks exceed ERA's risk acceptance threshold and will be the subject of further work to reduce uncertainty and strengthen the controls and/or corrective actions.

Further details on the preventative controls, monitoring program and corrective actions for the ecosystem theme are provided in Section 9.5, Section 9.6 and Section 9.7 respectively.

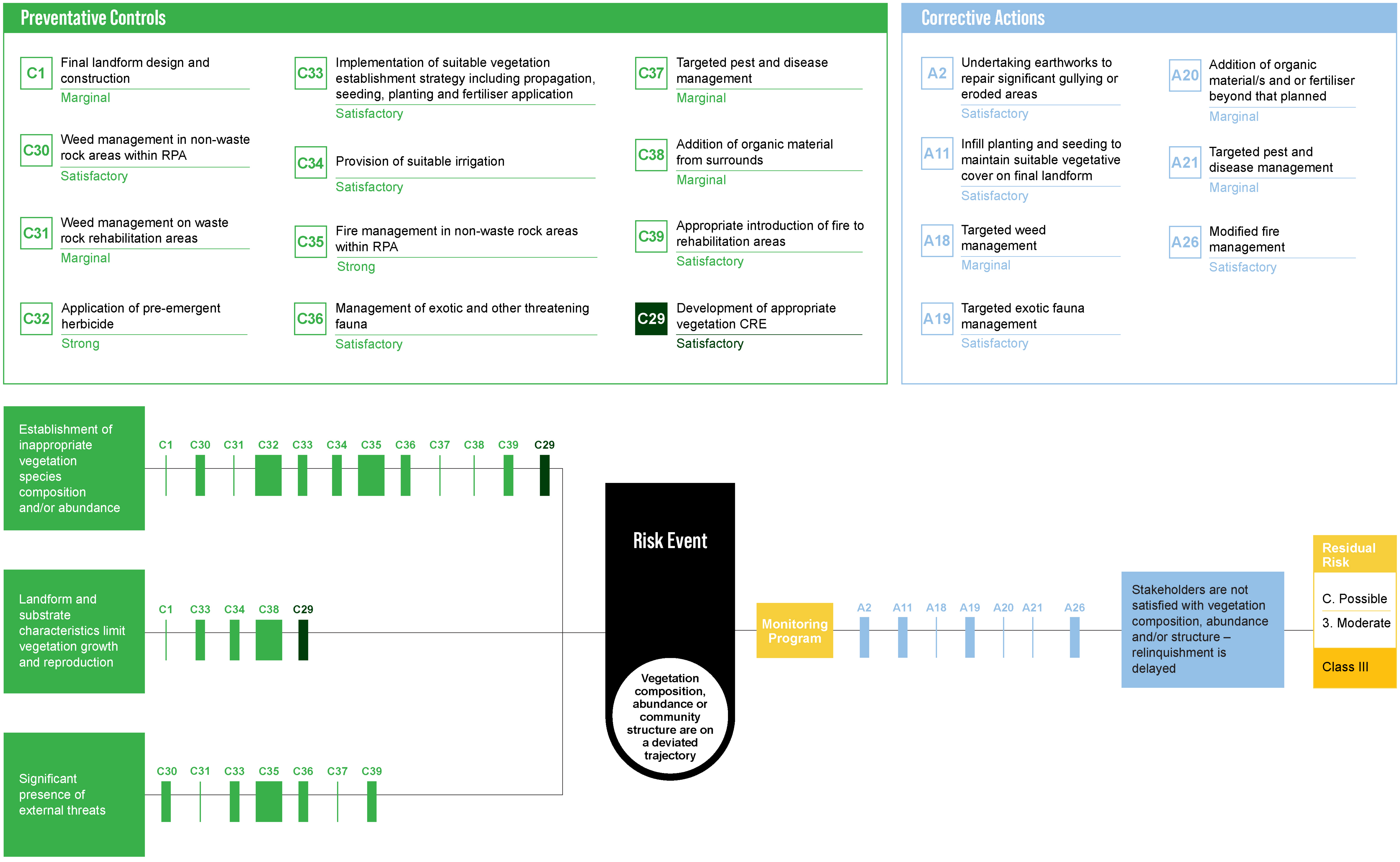


Figure 9-4: Bow-tie diagram for vegetation composition, abundance and community structure (ES1)

Preventative Controls

- **C1** Final landform design and construction — Marginal
- **C30** Weed management in non-waste rock areas within RPA — Satisfactory
- **C31** Weed management on waste rock rehabilitation areas — Marginal
- **C32** Application of pre-emergent herbicide — Strong
- **C33** Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application — Satisfactory
- **C34** Provision of suitable irrigation — Satisfactory
- **C35** Fire management in non-waste rock areas within RPA — Strong
- **C36** Management of exotic and other threatening fauna — Satisfactory
- **C37** Targeted pest and disease management — Marginal
- **C38** Addition of organic material from surrounds — Marginal
- **C39** Appropriate introduction of fire to rehabilitation areas — Satisfactory
- **C41** Installation of appropriate habitat — Marginal
- **C40** Development of appropriate fauna CRE — Satisfactory

Corrective Actions

- **A2** Undertaking earthworks to repair significant gullying or eroded areas — Satisfactory
- **A11** Infill planting and seeding to maintain suitable vegetative cover on final landform — Satisfactory
- **A18** Targeted weed management — Marginal
- **A19** Targeted exotic fauna management — Satisfactory
- **A20** Addition of organic material/s and or fertiliser beyond that planned — Marginal
- **A21** Targeted pest and disease management — Marginal
- **A22** Supplementation of habitat features and/or migration corridors — Marginal
- **A26** Modified fire management — Satisfactory

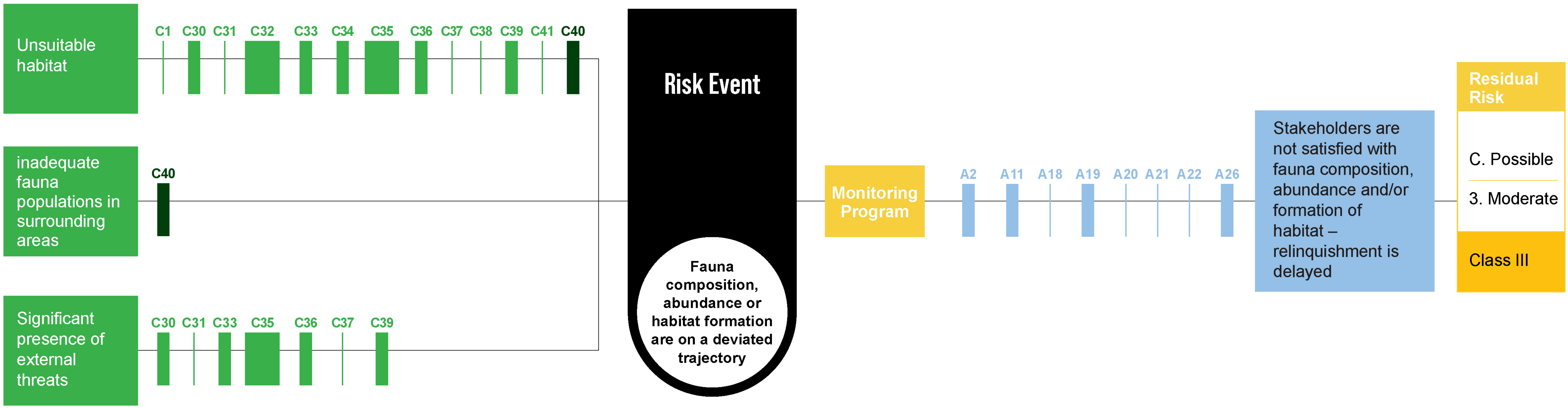


Figure 9-5: Bow-tie diagram for fauna composition, abundance or habitat formation (ES2)

Preventative Controls

C1 Final landform design and construction
Marginal

C33 Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C38 Addition of organic material from surrounds
Marginal

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

Corrective Actions

A2 Undertaking earthworks to repair significant gullying or eroded areas
Satisfactory

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A20 Addition of organic material/s and or fertiliser beyond that planned
Marginal

A26 Modified fire management
Satisfactory

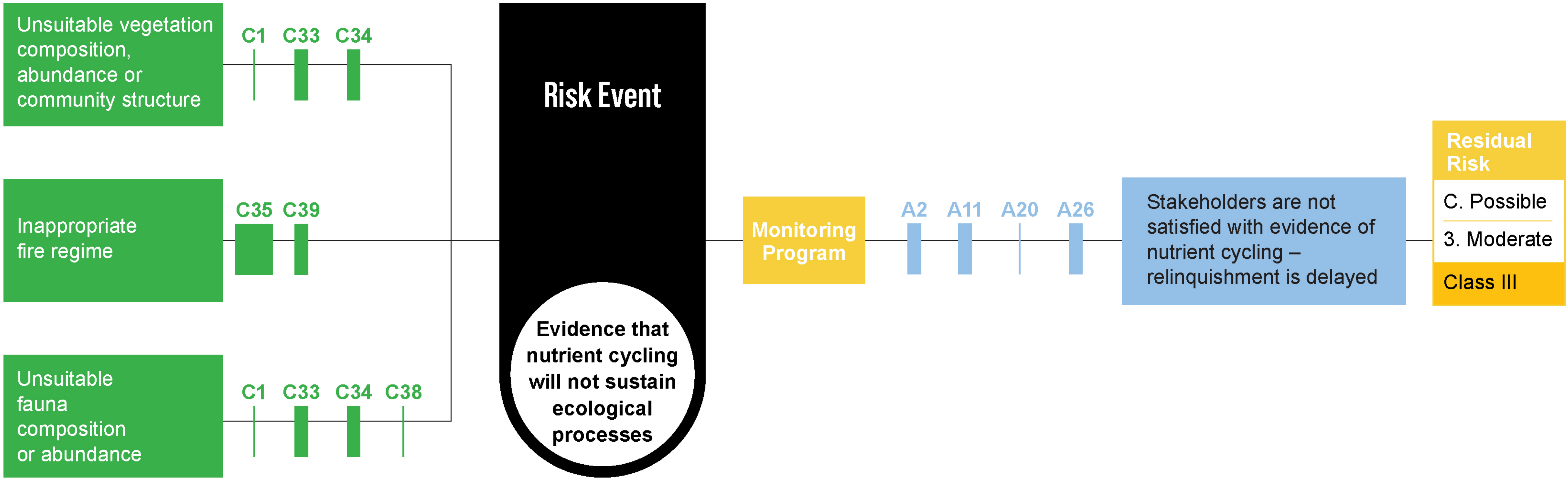


Figure 9-6: Bow-tie diagram for nutrient cycling (ES3)

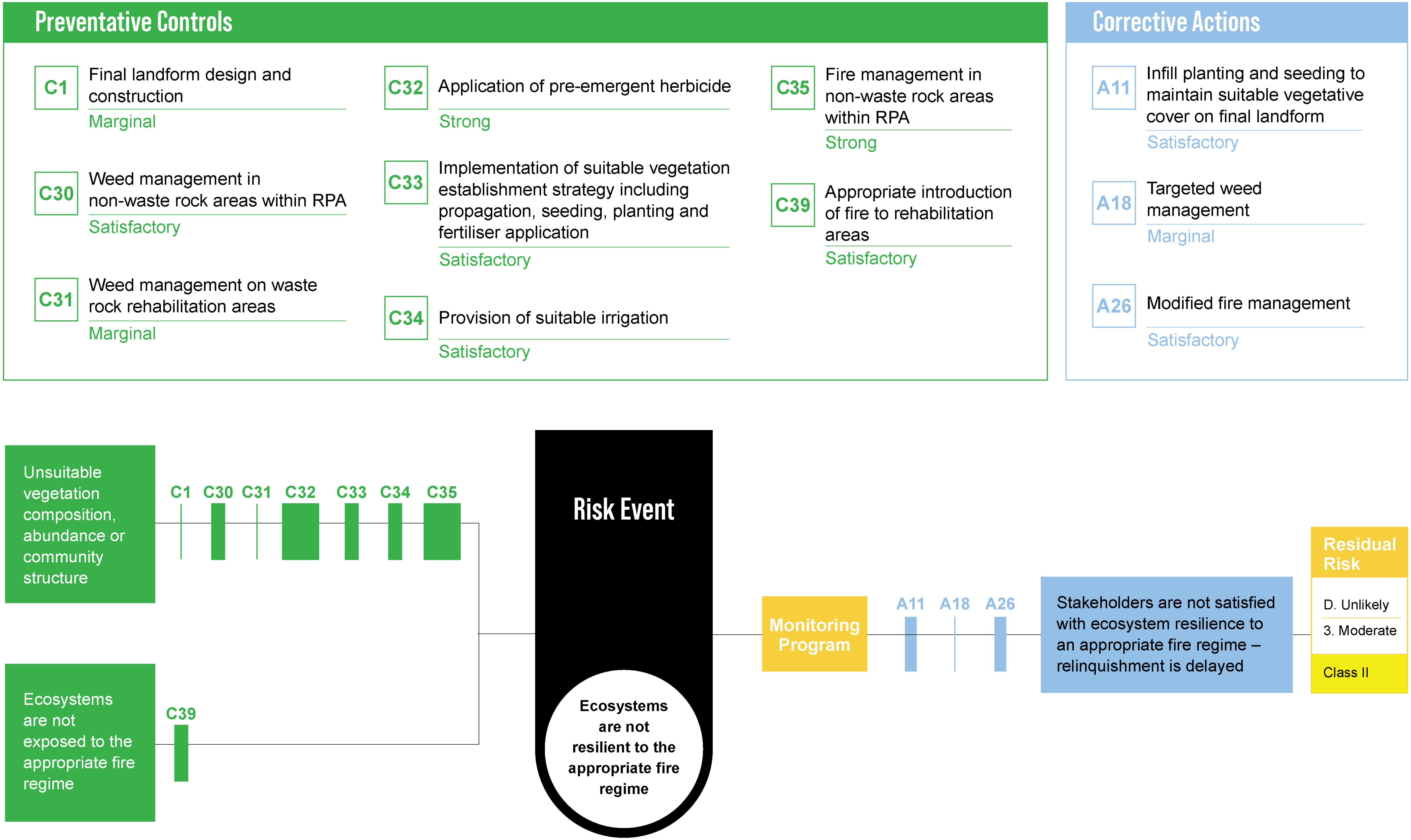


Figure 9-7: Bow-tie diagram for fire resilience (ES4)

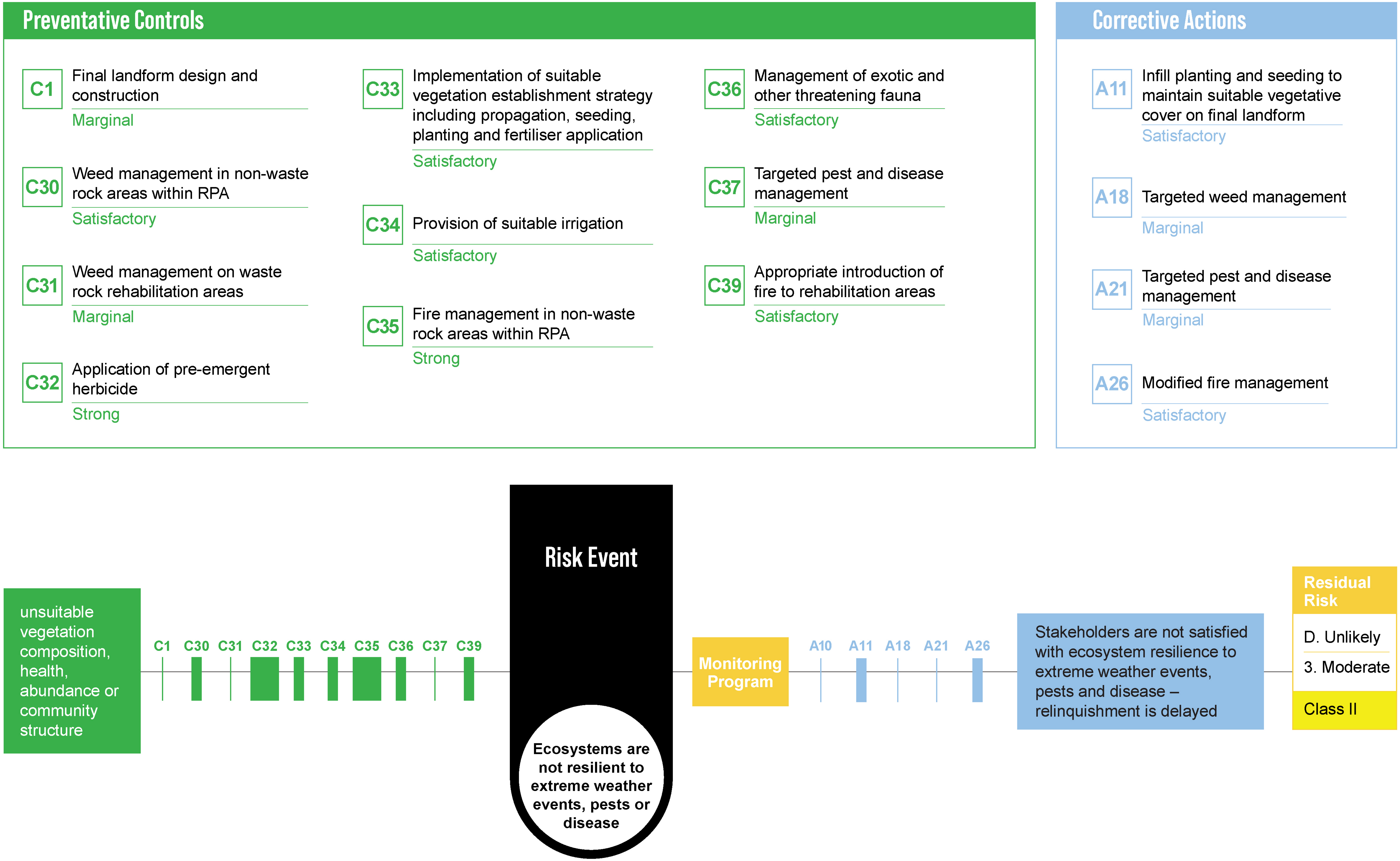


Figure 9-8: Bow-tie diagram for resilience to other disturbances (ES5)

Preventative Controls

C1 Final landform design and construction
Marginal

C30 Weed management in non-waste rock areas within RPA
Satisfactory

C31 Weed management on waste rock rehabilitation areas
Marginal

C32 Application of pre-emergent herbicide
Strong

C33 Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C36 Management of exotic and other threatening fauna
Satisfactory

C37 Targeted pest and disease management
Marginal

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

Corrective Actions

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Marginal

A21 Targeted pest and disease management
Marginal

A26 Modified fire management
Satisfactory

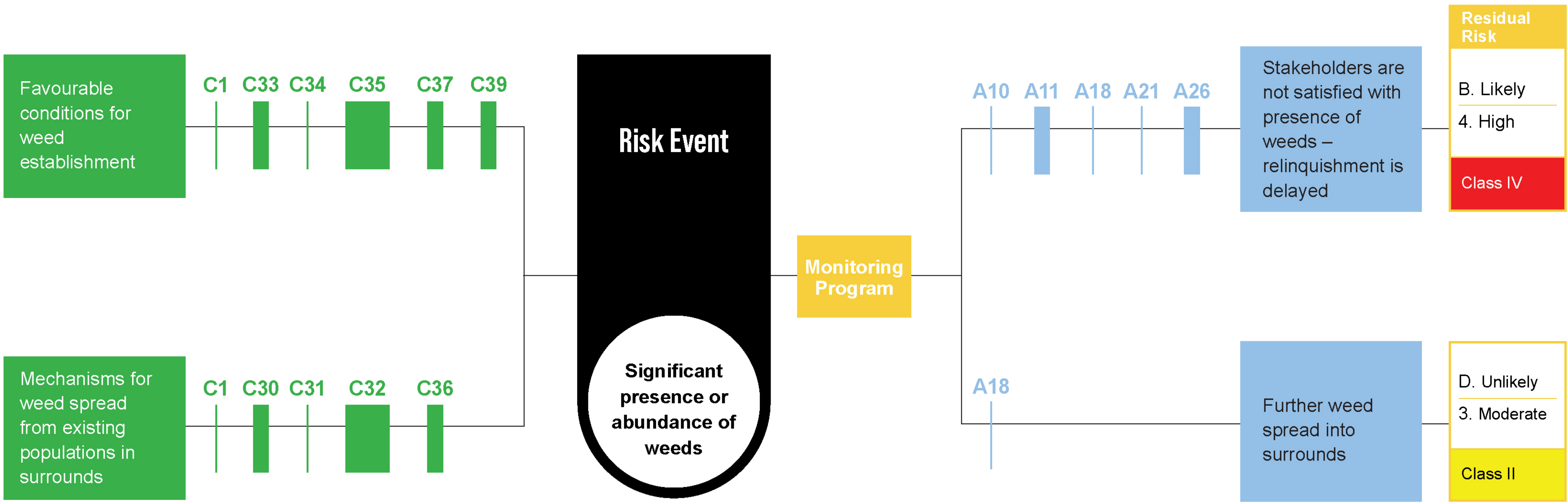


Figure 9-9: Bow-tie diagram for significant presence or abundance of weeds (ES6)

Preventative Controls

C1	Final landform design and construction	Marginal
C30	Weed management in non-waste rock areas within RPA	Satisfactory
C31	Weed management on waste rock rehabilitation areas	Marginal
C32	Application of pre-emergent herbicide	Strong
C33	Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application	Satisfactory
C34	Provision of suitable irrigation	Satisfactory
C35	Fire management in non-waste rock areas within RPA	Strong
C36	Management of exotic and other threatening fauna	Satisfactory
C39	Appropriate introduction of fire to rehabilitation areas	Satisfactory

Corrective Actions

A2	Undertaking earthworks to repair significant gullying or eroded areas	Satisfactory
A11	Infill planting and seeding to maintain suitable vegetative cover on final landform	Satisfactory
A18	Targeted weed management	Marginal
A19	Targeted exotic fauna management	Satisfactory
A26	Modified fire management	Satisfactory

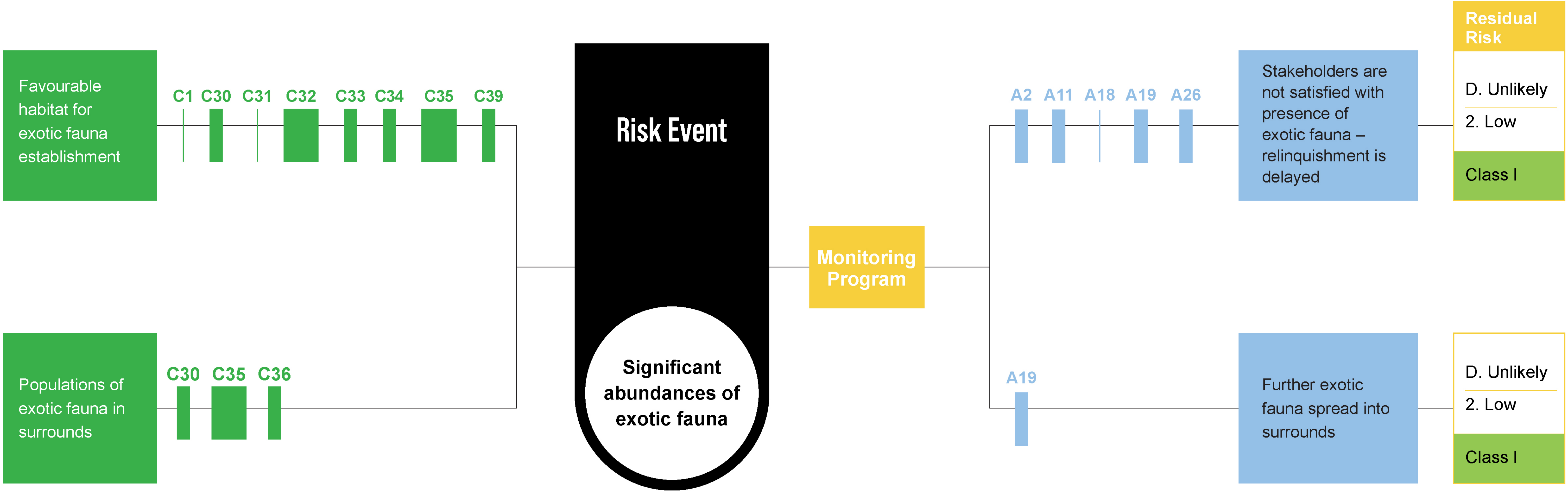


Figure 9-10: Bow-tie diagram for significant abundances of exotic fauna (ES7)

9.5 Preventive Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well ERA understand and can demonstrate the effectiveness of the controls that will be put in place between now and the creation of the final landform, or shortly thereafter (thus termed preventative controls), to ensure that the ecosystem ERs can be achieved or are on the desired trajectory to being achieved. The spider web diagram at the beginning of this chapter assigns a subjective 40% complete for the progress status relating to preventative controls and their effectiveness. This is possibly a little conservative as ERA have demonstrated considerable success in collecting and propagating local provenance plant species, establishing these species on waste rock (particularly on the TLF and Pit 1), and weed management controls are widely proven and well established. However, the 40% progress reflects the current uncertainty in the effectiveness of the controls proposed to manage the threats identified to establishing ecosystem similarity and sustainability. The threats that relate to the following controls are shown in the bow-tie diagrams above. Table 9-7 outlines preventative controls along with status and effectiveness. The table is followed by a brief discussion of each.

Table 9-7: Preventative Controls for Ecosystem

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C1	Final landform design and construction	Marginal	Confidence around the suitability of a minimum growth layer thickness of 6 m, with at least 25% fines content is well progressed. However, there remains uncertainty regarding the preparation of cut-to areas and the suitability of backfill material. Further investigations will be conducted.
C30	Weed management in non-waste rock surrounds within RPA	Satisfactory	There is an active, accepted and successful current weed management program.
C31	Weed management on waste rock rehabilitation areas	Marginal	Compared with remnant vegetation, ERA has less experience with weed management in revegetated areas, where selective and species-specific application of herbicides is more important. Effectiveness will be increased with further planning, including methods for removal of existing weed cover and implementation at scale.
C32	Application of pre-emergent herbicide	Strong	This control has seen demonstrated success at Pit 1, with high confidence in the methodology to be applied to subsequent areas.
C33	Implementation of suitable vegetation establishment strategy, including propagation, seeding, planting and fertiliser application	Satisfactory	Establishment of the majority of dominant and important species has been demonstrated on waste rock and other substrates. However, there are remaining uncertainties for some species and particular methods for propagation and establishment. Understanding and effectiveness will increase with continued monitoring of current trials, and additional targeted trials for particular species.
C34	Provision of suitable irrigation	Satisfactory	Considerable learnings have been gained from previous application, however the effectiveness will be improved with further refinement of the pre-planting hand over process. This ensures appropriate irrigation infrastructure and pump capacity.

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
C35	Fire management in surrounds within RPA	Strong	This control is well understood and actively managed as per the annual *Fire Management Plan*.
C36	Management of exotic and other threatening fauna	Satisfactory	Although there is an active, accepted and successful current program, effectiveness is expected to improve with advancements in regional understanding and research.
C37	Targeted pest and disease management	Marginal	Previous application demonstrated some effectiveness, however ongoing monitoring outcomes will improve understanding in regard to the importance and effectiveness of this control for further application on rehabilitation areas.
C38	Addition of organic materials from surrounds	Marginal	Whilst collection of organic materials from surrounds may be feasible, further consideration is required with regards to the environmental impact should this occur at a larger scale.
C39	Appropriate introduction of fire to rehabilitation areas	Satisfactory	With two trial burns applied to the TLF this control is well understood and expected to be further improved with long-term implementation and monitoring.
C41	Installation of appropriate habitat	Marginal	Installation of artificial habitat features may have some merit but is considered of lower importance than other preventative controls, such as suitable vegetation establishment. Further monitoring of constructed nest boxes and rockpiles will help to inform this.
'Knowledge-based / Administrative' controls			
C29	Development of appropriate vegetation CRE	Satisfactory	Whilst the largely dominant Savanna Woodland CRE is well developed, other CRE types (e.g. seasonally inundated savanna, riparian) require further development.
C40	Development of appropriate fauna CRE	Satisfactory	Whilst studies have been conducted around actual reference populations, further work is required to understand appropriate fauna reference populations that may return to the proposed final landform vegetation communities.

9.5.1 Final landform design and construction

The studies relating to this control are described in Section 9.3.1.2, with the effectiveness considered to be marginal. Confidence around the suitability of a minimum growth layer thickness of 6 m, with at least 25% fines content is well progressed, however there remains uncertainty regarding the preparation of cut-to areas. Further investigations will be conducted regarding material sourcing for infill areas and appropriate treatment for cut-to areas.

9.5.2 Weed management in non-waste rock surrounds within RPA

ERA currently manages weeds according to the *Weed Management Act 2001* (NT) and ER 2.2 (a), with outcomes and plans reported annually in the Weed Control Program.

One particular species (*Spigelia anthelmia*) is managed separately. 'Spigelia' was identified on the RPA in 2019, and immediately reported, which was the first known occurrence of this weed in Australia. Due to the significance of this, and a substantial abundance of the species across disturbed areas of the RPA, ERA has committed to eradication, with progress and planning reported annually in the Spigelia Weed Management Report, the most recent of which was finalised in July 2023 (ERA, 2023a).

The effectiveness of this control is considered to be satisfactory. There is an active, accepted and successful weed management program.

9.5.3 Weed management on waste rock rehabilitation areas

Effectiveness for the control is considered to be marginal, and will be increased with further planning, and implementation at scale.

Due to safety requirements, access restrictions and regular movement of materials by heavy machinery, weed management on waste rock and active 'operational' areas has not occurred historically. The planned bulk material movement and construction of the waste rock final landform over the coming years will introduce considerable disturbance to current weed populations and has the potential to spread weeds across the final landform surface. Conversely, it could bury much of the weed seed bank to depths that would make the seeds unviable. For example, some existing weed populations will require treatment prior to disturbance, some may be carefully scalped and disposed, and for others there may be opportunity to bury beneath backfill.

For the Stage 13.1 and Pit 1 research trials, weed populations within 200 m of proposed planting areas were treated in the preceding seasons. These areas were termed 'weed buffer zones', with the purpose being to reduce movement of weed seed onto planting areas. The inclusion of previously unmanaged waste rock areas into annual weed control programs will help to maintain a similar approach for future planting areas.

The current plan with regards to weed management is to intensify the treatment of weeds over the next few years before bulk material movement commences in earnest. Even with the effective implementation of this, weed incursion over planting areas will require ongoing management. If this is executed well and consistently in the earlier years, rates of colonisation will be reduced, and management intensity may be reduced in later years. Conversely, if the presence of weed and weed seed is not managed well, particularly during the initial stages of revegetation, active management is likely to substantially increase in later years and may contribute to decreased resilience of establishing vegetation to fire and other disturbances.

Procedures to prevent the spread of weeds are integrated with the project culture. These are most applicable during the early stages of revegetation, where bare areas are less resilient to weed colonisation, and may be strategically removed over time.

Administrative elements include enforced weed and seed checks for persons, vehicles and machinery, as well as education/awareness campaigns including basic weed and seed identification, causes of weed spread and potential impacts. Design elements include fences and lockable gates around rehabilitation areas, stop/check-point signs as well as vehicle washdown and/or bootwash stations at access points.

Compared to weed management in remnant vegetation, such as in the non-waste rock surrounds, ERA has less experience with weed management in revegetated areas, where selective and species-specific application of herbicides is more important. Further research into management methodologies, and the establishment of targeted training courses for environmental officers and contractors will be essential for continued success.

9.5.4 Application of pre-emergent herbicide

For most areas of Stage 13 and Pit 1, Cavalier (a pre-emergent herbicide with active ingredient Oxyfluorfen at 240 g/L) was applied evenly at a rate of approximately 1.9 L/ha, either under irrigation or during the wet season, a minimum of two weeks prior to planting. The active ingredient in this herbicide kills seedlings upon germination and can be very effective in preventing colonisation of bare surfaces. To optimise effectiveness, the substrate surface was not disturbed for at least two weeks following application, and germination of the weed seeds was encouraged (via irrigation and/or seasonal rainfall). In areas where this wasn't applied, the effect has been clear, with substantially increased weed cover, competition with establishing vegetation and ongoing management required.

For subsequent areas of the final landform, a similar methodology will be applied during the wet season following construction of the surface layer, and prior to planting. A period of time will need to be allowed between application of a pre-emergent herbicide and planned direct seeding activities. At this stage, considering typical rates of decomposition, a conservative approach of at least four weeks is proposed.

In addition to the application of pre-emergent herbicide, emergent weeds will be treated with appropriate short acting herbicides prior to planting. With demonstrated success and high confidence in the methodology, the effectiveness of this control is considered to be strong.

9.5.5 Implementation of suitable vegetation establishment strategy

There are a number of ongoing studies relating to this control, which are described in Section 9.3.1.3. The overall effectiveness is considered to be satisfactory, with demonstrated successful establishment for the majority of dominant and important species on waste rock and other substrates.

There are remaining uncertainties for some species and particular methods for propagation and establishment. Understanding and effectiveness will increase with continued monitoring of current trials, and additional targeted trials for particular species.

9.5.6 Provision of suitable irrigation

Due to the harsh environmental conditions and unreliable rainfall, initial irrigation for up to six months has proven to be essential for successful establishment of tubestock on waste rock, as indicated by trials at the TLF (Daws and Gellert, 2010, Daws and Gellert, 2011), Stage 13 and Pit 1. These trials have included networks of raised rotational sprinklers and a travelling large-scale pivot system, both with relatively gentle application so not to displace newly planted seedlings or substantially contribute to erosion of the new landform. Georgetown Creek Median Bund Leveline (GCMBL) was used as the water source for both the Pit 1 and Stage 13 trials, with regular water quality testing undertaken to indicate the suitability of water for irrigation.

The optimal regime will be unique for each area and influenced by rainfall patterns, season, substrate, temperatures, wind, evaporation, and infiltration rates. Irrigation should aim to optimise survival while ensuring appropriate root development and long-term resilience to drought conditions. Ongoing irrigation management is best informed by regular monitoring of vegetation response and may require maintenance and operation for up to six months.

Similar to what was applied at Pit 1, the following broad principles will be considered, at least for the establishment of a Savanna Woodland CRE:

- irrigation applied immediately prior, during (if practical) and following planting to cool surface temperatures and minimise planting shock (this may be achieved with a combination of automated irrigation and/or low pressure hoses);
- revegetation areas to receive up to 5 mm of irrigation every 12 hours immediately following planting to maintain moisture levels in the upper substrate profile;
- irrigation gradually reduced to nightly soaks over the course of a few weeks; and
- as plants begin to settle (i.e. post-planting mortality rate is stabilised with plants showing signs of new growth), less frequent, heavier soaks applied over several months, with the upper substrate profile partially drying in between.

Considering the learnings gained from previous applications, the overall effectiveness is considered to be satisfactory. This will be improved upon further application over subsequent areas of the final landform.

9.5.7 Fire management in surrounds within RPA

This control includes the maintenance of firebreaks and surrounding area fuel loads, particularly in early stages of ecosystem development, and is actively managed as per the annual Fire Management Plan. The overall control effectiveness is considered strong.

During operation, ERA's fire management was historically focussed on protecting assets from wildfire by maintaining fire breaks and conducting fuel reduction burns. In the years leading up to closure, the fire strategy has shifted to incorporate a greater focus on land management and rehabilitation across the site. With consultation from Kakadu Native Plant Supplies, the Fire Management Plan now incorporates wet season burning to deliver a patchwork mosaic of low and medium fuel loads across the RPA.

Early dry season burning (April to June) is conducted to reduce the intensity of potential fires and ultimately minimise the area burnt by wildfire each year. Weather is closely monitored throughout the burn season to identify favourable burn windows, and burning is typically not conducted from July to November due to the hotter conditions and variable winds.

Wet season burning (December to March) produces cooler fires that have less impact on the ecosystem. They also allow the fire teams to reduce fuel loads with minimal risk, as the burn moves more slowly and is less likely to cross containment lines. Carefully timed wet season burning can also be highly effective for reducing spear grass (*Sorghum spp.*) cover, which contributes to more intense fires if left unmanaged. Wet season burns not only offer an additional mechanism for the prevention of wildfires but also improve land accessibility for weed management and seed collection.

Over time, continued early dry season and wet season burns should improve groundcover biodiversity, overall health of the ecosystem and reduce the likelihood of intense fires to travel through and impact rehabilitation areas. This transition will be achieved through a multi-year fire management campaign during closure, driven by annual management plans. At the time of relinquishment, the surrounding areas should have transitioned to a state where frequent burning and firebreaks are no longer required to protect the rehabilitated landform. At this stage, fire management by future land managers will ideally be more ecologically driven, with fine-scale, patchy areas (mosaics) burnt at varying intervals.

9.5.8 Management of exotic and other threatening fauna

ERA currently manages exotic fauna in accordance with the *Northern Territory Parks and Wildlife Conservation Act 2006* and the ERA Feral Animal Management Plan, which was most recently revised in December 2020 (ERA 2020e). Active and responsive control methods include ground shooting, trapping, pesticides and/or removal.

Besides the four species listed in closure criteria, additional exotic and native fauna may also be managed under this plan, particularly where they present a threat to human health and safety, cultural heritage sites, establishing vegetation or other environmental factors. One example of this is the Browsing Ant (*Lepisiota frauenfeldi*). This species is a declared pest of National Significance and is currently managed by the NT government at Ranger.

The effectiveness of this control is considered to be satisfactory. Although there is an active, accepted and successful current program, effectiveness will be improved with increased understanding.

9.5.9 Targeted pest and disease management

Treatment with systemic insecticide has previously been implemented at the TLF on two occasions, where a species of wood moth (potentially *Maroga melanostigma*; Gellert, 2012) or longicorn beetle, (*Acalolepta mixtus*) and subterranean termite (*Mastotermes darwiniensis*; unreported, 2022) were suspected to have a substantial and potentially lasting impact to establishing vegetation. Monitoring has indicated effective declines for the target pests, however the impact of this practice on desirable invertebrate communities is not well understood.

Considering this, effectiveness is considered to be marginal. Ongoing monitoring outcomes will improve understanding in regard to the importance and effectiveness of this control for further application on rehabilitation areas.

9.5.10 Addition of organic materials from surrounds

The primary benefit of this control is increased species richness from imported seed and other complementary organic materials, however other benefits may include erosion control, habitat enhancement (particularly for invertebrates), nutrient cycling and weed suppression.

Effectiveness is considered to be marginal. Whilst collection of organic materials from surrounds may be feasible, further consideration is required with regards to the environmental impact should this occur at a larger scale.

9.5.11 Appropriate introduction of fire to rehabilitation areas

Two trial burns have so far been applied to the TLF, where laterite was mixed with waste rock material and contributed to increased weed loads. Key learnings have been applied to the current understanding of resilience mechanisms, as well as weed management and vegetation response (Wright, 2019a; 2019b). and will be considered in the planning of subsequent controlled burns on a variety of substrates.

The introduction of fire is discussed further in Section 9.3.4. As rehabilitation areas mature (estimated 10-15 years), trial burns will be introduced after careful consideration of weather conditions, fuel load, specific burn methods and monitoring data from previous burns in consultation with relevant stakeholders.

Learnings at this stage will be incorporated into management plans and in the longer term, contribute to the gradual introduction of an appropriate fire regime, with a focus on purposeful burns and desired burn patterns, in partnership with Traditional Owners and traditional knowledge. Eventually, firebreaks can be removed and a regime that is similar to the surrounds will be extended to rehabilitation areas.

Overall effectiveness is considered to be satisfactory and expected to be further improved with long-term implementation and monitoring.

9.5.12 Installation of appropriate habitat

The studies relating to this control are described in Section 9.3.2.2. Installation of artificial habitat features may have some merit but is considered of lower importance than other preventative controls, such as suitable vegetation establishment. The effectiveness of nest boxes and/or rockpiles is considered to be marginal, with further monitoring of constructed nest boxes and rockpiles expected to improve understanding.

9.5.13 Development of appropriate vegetation CRE

The studies relating to this control are described in Section 9.3.1.1 with effectiveness considered to be satisfactory. Whilst the largely dominant Savanna Woodland CRE is well developed, other CRE types (e.g. seasonally inundated savanna, riparian) require further development.

9.5.14 Development of appropriate fauna CRE

The studies relating to this control are described in Section 9.3.2.1, with effectiveness considered to be satisfactory. Whilst studies have been conducted around actual reference populations, an understanding of particular fauna that may return to the final landform will improve with further monitoring of revegetation areas.

9.6 Monitoring Program

A detailed monitoring program for the established final landform ecosystems is imperative for understanding processes and the timing of adaptive management through corrective actions (this is the focus of KKN ESR9A, Appendix 5.1). The program will continue throughout the post-closure phase until results demonstrate that all closure criteria have been satisfied or are on the trajectory to being satisfied, and close-out certificate/s are obtained for the entirety of the RPA. A nominal timeframe for this is currently 25 years following the completion of the final landform.

The spider web diagram presented at the start of the chapter assigns a subjective 60% complete for the progress status relating to ‘monitoring program’. This is reflective of the significant program that is already underway in areas such as the TLF, Pit 1, Stage 13 and more recently Stage 52, but also recognising that further development and implementation of appropriate methodologies and spatial extents is needed.

In addition to that described below, monitoring is also undertaken for the purposes of specific research trials (e.g. particular treatments applied to groups of plantings on Pit 1), as well as quality control and quality assurance (e.g. nursery produced tubestock).

9.6.1 Adaptive management monitoring

The purpose of this type of rapid assessment monitoring is to detect early signs of trajectory deviation or threat, across large spatial extents. Regular monitoring will be needed until the developmental trajectory can be seen to be steadying and the risk of deviation and requirements for active management and corrective action are sufficiently reduced. Monitoring frequencies for adaptive management monitoring will decrease over time, with consideration of the following indicative timeframes:

- Monthly/bimonthly for the first six months;
- Monthly/bimonthly (wet season) to quarterly (dry season) from six months to three years;
- bimonthly (wet season) to quarterly (dry season) from three years to five years; and
- quarterly from five years until relinquishment (depending on seasonal factors).

Data from rapid adaptive management monitoring will be used to update and improve knowledge around appropriate CREs, trajectories, substrate suitability, revegetation strategy and introduction of fire. It will also inform effective management of weeds, exotic fauna, pests and disease. The methodology for adaptive management monitoring is still under development, in consultation with stakeholders and external subject matter experts.

A regular, rapid-assessment, adaptive management monitoring program allows for triggers and signs of potential deviation to be identified early on, which allows for corrective actions and remediation activities to be implemented early where required, which is reflected in the preliminary TARP (Section 9.8).

9.6.2 Vegetation ground surveys and habitat monitoring

The purpose of this type of monitoring is to understand the status and trajectory of vegetation composition, abundance and community structure, as well as indicators of habitat formation across defined spatial extents. Monitoring will be undertaken at an indicative three-year frequency, commencing at year one (year one will be staggered across the final landform as it will reflect the first year that each area achieving final landform has been planted). From year 12 on, the frequency of monitoring in each area of the final landform will reduce to every five years until the relinquishment of the RPA. Plot size and density for this type of monitoring will be confirmed as rehabilitation areas progress.

Recorded data for each woody stem may include differential GPS tagging, species identification and diameter at breast height (DBH: 1.5 m). Recorded data for non-woody species (understorey) may include species identification and percentage ground cover. Habitat formation indicators are to be confirmed after further discussion and consultation with stakeholders.

Quantitative data will be compared with closure criteria and plotted to inform trajectory modelling, so consistent methodology is important.

9.6.3 Multispectral machine learning data capture

Data from vegetation ground surveys can be used to improve machine learning datasets, and general compositions across the entire landform may be assessed with a level of certainty that is expected to increase over time.

In 2022, Dendra (a company specialising in remote-sensing for broadscale landscape monitoring) was engaged to apply this method to revegetation on the TLF, Pit 1 and surrounding disturbed areas within the RPA. Results so far have indicated value, allowing plant identification of more mature vegetation to at least a genus level, but there remains an unsuitable level of uncertainty at this point in time. It is acknowledged that this technology is currently in the early stages of development, and with further advancement, may eventually be a suitable replacement for some components of ground-based monitoring.

With regard to weed monitoring, the Dendra survey proved effective for the remote detection of *Acacia holosericea* populations and is considered to be suitable for this purpose. In future, this method may be applied for other weed species with a suitably distinct presence and unique spectral signature.

Indicative timing at this stage for the multispectral remote sensing is to start at three years, and then conduct the monitoring every three years during late dry (when flowering and spectral signature is optimal) until relinquishment. This timing however is based on presumed improvements in technology.

9.6.4 Image and/or LiDAR capture

When combined with ground-based survey methods, aerial imagery and LiDAR data can be used to assess a range of ecosystem establishment parameters, with the benefit of whole of site coverage in a timely and cost-effective manner. Aerial imagery data at early stages provides an indication of early ground cover and surface stability, as well as general health of establishing vegetation. At later stages, LiDAR provides increased confidence in the trajectory of size class distribution and canopy cover across the landform.

Contextual data can also be collected, for example through the use of thermal imagery to identify operational issues (e.g. leaks in irrigation systems) and environmental variables (e.g. soil surface temperature) that affect plant survival, health and growth.

It is expected that this type of monitoring will occur quarterly for the first five years after landform construction, reducing to biannually (wet and dry season) until relinquishment.

9.6.5 Litter decomposition and nutrient cycling monitoring

Monitoring of microbial communities, soil organic carbon/nitrogen, mineral nitrogen and soluble organic nitrogen will be conducted once after final landform preparation and five yearly thereafter, providing an understanding of the development of nutrient cycling processes over time. An appropriate spatial extent for sampling locations has not yet been determined.

Additionally, an assessment of rates of litter decomposition will be conducted at the same frequency. The specific method for this assessment has not yet been determined.

9.6.6 Mammal, bird and reptile monitoring

The purpose of this type of monitoring is to understand the status and trajectory of mammal, bird and reptile composition and abundance, including exotic species. Monitoring methods are still to be confirmed, however should allow for systematic and repeatable surveys and collection of suitable species specific abundance data.

Currently applicable methodologies may include diurnal (day) bird surveys, microbat surveys (trapping and echolocation), diurnal herpetofauna surveys, spotlighting surveys, call playback surveys, remote camera surveys and fauna trapping. Advances in technology (e.g. omics – which in broad terms studies the structure, function and mapping of genomes) may provide opportunities for alternative methodologies in the future.

As fauna colonisation is likely to occur progressively after the completion of the final landform area as vegetation establishes, monitoring will commence at five years after initial revegetation, and continue at five-year intervals until relinquishment.

9.6.7 Ant monitoring

The purpose of this monitoring is to understand the status and trajectory of ant populations, as they provide an important functional role for natural processes.

Ant monitoring will be conducted with a methodology consistent to that described by Oberprieler and others (2020), commencing at five years after initial revegetation and at five-year intervals thereafter until relinquishment.

Considering the presence of brown browsing ants and the active management undertaken by the NT government at Ranger, there is a possibility that active monitoring and management of exotic invertebrates will also be included.

9.6.8 Planned fire regime monitoring

The purpose of this type of monitoring is to understand the impact of managed fire on vegetation composition, abundance and structure, ground cover, nutrient cycling and other habitat features. Resilience and response of the developing ecosystem will be considered in the gradual implementation of an appropriate fire regime.

Pre and post fire monitoring methods applied at the TLF (Wright, 2019a, Wright, 2019b) and at Jabiluka in 2022 and 2023 (in collaboration with University of Queensland PhD candidates Kate Harries and Phil McKennan) included:

- quantitative ground cover assessment, including estimated fuel loads and post-fire recovery;
- midstorey and overstorey height and DBH, char and scorch heights and post fire recovery (e.g. observations around health, reshooting);
- drone imagery to map extent;
- field rating of fire severity using standard photographic references; and
- fauna observations (including invertebrates).

These methodologies will be considered for similar monitoring of future planned fires. Depending on the planned and actual extent of the prescribed burn, appropriate sampling densities will be determined in consultation with subject experts.

9.6.9 Resilience monitoring

For significant disturbance events (e.g. extreme weather, pests, disease or wildfire), an impact assessment and ongoing recovery monitoring plan will be developed, with corrective actions considered where appropriate.

The methods described above for fire regime monitoring may also apply to post wildfire or disturbance event monitoring. Depending on the nature of disturbance, additional components may include:

- qualitative and/or quantitative assessment of impacted flora and fauna;
- novel techniques to detect pests and disease; and/or
- physical characteristics of substrate and/or root profile at depth.

Appropriate sampling densities will be determined in consultation with stakeholders.

9.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subjective 50% complete for the progress status relating to ‘corrective actions’. This reflects considerable uncertainty around the effectiveness of weed management and several other corrective actions, which is expected to improve when the re-established ecosystem is sufficiently mature and corrective actions are implemented (if needed).

The monitoring program described in Section 9.6 will be used to detect potential deviations or threats, which will trigger further investigation. Clear deviations in trajectory may trigger a number of corrective actions. These are described in Table 9-8, along with status and effectiveness. The table is followed by a discussion of each.

Table 9-8: Corrective Actions for Ecosystem (all 'Active' Corrective Actions)

Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
A2	Undertaking earthworks to repair significant gullying or eroded areas	Satisfactory	Landform reshaping is a common operational practice and although rework after several years of establishment is not an appealing option, it is well understood.
A11	Infill planting and seeding to maintain suitable vegetative cover on final landform	Satisfactory	Methods are well understood and have previously proven successful, with effectiveness expected to be improved with further implementation at scale.
A18	Targeted weed management	Marginal	Although this action is well understood, demonstrated effectiveness is poor for weed dominated areas such as those at the TLF. Effectiveness is expected to improve with further implementation.
A19	Targeted exotic fauna management	Satisfactory	This action is well understood, and effectiveness will be improved upon implementation, if required.
A20	Addition of organic materials and/or fertiliser beyond that planned	Marginal	This action is understood to be potentially beneficial for a range of scenarios. Effectiveness will be improved with implementation at scale, if required.
A21	Targeted pest and disease management	Marginal	Previous application has demonstrated some effectiveness, however ongoing monitoring outcomes will improve understanding in regard to the importance and effectiveness of this corrective action.
A26	Modified fire management	Satisfactory	This action is well understood, proven and will be implemented as required.
A22	Supplementation of habitat features and/or migration corridors	Marginal	With fauna return expected to take some time, this action will only be considered in extreme circumstances, and is expected to improve with further planning and implementation, if required.

Undertaking earthworks to repair significant gullying or eroded areas

As observed in particular areas of Stage 13 and Pit 1, variations in topography and substrate can lead to deviations in vegetation composition, abundance and structural trajectory. Relative to the extent of an unplanned deviation from the target CRE, re-clearing of established vegetation and further corrective earthworks may be required.

Landform reshaping is a common operational practice and although rework after several years of establishment is not an appealing option, effectiveness is considered to be satisfactory.

Infill planting and/or seeding of desirable species

Infill planting may be required to correct vegetation composition and abundance that has been impacted by unforeseen factors and other threatening processes, such as variations in substrate or competition with weeds. Depending on the extent, access restrictions may require manual 'hand' digging of planting holes, aligned with the monsoon period and use of water crystals (where irrigation cannot be applied). It is also likely that vegetative ground cover will require targeted removal (e.g. via herbicide, burning and/or slashing) to avoid competition with newly planted seedlings.

With methods well understood and previously proven successful, the effectiveness of this action is considered to be satisfactory. This will be improved with further implementation at scale.

Targeted weed management

This action may be required where planned weed management fails to manage source populations of weeds and weed seed on rehabilitation areas, leading to further spread and potential encroachment into surrounding areas and Kakadu National Park. Methods may include increased application (frequency, extent) of herbicide and/or fire for significant and threatening weed populations.

At the TLF, weeds have been an ongoing issue, particularly in areas mixed with laterite material, with a requirement for ongoing management. Daws and Poole (2010) concluded that a substantial weed seed bank was introduced with the laterite material used in constructing parts of the TLF, which has contributed to what is considered to be a deviated (weed dominated) state. As well as ongoing application of herbicide to affected areas, two controlled burns were trialled in 2016 and 2019 (Wright, 2019a, 2019b) to reduce weed cover, and particularly that of *Acacia holosericea*. Although immediately effective, without follow-up management weed populations were observed to return rapidly.

For consideration in future application of fire for targeted weed management, herbicide suppliers have advised that the presence of ash may reduce the effectiveness of pre-emergent herbicides, so application of short acting herbicides to new seedlings post-fire is likely to be the most effective follow-up treatment.

Increased herbicide application may also present implications to catchment water quality, prompting investigation into alternative practices and/or additional water treatment.

Although this action is well understood, demonstrated effectiveness is poor for weed dominated areas such as those at the TLF. Effectiveness is currently considered to be marginal, however with further implementation, is expected to improve.

Targeted exotic fauna management

This action may be required where planned exotic fauna management fails, potentially leading to breeding populations in rehabilitation areas, further spread and potential increased populations in surrounding areas and Kakadu National Park.

Considering current understanding of control methods, effectiveness is considered to be satisfactory. This will be improved upon implementation, if required.

Addition of organic materials and/or fertiliser beyond that planned

Beyond that proposed as a preventative control, this action may be beneficial when combined with other controls for correction of deviated vegetation species richness, habitat (particularly for invertebrates), nutrient cycling and weed abundance. Commercial fertilisers may also be used in combination with organic materials to aid vegetation establishment from an imported seedbank, enhance vegetation growth or improve nutrient cycling processes.

Effectiveness considered to be marginal, and may be improved with implementation at scale, if required.

Targeted pest and disease management

In the context of a deviated ecosystem that is not resilient to pests and disease, this action relates to targeted treatment and facilitation of recovery.

This action is also referred to as a preventative control, with effectiveness considered to be marginal.

Modified fire management

Exclusion of fire from rehabilitation areas

In the event that ecosystems are proven to be non-resilient to fire, exclusion of fire is essential until resilience mechanisms can be restored.

This action is also referred to as a preventative control, with effectiveness considered to be strong.

Strategic introduction of fire

This action is also referred to as a preventative control, with effectiveness considered to be satisfactory.

Following the implementation of other corrective actions and the restoration of fire resilience, the strategic introduction of fire over time will continue to strengthen those resilience mechanisms.

Supplementation of habitat features and/or migration corridors

It is most likely that delays with fauna return will be corrected passively over time, and no active intervention other than maintaining the establishing ecosystems is required. In some circumstances however, active improvement of migration corridors and/or construction of additional habitat features, such as nest boxes, rock piles, imported logs and other structures, may be considered.

Effectiveness considered to be marginal and is expected to improve with further planning and implementation, if required.

9.8 Trigger, Action, Response Plan

Due to the relatively slow timeframes for ecosystem establishment, most of the closure criteria are described with reference to expected trajectories towards reference ecosystems. Therefore, detailed descriptions of states along these trajectories are required for comparison, with TARPs designed for practical adaptive management (this is the focus of KKNs ESR1C and ESR5B, Appendix 5.1).

A preliminary, conceptual state and transition (S&T) model for Ranger was previously developed by scientific, industry and local ecology experts at a workshop held in April 2019 (Richards *et al.,* 2020). Unearthed Environment Services Pty Ltd (UES) were subsequently engaged by ERA to critically review and revise this model and develop a more 'fit-for-purpose' S&T model (Grant and Grant, 2023). The revised model is intended as a practical management tool to help drive rehabilitated areas along the desired successional trajectory towards the identified end state.

With consideration of the current S&T model presented by Grant and Grant (2023), proposed closure criteria and reference site data, a TARP has been developed for the proposed Savanna Woodland CRE (as described in Section 9.3.1.1) and is presented in Table 9-9. It is acknowledged that there are remaining gaps and a lack of specificity for some triggers, which will be further developed upon implementation and included in subsequent iterations of the MCP.

Notably, this TARP is reliant on a single trigger level, which was the approach suggested by Grant and Grant (2023). This approach is based on the detection, investigation, and correction of deviations at an early stage. The bow-tie diagrams presented in Section 9.4 may be used to guide investigation into causes and relevant corrective actions.

The development of similar TARPs for other CREs (e.g. seasonally inundated savanna) will also be established for future iterations of the MCP.

Table 9-9: Trigger, Action, Response Plan for Savanna Woodland CRE

Rehabilitation Age	Normal State	Triggers
Post planting (0-6 months)	Monitoring indicates: • Appropriate composition and relative abundance for relevant planting/seeding list, considering topography and substrate. • At least 75% surviving tubestock per hectare, in good health.	Monitoring indicates: • Inappropriate composition or relative abundance for relevant planting/seeding list, considering topography and substrate. • Less than 75% surviving, or of poor health, tubestock per hectare. • Presence of erosion is considered to be increasing. • Presence of weeds is considered to be increasing.
Years 1–2	Monitoring indicates: • Early separation of overstorey strata from ground cover. • At least 650 surviving overstorey/midstorey stems/ha (up to 3 m). • 5–20% groundcover spreading from planted/seeded understory species.	Monitoring indicates: • Less than 650 healthy overstorey/midstorey stems/ha included stunted Eucalyptus. • Less than 5% groundcover and/or presence of erosion. • Greater than 20% grass cover spreading from planted/seeded species, that competes with establishing trees. • Weed cover greater than 5% or locally increasing.
Year 5	Monitoring indicates: • Clear stratification of vegetation. • 500-700 overstorey/midstorey stems/ha (up to 5 m), in good health with appropriate composition/abundance relative to CRE. • Vegetative ground cover of 20-60% with recruitment of additional understorey species increasing richness to >25 species/ha with appropriate composition relative to CRE. • Early vertebrate colonisation with presence of some adaptable species. • Presence of invertebrate diversity (e.g. ants, grasshoppers, termites, beetles, wasps, spiders). • Evidence of nutrient cycling.	Monitoring indicates: • Limited stratification. • Less than 500 or more than 700 healthy overstorey/midstorey stems/ha and/or inappropriate composition/abundance relative to CRE (e.g. proportion of *Acacias*). • Less than 20% groundcover and/or presence of erosion. • Greater than 60% grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Understorey richness less than 25 species/ha or with inappropriate composition relative to CRE. • Lack of early vertebrate/invertebrate colonisation. • Limited evidence of nutrient cycling. • Weed cover greater than 10% or locally increasing. • Presence of exotic fauna, pests or disease.

Rehabilitation Age	Normal State	Triggers
Year 10	Monitoring indicates: • Clear stratification of vegetation with increasing heterogeneity. • 400-900 overstorey/midstorey stems/ha (dominant trees are 5–10 m, 5–10 cm DBH), in good health with appropriate composition/abundance relative to CRE. Most flowering and fruiting with some recruitment. • Vegetative ground cover of 20–60% with recruitment/ introduction of additional niche understorey species increasing richness to >30 species/ha with appropriate composition relative to CRE. • Increasing vertebrate richness with additional specialist species (>20 bird species). • Increasing invertebrate richness (e.g. ants, grasshoppers, termites, beetles, wasps, spiders), with high abundance of Iridomyrmex ants. • Evidence that nutrient cycling processes are increasing, aligned with increased accumulation of leaf litter and coarse woody debris.	Monitoring indicates: • Limited stratification and/or heterogeneity. • Less than 400 or more than 900 overstorey/midstorey stems/ha and/or inappropriate composition/abundance relative to CRE (e.g. proportion of *Acacias*). • Limited flowering/fruiting. • Less than 20% groundcover, lack of accumulated organic materials and/or presence of erosion. • Greater than 60% grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Understorey richness less than 30 species/ha or with inappropriate composition relative to CRE. • Vertebrate/invertebrate richness is not increasing. • Evidence that nutrient cycling processes are not developing appropriately. • Weed cover greater than 10% or locally increasing. • Presence of exotic fauna, pests or disease.
Year 15	Monitoring indicates: • At least three vegetation strata with moderate heterogeneity. • 300-1100 overstorey/midstorey stems/ha (dominant trees are 10-15 m, 10-20 cm DBH), in good health with appropriate composition/abundance relative to CRE. Most flowering and fruiting with increased recruitment. • Vegetative ground cover of 20-60% with recruitment/introduction of additional niche understorey species increasing richness to >35 species/ha and appropriate composition relative to CRE. • Increasing vertebrate/invertebrate richness and abundance. • Evidence that nutrient cycling processes are stabilising and supporting sustainable growth.	Monitoring indicates: • Less than three strata and/or limited heterogeneity. • Less than 300 or more than 1100 overstorey/midstorey stems/ha and/or inappropriate composition/abundance relative to CRE (e.g. proportion of *Acacias*). • Limited flowering/fruiting/recruitment. • Less than 20% groundcover, lack of accumulated organic materials and/or presence of erosion. • Greater than 60% grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Understorey richness less than 35 species/ha or with inappropriate composition relative to CRE. • Vertebrate/invertebrate richness/abundance is not increasing. • Evidence that nutrient cycling processes are not developing appropriately. • Weed cover greater than 10% or locally increasing. • Presence of exotic fauna, pests or disease.

Rehabilitation Age	Normal State	Triggers
Year 25+	Monitoring indicates: • At least three vegetation strata with moderate heterogeneity. • 150-1300 overstorey/midstorey stems/ha (dominant trees are 15-25 m, 20-40 cm DBH, 10-50% canopy cover), in good health with appropriate composition/abundance relative to CRE. Most flowering and fruiting and recruiting to fill gaps. • Vegetative ground cover of 20-60% with recruitment/introduction of additional niche understorey species increasing richness to >40 species/ha and appropriate composition relative to CRE. • Increasing vertebrate richness and abundance. • Increasing invertebrate richness and abundance with several distinct ant taxonomic groups. • Evidence that nutrient cycling processes are stabilising and supporting sustainable growth.	Monitoring indicates: • Less than three strata and/or limited heterogeneity. • Less than 150 or more than 1300 overstorey/midstorey stems/ha and/or inappropriate composition/abundance relative to CRE (e.g. proportion of *Acacias*). • Limited flowering/fruiting/recruitment. • Less than 20% groundcover, lack of accumulated organic materials and/or presence of erosion. • Greater than 60% grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Understorey richness less than 40 species/ha or with inappropriate composition relative to CRE. • Vertebrate/invertebrate richness/abundance is not increasing and/or expected taxonomic groups are not present. • Evidence that nutrient cycling processes are not developing appropriately. • Weed cover greater than 10% or locally increasing. • Presence of exotic fauna, pests or disease.

Responsible Person	Action/Response	Action/Response
Site Environmental Officer (or delegate)	Continue to monitor the trajectory of establishing vegetation towards the agreed ecosystem(s) until relinquishment, as per monitoring program.	Increase monitoring effort to determine contributing causes and extent, and likely trajectory path. Implement corrective actions as required, and continue with increased monitoring until return to desired trajectory.

9.9 Future Work

The spider web diagram at the beginning of this chapter provided a subjective progress status for the ecosystem theme. Where <100% is indicated, future work is occurring, planned and/or required. The following outlines the future work for each of the metrics shown in the spider web diagram.

With regards to closure criteria (80%, Section 9.1), Ministerial approval is required following considerable updates. Following this, further development of the following components is required:

- S&T models, considering proposed CRE, and quantitative indicators for flora, fauna and habitat at specific points in time;
- typical litter decomposition rates for northern savanna ecosystems;
- post-fire mortality rates for overstorey species in reference ecosystems;
- presence and abundance of Class B weeds in the reference ecosystem 'at a landscape scale'; and other introduced flora in adjacent areas of Kakadu National Park; and
- abundance of: i) buffalo; ii) horses; iii) pigs; and iv) cats in adjacent areas of Kakadu National Park.

With regards to relevant studies and knowledge base (70%, Section 9.3), required additional work includes:

- Further development of the Savanna Woodland CRE, particularly regarding fauna and understorey composition.
- Development of proposed additional CRE, including 'seasonally inundated savanna', 'riparian' and a potential RWD alternative, with integration of these into the SERP and identification of data gaps and requirements for future research trials in these areas.
- Further investigation of reconstructed landform areas with a suspected elevated proportion of fines (e.g. Stage 13, Stage 52) and the resulting impact to establishing savanna woodland species, in order to determine an upper allowable limit. This work will focus on how to avoid these conditions as much as possible, whether there are amelioration methods to alleviate the constraining conditions present, and finally, how to opportunistically enhance the ecosystem in these areas where they unavoidably occur.
- Continued analysis of monitoring data for research trials and other non-waste rock disturbance areas, with learnings included in the SERP, used to refine the CRE and to further develop the revegetation strategy.
- Targeted research trials for important Savanna Woodland CRE species which are data deficient, and/or have had limited success.
- Optimisation of methods and timing for fertiliser re-application.
- Further investigation into the decomposition rates of biopots used in previous research areas.
- Further assessment of the environmental impact and large scale feasibility of strategic addition of organic materials to the final landform surface.

- Continued implementation of the nest box trial and associated monitoring, with outcomes after 12 months to be critically reviewed.
- Characterisation and monitoring of existing rockpiles to help inform future design and implementation across the final landform.
- Continued documentation of threatening weed and exotic fauna species, including their ecology and effective management.

With regards to preventative controls (40%, Section 9.4), these will be improved through development of the items listed above. More practical improvements may also include:

- further development of schedule for final landform construction, initial planting of large areas and connectivity to surrounds;
- detailed planning for weed management in previously less accessible, unmanaged areas;
- further research and implementation of effective controls for preventing weed spread to rehabilitation areas and surrounds; and
- dedicated resource planning, and training for weed management in revegetation areas.

With regard to the monitoring program (60%, Section 9.5), this will be improved through:

- continued implementation and refinement of adaptive management monitoring, with appropriate frequency across all waste rock research and non-waste rock areas;
- development of appropriate and repeatable plot size, frequency and methodology for vegetation ground survey, with implementation across all waste-rock research and non-waste rock areas;
- continued support of remote sensing methods, which are likely to increase efficiencies and confidence in future;
- development of monitoring methodologies for fauna and habitat formation;
- development of methodologies for assessment of nutrient cycling and litter decomposition on waste rock, with implementation on current research areas; and
- development of a structured decision-making framework to inform a pest invertebrate management plan.

With regards to corrective actions (50%, Section 9.6), these will be improved through development of the items listed above, and implementation at current and future rehabilitation areas. More immediate improvements may also include:

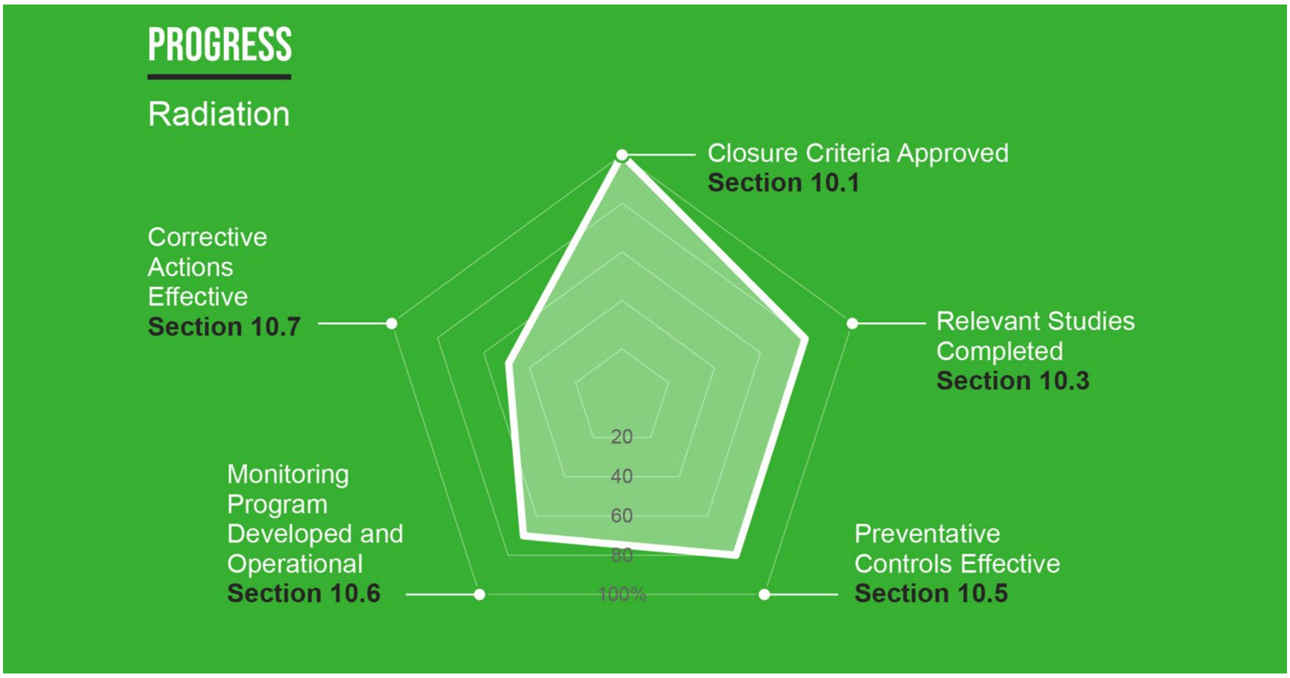
- development of more specific triggers in the TARP to inform corrective actions; and
- further trials at TLF sections two and three to correct the deviated ‘weed dominated’ state.

10 RADIATION

The purpose of this chapter is to consolidate information relevant to radiation with regards to the closure of Ranger. There are two ERs related to radiation, 2.2(b) and 11.3(iii) (see Table 10-1). The objectives are to manage mine-derived radiation doses received by members of the public, and radiological impacts to non-human biota (animals and plants), to within applicable limits.

An indication of progress against key metrics for radiation is summarised in the spider web diagram below. It shows:

- All relevant Closure Criteria have been approved (100%, Section 10.1).
- There is a substantial body of knowledge that has been generated by ERA and the OSS to understand and predict radiation doses to people and radiological risks to plants and animals arising from mining activities at Ranger. Having said that, further studies to refine this understanding will be undertaken, with some of these already started (80%, Section 10.3).
- Preventative controls to manage post-closure radiation doses (e.g. transferring the tailings to the mined out pits and burying them at depth) are well advanced and predicted doses are within applicable limits for people and non-human biota. Further work is occurring, which is expected to reduce the radiation doses further (80%, Section 10.5).
- Radiation protection and atmospheric monitoring, and annual reporting of the findings, at Ranger occurs at present, and a post-closure monitoring program has been developed and is included in this chapter (70%, Section 10.6).
- Corrective actions in the event of a deviated trajectory for radiation exposure are well understood but not easily, or quickly, implemented (50%, Section 10.7).



10.1 Closure Objectives and Criteria

Table 10-1 lists the ERs relevant to the radiation theme.

Table 10-1: Radiation Theme: Environmental Requirements

Environmental Requirement	ER Reference
2 Rehabilitation *2.2 The major objectives of rehabilitation are:* *(b) stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is ALARA; 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.*	2.2(b)
11 Management of Tailings *11.3 Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that:* *iii) radiation doses to members of the public will comply with relevant Australian law and be less than limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines effective at the time of the final tailings disposal.*	11.3 (iii)

Table 10-2 lists the closure outcomes, parameters and closure criteria derived from the ERs listed in Table 10-1. These closure criteria received Ministerial approval on 30 September 2021 with the approval of the 2020 MCP.

Table 10-2: Radiation – Approved Closure Criteria

Objective	Outcome	Parameter	Summary of Criteria
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.	Radiation dose constraints to members of the public are ALARA.	Using the agreed restrictions on land use the total above-baseline radiation dose from pathways: External gamma; Inhalation of Radon decay products (RDP); Inhalation of dust; Ingestion of bush food (including water).	0.3 mSv/a
	Radiation dose constraints to members of the public are below limits.	Should land use restrictions fail, the total above-baseline radiation dose from pathways: External gamma; Inhalation of RDP; Inhalation of dust; Ingestion of bush food (including water).	1 mSv/a
	Minimise the deleterious radiation effects on terrestrial biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities, and ecosystems.	Total above-baseline absorbed dose rates to the most highly exposed terrestrial plants and animals.	100 µGy/h to the most highly exposed terrestrial species
	Minimise the deleterious radiation effects on aquatic biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities, and ecosystems.	Total above-baseline absorbed dose rates to the most highly exposed aquatic plants and animal.	400 µGy/h to the most highly exposed aquatic species

mSv/a = millisieverts per annum; µGy/h = micrograys per hour.

10.2 Design elements

Chapter 4 describes the closure activities completed and yet to occur at Ranger. Of most relevance to the radiation theme are the following design elements:

- The uranium grade of the waste rock that will be covering the final landform (i.e. grade 1s) is described in Section 4.8.2.
- Whilst the majority of uranium was extracted from the mineralised ore, some uranium remains as a potential source for mobilisation in water from the waste rock and tailings. Section 4.8.2 describes the discrimination that will occur to facilitate burial of the mineralised waste rock (grade 2s and 3s), and Section 4.1.1 and Section 4.2.3 describe the at-depth burial of tailings in Pit 1 and Pit 3, respectively.
- Radionuclides will be removed from process water, and the concentrated brine waste will be injected at depth in Pit 3 (see Section 4.2.2) to prevent any effect on near surface groundwater.

10.3 Relevant Studies / Knowledge Base

10.3.1 Radiation exposure pathways

A radiological impact assessment aims to quantify the impacts of radiation that originate from sources associated with a particular activity or practice, and to compare the results to existing and accepted standards. For people, the radiological impact is calculated as a potential radiation dose, where the incremental impacts above natural background levels are assessed and compared against relevant standards and limits to determine whether the impacts are acceptable.

The potential exposure pathways to radiation are:

- dust lift off leading to subsequent deposition of radionuclides in the wider environment and uptake into plants and animals that are consumed;
- dust lift off leading to radionuclides in air that can be inhaled;
- radon emission from the rehabilitated landform and the LAAs resulting in elevated radon decay product concentrations and subsequent inhalation;
- mobilisation of radionuclides into groundwater and surface water resulting in changes in concentrations and subsequent ingestion of water or uptake into plants and animals; and
- Gamma irradiation to people in the immediate vicinity of rehabilitated landform and the LAA from elevated radionuclide concentrations.

10.3.1.1 Natural background levels

The pre-mining radiological conditions for Ranger were investigated and reported by OSS (Bollhöfer *et al.,* 2014). Average radium concentrations over the orebodies (880–1,800 Becquerels (Bq)/kg) were much higher than for the surrounding area (110 Bq/kg), as were the average radon flux densities over the orebodies (1.3–2.7 Bq per square metre per second) relative to the surrounding area (0.15 Bq per square metre per second).

ERM (2020a) investigated background levels of uranium and radium in groundwater as the focus of KKN WS1. Table 10-3 shows the findings of this study.

Table 10-3: Calculated background average values in groundwater (ERM, 2020a)

Analyte	Unit	Shallow Bedrock Cahill	Deep Weathered Cahill	Shallow Weathered Cahill	Shallow Bedrock Nanambu	Deep Weathered Nanambu	Shallow Weathered Nanambu	MBL zone
Uranium	µg/L	7.74	21.9	3.03	5.76	5.7	3.37	1.92
Radium	mBq/L	130	50	27.3	130	90	30	37.3

ERA routinely monitor radionuclide concentrations in Magela Creek upstream of the disturbed operational area (Magela Creek Upstream – MCUS). Water quality at this location is unaffected by historical mining and rehabilitation activities, and it therefore used to represent natural background conditions. The data from the year 2000 to 2021 wet seasons is shown on Figure 10-1 (ERA, 2023b), and shows the dissolved uranium concentrations (<0.45 µm filtered fraction) are typically well below the Focus (0.3 µg/L), Action (0.9 µg/L) and Limit (2.8 µg/L) concentrations.

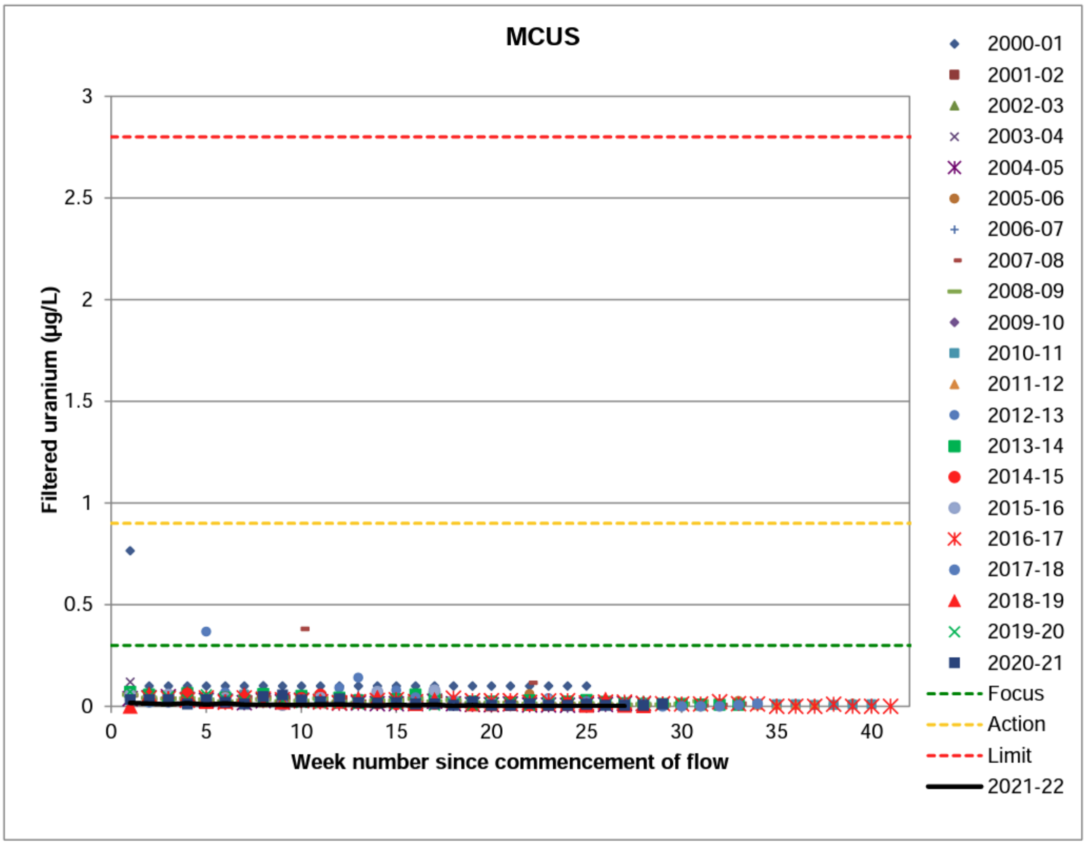


Figure 10-1: Dissolved uranium concentrations in Magela Creek Upstream of Ranger

Indigenous people living a traditional lifestyle in Kakadu National Park consume bush foods that contain natural background concentrations of radionuclides. A summary of the available data on the uptake of radionuclides into aquatic and terrestrial foodstuffs was completed by ERISS and published in its annual research summary (Ryan *et al*., 2009). ERISS collated all available data on radionuclide activity concentrations in bush foods (from natural sources) and used this to determine a baseline radiation dose to Aboriginal people living in the region from ingestion of foodstuffs of 0.84 millisieverts per year (mSv/year). This radiation dose is irrespective of the mining activity and reflects the natural state for Aboriginal people living in Kakadu National Park.

10.3.1.2 Factors impacting dose assessment

The rehabilitated site will most likely be utilised for both recreational and cultural use by the local Indigenous people. ERA has a long history of engagement with the Mirarr people through consultation with the NLC and GAC. In 2014, ERA formalised the engagement regarding post-mining land use and closure criteria through extensive consultation with Traditional Owners via the consulting linguist and anthropologist Murray Garde (Garde, 2015). This report was summarised by Paulka (2016) and refined for habitation, use of traditional plants and animals, and the assumed post closure bush food diet.

The occupancy intentions (in terms of estimated hours per year spent on the rehabilitated Ranger mine area) and bush tucker diet are those documented in Garde (2015) and Paulka (2016). This information is summarised in Table 10-4 and Table 10-5.

For the dose assessment, the following assumptions were made:

- water from local creek system ingested is 2,000 litres (L) per year; and
- ingestion rates from Table 10-5 were also scaled for age.

Table 10-4: Occupancy intentions on the former mine area

Purpose of visit	Estimated time[1]	Location	%	Estimated hours per year
Hunting and food gathering (day trips)	30 days per person per year[2]	Magela riparian zones (undisturbed)	70	126
		LAA, RP1, water management areas and site billabongs	20	36
		Landform waste rock	10	18
Seasonal camping (extended camping)	20 days per person per year[3]	Magela riparian zones (undisturbed	75	360
		Site billabongs	20	96
		LAA, RP1 and water management areas	3	14
		Landform waste rock	2	10
Recreation	10 days per person per year[3]	Magela riparian zones (undisturbed)	90	216
		Site billabongs	7	17
		LAA, RP1 and water management areas	2	5
		Landform waste rock	1	2
Land management and monitoring	10 days per person per year[4]	Site billabongs	25	20
		LAA, RP1 and water management areas	25	20
		Landform waste rock	50	40

Purpose of visit	Estimated time[1]	Location	%	Estimated hours per year
Ritual	5 days per year[5]	Magela riparian zones (undisturbed)	90	54
		Site billabongs	5	3
		LAA, RP1 and water management areas	5	3
TOTAL				**1,040**

[1] – Estimated time from Garde (2015).
[2] – A 6 hour day has been assumed (Garde estimated both half and full day trips).
[3] – Full 24 hour day assumed (conservatively assume camping overnight for bush walks).
[4] – Land management assumed to be conducted on an 8 hour day.
[5] – Rituals assumed to last for 12 hours on average (some may be overnight, some very short).

Table 10-5: Annual intake of bush tucker

Food item	Flesh eaten	Organs eaten	kg per person consumed from the RPA over 1,040hrs
Buffalo flesh	X		5[1]
Buffalo kidney		X	0.5[1]
Buffalo liver		X	0.5[1]
Wallaby	X	X	20
Pig	X		25
Magpie goose	X	X	20
Other waterfowl	X	X	3
Fish group 1	X	X	10
Fish group 2	X		20
Mussels	X		4
Turtle flesh (pig nose, long neck and snapping)	X		5
Turtle liver (long neck only)		X	0.5
File snake	X		3
Crocodile flesh	X		3
Goanna	X	X	2
Yams	X		20
Fruit	X		3
Water Lilly	X		3
Flying fox	X		5
Emu	X	X	2
TOTAL		**154.5**	

1 – Revised number from RPA consumption only (ERA, 2022c) – other Buffalo not sourced from the RPA is consumed.

The dose assessment method uses internationally accepted processes and recognised dose factors (ICRP 2006, ICRP 2012). The assessment also considers doses from the following exposure pathways for a range of age groups:

- gamma radiation exposure;
- radioactive dust inhalation;
- radon decay product inhalation; and
- ingestion of drinking water and bush tucker.

For the assessment:

- The post-closure air quality modelling results from SLR (2018) are used for dust inhalation and radon decay product inhalation doses.
- The ERA 2023 water quality modelling (based on the INTERA 2022 and 2023a groundwater modelling of contaminant loads) and the SLR (2018) air quality dust deposition results are used for the ingestion doses. Both a base case (P50 contaminant load and 50% exceedance) and conservative case (P90 loads and 10% exceedance) water quality data have been used (see Chapter 7 for details). For both cases, the contaminant concentrations at peak loads and 10,000 years post closure have been assessed.
- For gamma radiation, a combination of increases in dose rate from dust deposition and any changes due to placement of material (e.g. the LAA).

Potential doses to members of the public are calculated for groups of people at locations of interest. The population at Mudginberri Billabong has been chosen as the group and location of most relevance, being the closest resident population downstream of the RPA.

JRHC Enterprises (2023) completed assessments for five scenarios:

1. Residents who spend all their time in Mudginberri and only consume bush tucker from the immediate region of Mudginberri.
2. Residents of Mudginberri who spend 1,040 hours on the rehabilitated mine site and only consume bush tucker from the area in proportion to the time that they are present (i.e. 11.9% of the bush tucker diet is from area, 88.1% of the bush tucker diet comes from the Mudginberri area).
3. Residents of Mudginberri who spend 1,040 hours on the mine site and consume bush tucker from the site for 50% of the time (i.e. 50% of the bush tucker diet comes from the mine area and 50% of the bush tucker diet comes from the Mudginberri area).
4. Residents of Mudginberri who spend 1,040 hours on mine area and consume bush tucker from the area for 100% of the time.
5. Residents of Mudginberri who spend 1,040 hours on mine area and consume full bush tucker from the wider Magela Creek system (one third of food from Mudginberri, one third from Magela Creek adjacent to the mine area, one third from Magela Creek upstream of Ranger).

Table 10-6 summarises the key findings from the mine-related radiation assessment for people (the focus of KKN RAD7A). As noted in Table 10-2, the agreed closure criteria for mine-related radiation doses to people are 0.3 millisieverts per year (mSv/y) to demonstrate ALARA and 1 mSv/y as the public dose limit.

The results in Table 10-6 demonstrate that the nearest resident community to the rehabilitated Ranger mine area would receive a mine-related dose that achieves the principles of ALARA under the base case and worse case scenarios (i.e. less than 0.3 mSv/y).

Table 10-6: Radiation dose to the public (mSv/y)

Age Group	Total Dose* – Base Case (P50)		Total Dose* – Worse Case (P90)	
	Peak Load	10,000 year	Peak Load	10,000 year
Scenario 1: Resident and bush tucker from Mudginberri				
1Y	0.008	0.003	0.018	0.007
5Y	0.008	0.003	0.018	0.007
10Y	0.009	0.004	0.021	0.008
15Y	0.014	0.006	0.030	0.013
Adult	0.006	0.003	0.014	0.006
Scenario 2: Resident at Mudginberri – 1,040 hours on mine area – 11.9% of bush tucker from mine area				
1Y	0.003	0.022	0.006	0.023
5Y	0.004	0.020	0.007	0.021
10Y	0.006	0.020	0.010	0.021
15Y	0.008	0.022	0.013	0.023
Adult	0.009	0.017	0.011	0.018
Scenario 3: Resident at Mudginberri – 1,040 hours on mine area – 50% of bush tucker from mine area				
1Y	0.005	0.078	0.018	0.082
5Y	0.006	0.065	0.020	0.070
10Y	0.008	0.057	0.023	0.062
15Y	0.010	0.058	0.031	0.064
Adult	0.010	0.037	0.020	0.040
Scenario 4: Resident at Mudginberri – 1,040 hours on mine area – 100% of bush tucker from mine area				
1Y	0.005	0.151	0.023	0.159
5Y	0.007	0.125	0.025	0.133
10Y	0.009	0.106	0.027	0.115
15Y	0.011	0.106	0.035	0.118
Adult	0.011	0.063	0.024	0.069
Scenario 5: Resident at Mudginberri – 1,040 hours on mine area – bush tucker from wider Magela Creek				
1Y	0.009	0.079	0.027	0.086
5Y	0.010	0.067	0.029	0.073
10Y	0.013	0.059	0.033	0.066

Age Group	Total Dose* – Base Case (P50)		Total Dose* – Worse Case (P90)	
	Peak Load	10,000 year	Peak Load	10,000 year
15Y	0.018	0.061	0.046	0.071
Adult	0.013	0.038	0.027	0.043

* ALARA dose = 0.3 mSv/y; Public dose limit = 1 mSv/y.

10.3.2 Radiation effects on terrestrial and aquatic biota

For non-human biota (animals and plants), the changes in radionuclide concentrations due to emissions from the rehabilitated mine are calculated at relevant locations of interest. For potential radiological impacts to plants and animals, a combination of changes in soil concentrations due to dust deposition and the changes to water concentrations due to solute transfer are used. Two locations were assessed by JRHC Enterprises (2023):

1. Mudginberri Billabong:
   - Terrestrial – dust deposition modelling results for Mudginberri Billabong; and
   - Aquatic – addition of dust deposition results and water quality results for Mudginberri Billabong.
2. Adjacent and on the mine area:
   - Terrestrial – dust deposition modelling results for the rehabilitated area; and
   - Aquatic – addition of dust deposition results for the rehabilitated area and the average of the 2023 water quality modelling results from MG003 and MG005 (see Chapter 7).

The assessment was conducted using the ERICA software tool (Environmental Risk from Ionising Contaminant: Assessment and Management V2.0). The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) notes that the ERICA software tool is applicable for use in Australia (ARPANSA, 2010) for assessing radiological impacts to non-human biota. The software uses changes in media radionuclide concentrations and concentration ratios in species, derived from studies, to provide a measure of radiological impact to a number of reference species.

The representative organisms considered in this assessment were: Freshwater Fish (including benthic and pelagic species); Molluscs (including bivalve and gastropod species); Freshwater Reptile; Freshwater vascular plants; Amphibian; Arthropod; Bird; Grasses and Herbs; Mammal (large and small-burrowing; Reptile and Tree.

The source of the concentration ratios used in the assessment were:

- Doering and others (2016) for mammal (large) and reptile;
- Doering and others (2019) for freshwater fish, molluscs, freshwater reptile and freshwater vascular plants; and
- ERICA default for amphibian, arthropod, bird, grasses and herbs, mammal (small burrowing) and tree.

For changes in radionuclide concentration in soils, the only consideration is the additional radionuclides applied to the LAA. The final landform cover material has been assessed to contain lower radionuclide concentrations than pre-mining levels (Bollhöfer *et al.,* 2014) and therefore not considered.

Modelled increases in water radionuclide concentrations for Mudginberri Billabong and on the RPA (at MG003 and MG005) are detailed in Chapter 7. The water quality modelling provided concentration values for uranium, Ra-226 and Po210. For other radionuclides, values were derived from the modelled values and assessed for both peak concentrations and modelled concentrations at 10,000 years.

Table 10-7 presents the results from the ERICA assessments.

Table 10-7: ERICA output for terrestrial species – total dose rate per organism (µGy/h)*

Organism	Mudginberri Billabong		On RPA	
	Peak	10,000 Years	Peak	10,000 Years
Amphibian	0.06	0.04	0.12	0.04
Mollusc – bivalve	13.92	4.85	29.50	9.16
Mollusc – gastropod	13.89	4.74	29.29	9.09
Pelagic fish	0.49	0.18	1.03	0.32
Reptile	0.20	0.10	0.40	0.13
Vascular plant	1.01	0.32	2.15	0.66
Amphibian	0.00	0.00	0.00	0.57
Reptile	0.00	0.00	0.00	0.56
Arthropod – detritivores	0.00	0.00	0.00	0.87
Bird	0.00	0.00	0.00	0.12
Grasses & Herbs	0.00	0.00	0.00	0.80
Mammal – large	0.00	0.00	0.00	0.57
Mammal – small-burrowing	0.00	0.00	0.00	0.29
Tree	0.00	0.00	0.00	0.09

*ALARA dose rate = 100 µGy/h to the most highly exposed terrestrial species; 400 µGy/h to the most highly exposed aquatic species.

10.4 Bow-tie diagrams

As described in Chapter 5, this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. Depending on the theme, there may be multiple bowties, representing the relevant aspects being measured for that theme. For radiation, two bow-ties have been developed and these are provided as Figure 10-2 and Figure 10-3. Within each bow-tie diagram, threats and preventative controls are represented on the left side of the diagram, and corrective actions and consequences on the right side. The residual risk ratings reflect the current understanding and effectiveness of the controls and corrective actions. Class IV and Class III risks exceed ERA's risk acceptance threshold and will be the subject of further work to reduce uncertainty, strengthen the preventative controls, and/or strengthen the corrective actions.

Preventative Controls

C7 All tailings deposited into Pits 1 and 3
Strong

C11 Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met
Strong

C27 Tilling
Satisfactory

C44 Maintain tailings in near saturated state, and active dust control (water trucks, water cannons) prior to capping tailings and during movement of higher grade material
Satisfactory

C42 Understanding radiation emissions, exposure pathways, radionuclide concentrations and doses
Satisfactory

C43 Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bush foods
Satisfactory

Corrective Actions

A10 Short-term restrictions to land access and cultural activities
Satisfactory

A23 Remediation (as required) of surface radiation following construction and rehabilitation of final landform
Satisfactory

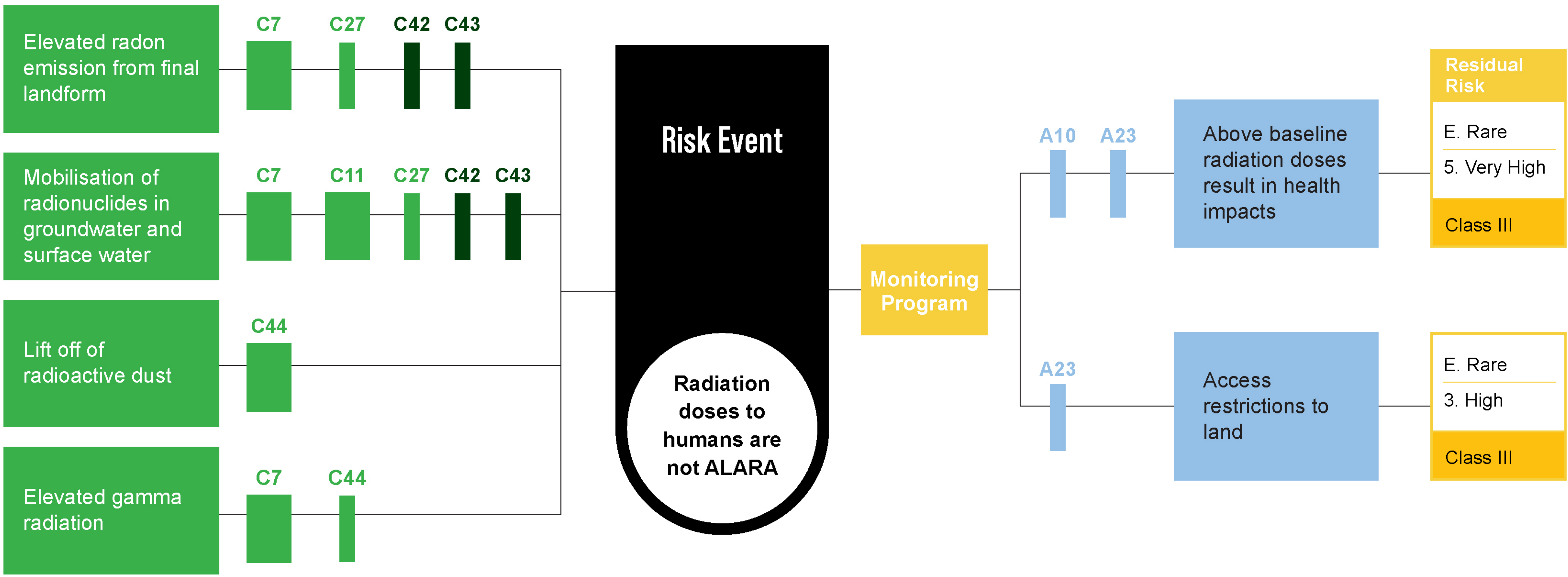


Figure 10-2: Bow-tie diagram for radiation doses to humans (R1)

Preventative Controls

C7 All tailings deposited into Pits 1 and 3
Strong

C11 Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met
Strong

C27 Tilling
Satisfactory

C33 Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application
Strong

C44 Maintain tailings in near saturated state, and active dust control (water trucks, water cannons) prior to capping tailings and during movement of higher grade material
Satisfactory

C42 Understanding radiation emissions, exposure pathways, radionuclide concentrations and doses
Satisfactory

C43 Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bush foods
Satisfactory

Corrective Actions

A23 Remediation (as required) of surface radiation following construction and rehabilitation of final landform
Satisfactory

A24 Increased monitoring of radiological contaminants in impacted environments and biota
Marginal

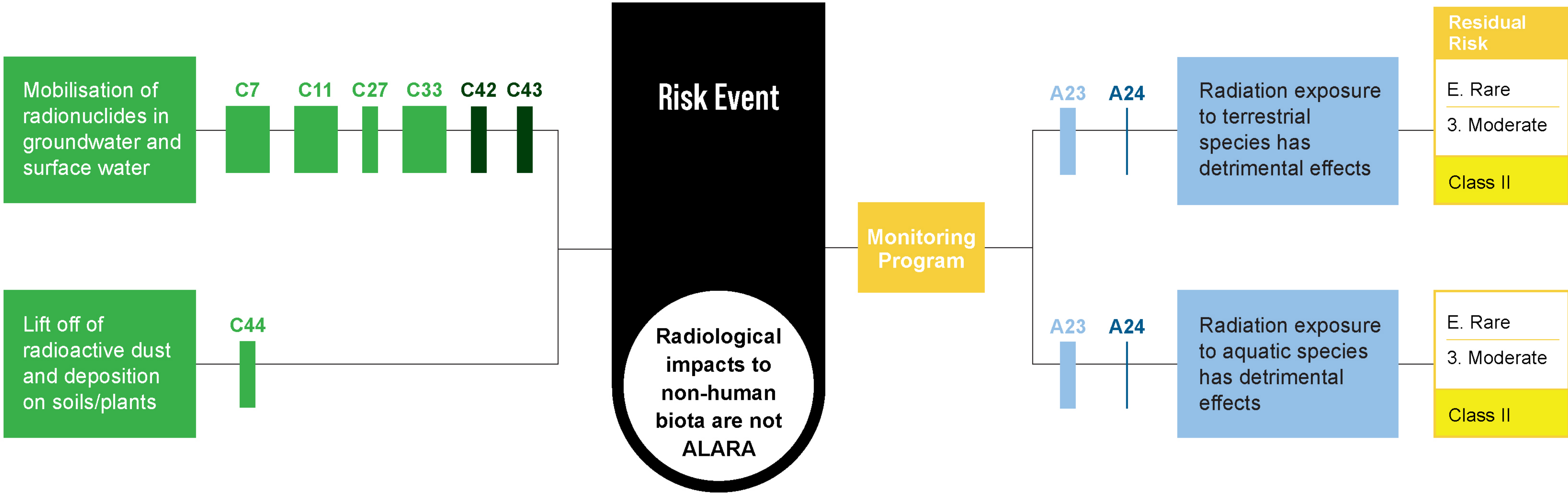


Figure 10-3: Bow-tie diagram for radiation doses to non-human biota (plants and animals) (R2)

10.5 Preventative Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well ERA understand and can demonstrate the effectiveness of the controls that will be put in place between now and the creation of the final landform, or shortly thereafter, to ensure that the radiation ERs can be achieved or are on the desired trajectory to being achieved.

The subjective assessment provided in the spider web diagram at the beginning of this chapter indicates that the current status of progress is 80%. This high progress status reflects the radiation assessment outcomes described in Section 10.3, which highlight the effectiveness of the controls with mine-related doses achieving the principles of ALARA under the base case (P50) and worse case (P90) scenarios (i.e. less than 0.3 mSv/y for members of the public, and below 100 µGy/h and 400 µGy/h for terrestrial and aquatic species respectively). Table 10-8 outlines the preventative control, current rating of effectiveness and status for each control.

Table 10-8: Preventative Controls for Radiation

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C7	All tailings deposited into Pits 1 and 3	Strong	'Strong' because all tailings have been deposited at depth into both Pit 1 and Pit 3. Higher grade material (grade 2s and 3s) have been (Pit 1) or will be (Pit 3) buried below the conservative long-term average water table.
C11	Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met	Strong	This is a proven technology at Ranger having been applied to the PTF in Pit 3 and as demonstrated in the annual Ranger Wet Season Reports of water quality downstream of the mine. The assessment of uranium and radionuclides describes in Chapter 7 also confirms the effectiveness for radiation-related CoPCs.
C27	Tilling of soils in the Magela LAA	Satisfactory	This is a well-established and proven remediation practice, however uncertainty remains on the extent required until the Phase 2 contaminated sites study is completed (see Section 8.5 for details).
C44	Maintain tailings in a near-saturated state, and active dust control prior to capping tailings and during movement of higher grade material	Satisfactory	This is a proven method and has been applied previously at Ranger with success. The effectiveness rating of Satisfactory rather than Strong has been applied recognising that there have been isolated dusting incidents.
'Knowledge-based / Administrative' controls			
C42	Understanding radiation emissions, exposure pathways, radionuclide concentrations and doses	Satisfactory	This control is supported by numerous studies by ERA and OSS with accepted methods and findings. Some uncertainty remains in the modelled inputs used to calculate doses however the conservative P90 case has been included in the assessment to account for this uncertainty.
C43	Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bushfoods	Satisfactory	The work by Garde (2015) established post-closure occupancy and verified dietary intakes first developed by Ryan and others (2011). These occupancy and dietary intake values are widely accepted. Considerable work by OSS (Doering et al. 2016, 2019) has established transfer factors in bushfoods and further studies are underway.

10.6 Monitoring Program

The objective of the radiation monitoring program is to confirm that workers, members of the public, and the environment are not exposed to unacceptable levels of ionising radiation from the planned rehabilitation activities to reach final landform and thereafter. Monitoring also provides a way to confirm the effectiveness of controls.

Annex F of the Ranger Authorisation stipulates the radiation monitoring program to be undertaken at Ranger. Annex D.2 of the Ranger Authorisation notes the requirement for ERA to provide an annual radiation and atmospheric monitoring interpretative report and dictates the information to be included within that report.

The latest report for year ending 31 December 2022 (ERA, 2023c) identified that doses to workers and members of the public remained very low, and below applicable limits (20 mSv for workers and 1 mSv for members of the public).

This section of the MCP does not duplicate all the monitoring described in the Ranger Authorisation or the annual report. Table 10-9 presents the radiation monitoring program that will be implemented to evaluate the calculated doses provided in Table 10-6 and Table 10-7. This monitoring program builds upon that reported annually because it is forward looking (i.e. is designed for future monitoring events to confirm predicted conditions resulting from the final landform after it is constructed), which differs from the annual report that interprets actual monitoring results from the preceding year.

Table 10-9: Radiation monitoring

Aspect	Methodology / Analysis	Location	Frequency
Gamma radiation exposure	Airborne radiometric survey, ground gamma survey and soil sampling (note: this is additional to personal monitoring of worker doses).	Final landform.	Once, at completion of Final Landform.
Radioactive dust inhalation	Dust deposition gauges (DDG): samples analysed by gamma spectrometry (U238, U235 and Th232 series radionuclides). High Volume Air Sampling (HVAS): filters counted for long lived alpha activity (LLAA). Captured dust may be aggregated and analysed by gamma spectrometry for U and Th series radionuclides. Investigative monitoring (medium volume air sampling): filter counted for LLAA.	DDG: proximal to Pit 3 (locations established mid-2023 to monitor dust deposition from exposed tailings in Pit 3). HVAS: 1-2 samplers additional to statutory monitoring, downwind of active areas (e.g. Pit 3 during active backfill, then FLF and RWD as bulk material movement progresses). Investigative: as deemed necessary to intercept any identified source term, or at areas occupied by workers.	DDG: while tailings material is exposed and drying. May be temporarily halted in wet season to mitigate damage or potential impact to sample from heavy rainfall or strong winds. Samples analysed quarterly to confirm total activity below trigger level of 1 Bq/g. HVAS: While tailings material is exposed and drying, filters changed and counted weekly. Set of samples may be aggregated (representing a month or a quarter) for gamma spectrometry analysis of dust. Number of samples in set will depend on dust loading and required size of sample for gamma spec. During backfill, 1–2 samplers additional to statutory monitoring will run for one week per month. Investigative: Pump run for up to 12 hours, frequency ad hoc.
Radon decay product (RDP) inhalation	Investigative monitoring using real time RDP monitors that samples the air at a known flow rate, measures the RDP activity in counts, and outputs a result. Measurement of radon exhalation and long term radon concentrations in air.	As deemed necessary to intercept any identified source term, or at areas occupied by workers. As areas of the mine reach final landform (FLF).	Duration and frequency ad hoc, depending on monitoring target. Once off as areas of the mine reach FLF.
Ingestion of drinking water	Chemical analysis as described for surface water (Chapter 7) for Uranium-238, Radium-226, Polonium-210 and Lead-210.	Magela Creek Upstream (MCUS), MG003, Coonjimba Billabong, MG009 and End of RPA.	Every three years until Pit 3 is no longer functioning as a groundwater sink (i.e. decant wells turned off), annually thereafter until relinquishment.
Ingestion of bush tucker	Alpha spectrometry analysis of bush food samples for Radium-226, Polonium-210 and Lead-210.	On the RPA, including Magela Creek.	Sampling program planned for 2024. Thereafter, annually for the 2 years after Pit 3 decant wells turned off.

10.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subjective 50% progress status for 'corrective actions'. The successful execution and effectiveness of the preventative controls presented in this chapter are expected to result in the achievement of the radiation-related closure criteria. If however the monitoring program discussed above detects a deviation from the expected findings, the corrective actions listed in Table 10-10 will be implemented.

Table 10-10: Corrective Actions for Radiation

Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
'Active' corrective actions			
A10	Short-term restrictions to land access and cultural activities	Satisfactory	Whilst neither planned nor desirable, restricting access to an area of potential radiation health risk is a Satisfactory corrective action until the area can be remediated as per the above corrective action.
A23	Remediation (as required) of surface radiation following construction and rehabilitation of final landform	Satisfactory	Monitoring will occur progressively as the different stages of the final landform are established and higher grade material (grade 2s and 3s) will be removed and replaced with lower grade material (grade 1s) if monitoring detects higher grade material at the surface.
'Knowledge-based / Administrative' corrective actions			
A24	Increased monitoring of radiological contaminants in impacted environments and biota	Marginal	If monitoring detects exceedances of the 'First' or 'Focus' level triggers (see Section 10.8), the frequency of the monitoring activity relevant to the exceedance will be increased beyond that shown in Table 10-9 in order for timely confirmation of whether there is a deviating trajectory or a monitoring anomaly.

10.8 Trigger, Action, Response Plan

Table 10-11 consolidates the monitoring and adaptive management programs described above into the form of a trigger, action, response plan. This TARP will be updated as required in future iterations of the MCP.

Table 10-11: Trigger, Action, Response Plan for Radiation

Material grade – final landform			
	Normal State	**Level 1 Triggers (Focus Level)**	**Level 2 Triggers (Action Level)**
Trigger Action Response Plan	Discrimination results below trigger levels	Discrimination results exceed focus level trigger	Discrimination results exceed action level trigger
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Radiation Safety Officer (or equivalent)	No Action	Support execution team as appropriate	Support execution team as appropriate
BMM Superintendent	No action	Adaptive management e.g. increased discrimination frequency	Adaptive management (e.g. increased discrimination frequency and review of material placement) Apply appropriate corrective action
Gamma radiation levels			
	Normal State	**Level 1 Triggers (Focus Level)**	**Level 2 Triggers (Action Level)**
Trigger Action Response Plan	Monitoring results below trigger levels	Small area (<100 m^2) exceeding focus level dose rate trigger (>1.5 μSv.h-1)	Large area (>100 m^2) exceeding focus level dose rate trigger (>1.5 μSv.h-1), OR Small area (<100 m^2) exceeding action level dose rate trigger (>3 μSv.h-1)
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Radiation Safety Officer (or equivalent)	No action	Confirm results of airborne survey via ground based survey Remediate any discrete pieces of material showing mineralisation or enhanced dose rate	Ground based survey to identify whether sources are discrete or widespread Identify material above 1's for localised remediation
HSE Manager / Closure Manager	No Action	To be briefed on the outcomes of the investigation and potential corrective actions if levels cannot be reduced	Implement surface remediation Apply appropriate corrective action

Radioactive dust lift off: inhalation			
	Normal State	**Level 1 Triggers (Focus Level)**	**Level 2 Triggers (Action Level)**
Trigger Action Response Plan	Monitoring results below trigger levels	Airborne dust concentration exceeds focus level trigger value (>0.04 Bqαm-3)[1]	Airborne dust concentration exceeds action level trigger value (>0.10 Bqαm-3)[1]
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Radiation Safety Officer (or equivalent)	Continue monitoring as per Table 10-9	Investigate cause, conduct additional monitoring to identify source	Advise on appropriate controls or corrective action
HSE Manager / Closure Manager	No Action	To be briefed on the outcomes of the investigation and potential corrective actions if levels increase	Apply control measures and/or appropriate corrective action
Radon exhalation			
	Normal State	**Level 1 Triggers (Focus Level)**	**Level 2 Triggers (Action Level)**
Trigger Action Response Plan	Monitoring results below trigger levels	Flux rate exceeds focus level trigger value (1.76 Bq.m-2.s-1 in wet season and 0.71 Bq.m-2.s-1 in dry season)	Flux rate exceeds action level trigger value (2.93 Bq.m-2.s-1 in wet season and 1.18 Bq.m-2.s-1 in dry season)
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Radiation Safety Officer (or equivalent)	No Action	Investigate potential cause	Repeat measurement, advise on appropriate control measures to reduce levels
HSE Manager / Closure Manager	No Action	To be briefed on the outcomes of the investigation and potential corrective actions if levels increase	Apply control measures and/or appropriate corrective action

[1] – assumes high volume sampling methodology – subject to change.

10.9 Future work

The radiation impact assessment demonstrates compliance with dose limits for human and non-human biota. Nevertheless, further engineering design of closure activities and additional remediation actions are planned, which are expected to lower radiation doses further. The following future work relevant to radiation is planned:

- a sampling program of bush tucker on the RPA will occur in 2024 to supplement existing data;
- the radiation assessment will be re-run and included in the RWD/FLF application after the following has occurred:
    - the 2024 bush tucker samples have been analysed;
    - the BPT for the additional Pit 3 groundwater remediation has been completed and surface water modelling has generated revised concentrations; and
    - the BPT for the additional RWD groundwater plume remediation has been completed and surface water modelling has generated revised concentrations.

It is also noted that the International Commission of Radiological Protection (ICRP) is developing a draft set of revised age dependent ingestion dose factors. If the new results are published before the RWD/FLF application is submitted, they will be included in the update to the radiological impact assessment.

11 CULTURAL

The purpose of this chapter is to consolidate information relating to the cultural values and cultural heritage of the rehabilitated landform and the broader RPA. This includes tangible and intangible elements that may be difficult to quantify.

An indication of progress against key metrics is summarised in the spider web diagram below. It shows:

- Closure criteria for the Cultural theme were developed, and agreed, in consultation with the Mirarr Traditional Owners and their representatives. ERA are seeking Ministerial approval for the cultural closure criteria in this MCP (100%, Section 11.1).
- There is a substantial body of knowledge that has been generated by ERA in consultation with Traditional Owners and this consultation will continue throughout the closure and post-closure phases (70%, Section 11.3).
- Preventative controls to achieve the agreed closure criteria are well advanced, however further work is required (60%, Section 11.5).
- A Traditional Owner Cultural Reconnection Steering Committee has been established to facilitate the cultural monitoring program and will continue to be developed. A triennial cultural heritage audit program began during operations and is continuing through rehabilitation (50%, Section 11.6).
- Corrective actions in the event of a deviated trajectory are well understood but, in some instances, may not be easily, or quickly, implemented (60%, Section 11.7).

11.1 Closure Objectives and Criteria

There is one objective for closure under the cultural closure criteria theme, which is a combination of two ERs: ER 1.1 (a) and ER 2.1:

1.1 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;

2.1 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.

To achieve this closure objective, seven outcomes have been defined. These outcomes along with the parameters and a summary of the associated criteria is outlined in Table 11-1. These criteria were developed in consultation with Mirarr Traditional Owners and their representatives as described below.

In 2006, a ‘first pass’ closure model was provided to the Mirarr Traditional Owners. In response, a series of consultation meetings were held with the Mirarr Traditional Owners with the goal of understanding their expectations and concerns for closure. Specific matters were raised, such as no new artificial water bodies; the recreation of previous water catchments; how areas such as the RWD, R3 Deeps and the Magela LAA would be remediated; the aesthetic of the final landform and visual connection across the landscape; climate change and intergenerational environmental effects; weeds and fire management; bush tucker availability and water monitoring compliance points.

In addition, the Traditional Owners raised a general concern regarding the timeframe for rehabilitation and the potential it would extend the period before the Traditional Owners are able to re-instate traditional practices. It was understood by the Traditional Owners that there would need to be ongoing consultation over the years as the closure model was refined and more detailed information was known by ERA.

Table 11-1: Cultural – Closure Criteria for Minister approval in the 2023 MCP

Objective	Outcome	Parameter	Summary of criteria[1]
The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list; 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.	Landform design supports cultural land use associated with: An-berrk, savanna woodland An-bouk, riparian margins An-kabo, water courses An-labbarl, billabongs Traditional Owners satisfied with the landform	Size of rocks	≥7 Surface rock suitability verified by Bininj[2] monitoring - confirm mostly correctly sized
		Presence / absence of erosion	≥7 Erosion verified by Bininj monitoring – limited to very minor concerns and only small areas
		Accessibility, traversability[3]	≥7 Traversability verified by Bininj monitoring – limited to minor difficulties only and few in number
		General aesthetics (does it look 'natural')	≥7 Natural aesthetic verified by Bininj monitoring – confirm most areas look natural, limit of a few not satisfactory
	Traditional Owners are observing improvement in the progression of revegetation on the landform	Vegetation growth rate	≥7 Growth rate verified by Bininj monitoring – relative to the number of seasons, the growth of plants across all areas is satisfactory and is improving
		Vegetation diversity	≥7 Diversity verified by Bininj – all of the expected species are present in a natural combination in nearly all of the area
		Correct species for ecological zone	≥7 Species verified by Bininj – all of the species are correct for nearly all ecological zones
		Presence of weeds	≥7 Weeds verified by Bininj – weeds are present in only a minor portion of the area, low level of concern
	Traditional Owners are satisfied that there are not additional water bodies present	Presence or absence of artificial water bodies	Absence of water bodies verified by Bininj monitoring – no artificial water bodies present
	Traditional Owners satisfied with the water quality and that no silting or sedimentation is occurring	Visual impressions of water quality (colour, flow, expected clarity, visible contaminants), silting, sedimentation	≥7 Water quality verified by Bininj monitoring – water appears to be of high quality in most areas, only very minor water quality concerns
	Traditional Owners satisfied that the riparian zones are in good condition	Condition of water course margins, creek banks	≥7 Watercourse margins and creek banks verified by Bininj monitoring – appear to be in a natural condition in most of the area, only minor concerns
	Traditional Owners are observing improvement in biodiversity on the landform	Natural species numbers and diversity appropriate for stage of rehabilitation	≥ Species numbers and diversity verified by Bininj monitoring – natural species occurring according to expectations for natural rate relative to the number of seasons and is improving

Objective	Outcome	Parameter	Summary of criteria[1]
	Traditional Owners are satisfied with the final landform and state of key landmarks	Line of sight assessment prior to finalising landform design	Visual connection with key cultural sites verified by Bininj monitoring – sites visible from the same areas and to the same extent as prior to disturbance.

[1] The values within the criteria summary relate to the scalar measurement tool described in Section 11.6.

[2] Bininj means many things depending on context. In the context of the Ranger mine closure, Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent.

[3] Bininj may agree that ripping of landform will lead to a better revegetation outcome, therefore there will be a need to consider and consult on 'pathways' through the landscape.

In 2012, ERA engaged Murray Garde to facilitate consultation with the Mirarr Traditional Owners to further develop the cultural closure criteria for Ranger. This consultation built on the initial discussions of the first pass closure model. In order to develop the criteria, the post closure land use and the nature of the Traditional Owners' interactions with the rehabilitated landscape needed to be understood. This is key to delivering a rehabilitated landform that will be accepted by Traditional Owners and provide them with a safe and healthy area to re-establish traditional practices. Garde's report (Garde, 2015) provides details of the end land use including a list of culturally important flora and fauna, the types and amount of bush foods consumed and the nature of past and predicted future occupancy of the rehabilitated landform (discussed below in Section 11.3).

Garde (2015) provided a list of specific cultural objectives and suggested closure criteria parameters. These objectives and parameters were the basis for further consultation and development of the now agreed cultural closure criteria presented in Table 11-1.

In addition to the Ranger closure criteria, Aboriginal cultural heritage is governed by both NT and Commonwealth legislation. Legislation that governs cultural heritage at Ranger includes the *Heritage Act 2011* (NT), the NTASSA, the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (*Cth) and the EPBC Act.

The Heritage Act protects places that are declared as heritage places. The Heritage Act specifies that all Aboriginal (and Macassan) archaeological sites are declared heritage places and therefore protected. The Heritage Act specifies requirements to obtain approval where proposed works may disturb an archaeological site or object, including where proposed works may require the site or object to be relocated. It also specifies criminal offenses for unauthorised damage to, or removal of, a heritage place.

All sacred sites in the Northern Territory are protected by the Sacred Sites Act and the Aboriginal and Torres Strait Islander Heritage Protection Act. The Aboriginal Areas Protection Authority (AAPA) maintains a register of all sacred sites that have been identified in the Northern Territory. The register has both registered (comprehensively documented and evaluated by the Authority) and recorded (in many cases have not been comprehensively documented and evaluated by the Authority) sacred sites.

The AAPA can issue certificates that are based on consultation with the custodians of sacred sites that provide clear instructions on what works can and cannot be undertaken in and around sacred sites. The application for an AAPA certificate is voluntary and provides statutory indemnity against prosecution in relation to works or uses covered by the certificate, provided the conditions imposed to protect the sacred sites are in place.

Places that are recognised for the natural or cultural values at a world or national level are protected under the Commonwealth EPBC Act. Kakadu National Park, which surrounds the RPA, is listed on both a national and world level and is therefore protected under the EPBC Act.

11.2 Design elements

Chapter 4 describes completed closure activities and future closure activities that will occur at Ranger. Of most relevance to the cultural theme are:

- All of the activities that contribute to non-polluted waters within and off the RPA. This includes the management of water during the closure activities, the isolation of tailings, the burial of contaminated material into Pit 3 and RP2, the remediation of the RWD groundwater plume and the Magela LAA, and the preventative controls that reduce CoPC concentrations.
- All of the activities that create a final landform that achieves the cultural closure criteria in that it is safe, stable, sustains the plants and animals representative of Kakadu National Park, and is easily traversed on foot.

11.3 Knowledge base

The spider web diagram at the beginning of this chapter assigns a subjective 70% complete for the progress status relating to ‘relevant studies’.

11.3.1 Cultural heritage management system

Throughout the operational phase at Ranger, a fit-for-purpose Cultural Heritage Management System was developed to promote the protection of cultural and historic heritage on the RPA. The Cultural Heritage Management System is a multi-faceted system comprising:

- Consultation with Traditional Owners.
- Cultural heritage/archaeological survey and assessment of significance.
- Recording of cultural heritage sites in a Geographical Information System database.
- Protection measures established to mitigate against unauthorised access (demarcation and signage).
- Land disturbance permit process, involving:
    - Assessment of proposed works outside the former operations boundary with respect to previously surveyed areas, site location and potential impact.
    - Additional mitigation measures designed to protect cultural heritage sites, if required. The additional measures are a set of standard requirements for all site types, which are triggered by the proximity of proposed work to a site.
    - Review/confirm controls in the field before work is undertaken.
    - Review and sign-off at the completion of works.
- Process for discovery of previously unrecorded cultural heritage sites or places (or potential cultural heritage sites or places).
- Cultural heritage training for all ERA personnel and contractors completing work outside the former operations boundary.
- Audit schedule for cultural heritage site condition and review of Cultural Heritage Management System effectiveness.

In 2006, ERA and GAC (on behalf of the Mirarr Traditional Owners) developed a protocol for cultural heritage management on the RPA. The protocol specifically applies only to the area outside the former operations boundary due to the significant level of previous disturbance. At the time, it was envisaged that a management plan would be developed and that the protocol would be an interim measure. In 2014, site specific management plans were developed by ERA, however, the *Interim Protocol Regarding Cultural Heritage on RPA* (Interim Protocol) remains the guiding document for managing cultural heritage on the RPA. The Interim Protocol does not outline a specific forum for engagement with Mirarr Traditional Owners on cultural heritage matters and as such ERA utilises existing forums such as the Relationship Committee Meetings, the Cultural Reconnection Steering Committee and if appropriate, and as directed by GAC, the GAC Board Meeting.

Under the Interim Protocol, the RPA has undergone extensive cultural heritage investigation since 2006 with approximately 75% of the lease area subject to systematic pedestrian survey. A total of 112 cultural heritage sites have been recorded on the RPA, with approximately 75 background artefact scatters also recorded.

As part of the 2022 Feasibility Study, a review of ERA's existing Cultural Heritage Management System was undertaken. The system was generally found to be suitable for closure with some improvements and updates to processes recommended that will be implemented to ensure cultural heritage protection throughout closure and rehabilitation. In addition, a specific closure and rehabilitation *Cultural Heritage Management Plan* was developed for the project. The draft management plan, which will be finalised through consultation with GAC, includes details of the following management aspects:

- direct and indirect impact management;
- induction and training requirements;
- management of previously unrecorded sites or human remains;
- Cultural heritage audit program;
- process and timeframes for decommissioning cultural heritage site signage and protective barriers;
- repatriation of cultural material;
- access to cultural heritage sites and culturally significant areas;
- corrective action for breach of the Cultural Heritage Management System; and
- transfer of cultural data to Traditional Owners.

11.3.2 Post-closure use and diet

ERA has a long history of stakeholder engagement with the Mirarr people through consultation with the NLC and GAC on their plans for the future of the rehabilitated site. They have indicated that the area will most likely be utilised for both recreational and cultural use by local Aboriginal people. In 2014, ERA formalised this engagement regarding post-mining land use and cultural closure criteria development through extensive consultation with Traditional Owners, via consulting linguist and anthropologist Murray Garde (Garde, 2015). Garde's report was the basis to further refine habitation, use of traditional plants and animals and the assumed post closure bush food diet (Paulka, 2016).

Consultation with Bininj, Aboriginal people of the West Arnhem region including the Mirarr People, has established that there is an “enthusiastic intention to continue visitation post-rehabilitation on the condition that Bininj are satisfied that the area is safe to enter and occupy” (Garde, 2015). Over the past 40 years there have been restrictions on visitation to this part of the Mirarr estate and people want to reconnect with country and places of cultural significance to them. Intended visitation can be organised into the following purposes:

- hunting, fishing, bush food gathering;
- recreation;
- land management activities; and
- cultural site visitation, ritual responsibilities.

Table 10-4 outlined the intentions to occupy or visit the rehabilitated RPA in terms of average number of days per person per year. These are estimates based on consultations with Bininj combined with knowledge about current occupation patterns for each of the four visitation purposes. It is highly likely that these four categories will not be discrete or mutually exclusive. For example, hunting may occur during visits originally associated with a different purpose (e.g. a monitoring or management visit).

The table of estimated occupancies contains the original Garde (2015) estimated days per activity and a breakdown over various locations. The table also provides an estimate of percentage of time for each location and an estimate of hours per year.

As can be seen in the table, and with the exception of land management and monitoring, Garde (2015) details that occupancies will be centred on Magela Creek and site billabongs (Georgetown and Coonjimba). It is expected that hunting and gathering (and to a lesser extent other activities) will also extend into the previously disturbed water management areas, including the old RP1 area, LAAs and Corridor Creek.

As the landform evolves into an ecosystem, drainage lines will reform and fauna will reinhabit the landform. It is assumed that occupancy at these locations, mainly in the form of hunting and food gathering, will occur. It is likely shorter, infrequent hunting, will occur on the remainder of the landform. The fauna detailed by Garde (2015) are either aquatic based or likely to gather in the riparian areas around water and food sources.

Bush food is an important part of everyday life for Bininj in the northern region of Kakadu National Park. Establishing how much bush food is consumed is important to inform the post-rehabilitation radiological dose assessment (refer Chapter 10; Table 10-5). Sources for meat fall largely into three categories: hunted by Bininj themselves in Kakadu; delivered as a community service by other agencies or non-indigenous individuals; and shared by more distant kin (e.g. relatives visiting from Gunbalanya or Western Arnhem Land outstations).

11.3.3 Culturally important flora and fauna

There are various criteria for establishing the cultural importance of a plant. The widest framework is linguistic reference. If it has a name and can be referred to, it must have some significance in the cultural life of Aboriginal people. A further criterion is utility. If it is used as some form of resource (e.g. food, medicinal, aesthetic, material culture, ritual) it is culturally important. On a number of occasions Bininj have indicated that culturally significant plants also include those that link animals together with other animals (including people). Plants that have flowers, seeds or fruit that attract birds and other animals are important for rehabilitation because they encourage the re-establishment of biodiversity (e.g. Owenia trees, *Owenia vernicosa*). Owenia will grow in very rocky habitats, their fruit is favoured by black cockatoos and emus and the sap is eaten by sugar gliders. People use the crushed leaves as an ichthycide (fish poison).

The majority of the floristic species identified in the Garde report are suitable for the Ranger rehabilitation area and have been able to be sourced, propagated and established (refer Chapter 9). The plants are those found across the three relevant ecological zones of the RPA – watercourses and billabongs, riparian margins and savanna woodland.

11.3.4 Potential impacts to cultural values

It is important to understand and address where closure activities may affect the cultural closure criteria outcomes and future land use by Traditional Owners. Table 11-2 describes potential impacts that may result from the activities described in this MCP and the related cultural criteria outcome that they may affect, and where these potential impacts are addressed in this MCP.

11.4 Bow-tie diagrams

As described in Chapter 5, this MCP uses bow-tie diagrams to provide on a single page a clear and transparent way of showing progress towards achieving each ER. For the cultural theme there are two bow-tie diagrams, one for creating a landform that meets Traditional Owner requirements (Figure 11-1), and one relating to cultural heritage management (Figure 11-2). The residual risk ratings reflect the current effectiveness of the controls and corrective actions.

Table 11-2: Preliminary Assessment of the Potential impacts to future cultural land use activities

Purpose of visit	Estimated time[1]	Location	Preliminary Assessment of the Potential Impact / Relevant Outcome[2]	Section
Hunting and food gathering (day trips)	30 days per person per year	Magela Creek and associated riparian zones (undisturbed)	No observable effect predicted from planned activities, human and animal drinking water quality all within limits, radiation doses all within limits.	7.3.5, 10.3
		Billabongs[2]	Preliminary and conservative calculations completed to date suggest that accumulation of manganese in older Mussels (bivalves) may pose a risk at Mudginberri Billabong.	7.3.10
Seasonal camping (extended camping)	20 days per person per year	Magela Creek and associated riparian zones (e.g. camp MG009)	No observable effect predicted from planned activities, all CoPCs within drinking water quality guidelines, potential for minor eutrophication effects (e.g. filamentous algal growth) in early recession period (April/May) reducing visual amenity of the waterway.	7.3.5, 7.3.8
		Billabongs[2]	No observable effect predicted from planned activities.	
Recreation	10 days per person per year	Magela Creek and associated riparian zones (undisturbed)	No observable effect predicted from planned activities, all CoPCs within drinking water quality guidelines, potential for minor eutrophication effects (e.g. filamentous algal growth) in early recession period (April/May) reducing visual amenity of the waterway.	7.3.5, 7.3.8
		Billabongs[2]		
Land management and monitoring	10 days per person per year	Magela Creek and associated riparian zones (undisturbed)	No material change to the proposed land management and monitoring.	6.6, 7.6, 8.6, 9.6, 10.6
		Billabongs[2]		
Ritual[3]	5 days per year	Magela Creek and associated riparian zones (undisturbed)	No observable effect predicted from planned activities. However, Traditional Owner perception may impact ritual land use. Ongoing consultation with Traditional Owners required.	7.3.5, 10.3
		Billabongs[2]		

[1] occupancy rates from Garde (2015) (refer Table 10-4 for further details).
[2] water quality modelling uncertainty remains and further work is being conducted to better understand potential impacts.
[3] Garde (2015) provides details on the type of rituals likely to be performed on the rehabilitated RPA and areas that may be utilised (including sacred sites, billabongs and camping areas).

Preventative Controls

- **C2** Erosion control measures including preparation of final landform surface — Marginal
- **C7** All tailings deposited into Pits 1 and 3 — Marginal - Strong
- **C11** Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met — Marginal - Strong
- **C25** Excavate and dispose contaminated soil/sediments into Pit 3 and RP2 — Strong
- **C33** Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application — Satisfactory
- **C45** Final landform designed and constructed to meet Traditional Owner requirements — Marginal - Satisfactory
- **C46** All sediment basins will be removed and rehabilitated — Satisfactory
- **C48** Management of the rehabilitated landform for weeds, exotic fauna, fire, pests and natural disturbances — Satisfactory
- **C49** Clean-up of all existing infrastructure and rubbish — Satisfactory
- **C43** Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bush foods — Satisfactory
- **C47** Line of site assessment for cultural landscape features undertaken and incorporated into final landform design and execution — Strong
- **C50** Final land use consultation with Traditional Owners — Satisfactory

Corrective Actions

- **A1** Maintenance of erosion and sediment control measures — Satisfactory
- **A2** Undertaking earthworks to repair significant gullying or eroded areas — Satisfactory
- **A5** Removing any contaminated or impacted material (water and sediment) — Marginal
- **A8** Planned duration of pump and treat extended to further reduce peak contaminant loads — Satisfactory
- **A9** Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels — Satisfactory
- **A11** Infill planting and seeding to maintain suitable vegetative cover on final landform — Satisfactory
- **A12** Additional interception system (e.g. passive reactive barrier) — Marginal
- **A13** Discontinue use/change pesticide — Satisfactory
- **A18** Targeted weed management — Marginal
- **A20** Addition of organic material/s and or fertiliser beyond that planned — Marginal
- **A21** Targeted pest and disease management — Marginal
- **A22** Supplementation of habitat features and/or migration corridors — Marginal
- **A23** Remediation (as required) of surface radiation following construction and rehabilitation of final landform — Satisfactory
- **A25** Reshape landform — Satisfactory
- **A26** Modified fire management — Marginal
- **A27** Remediation of surface sediment or salt deposition — Marginal

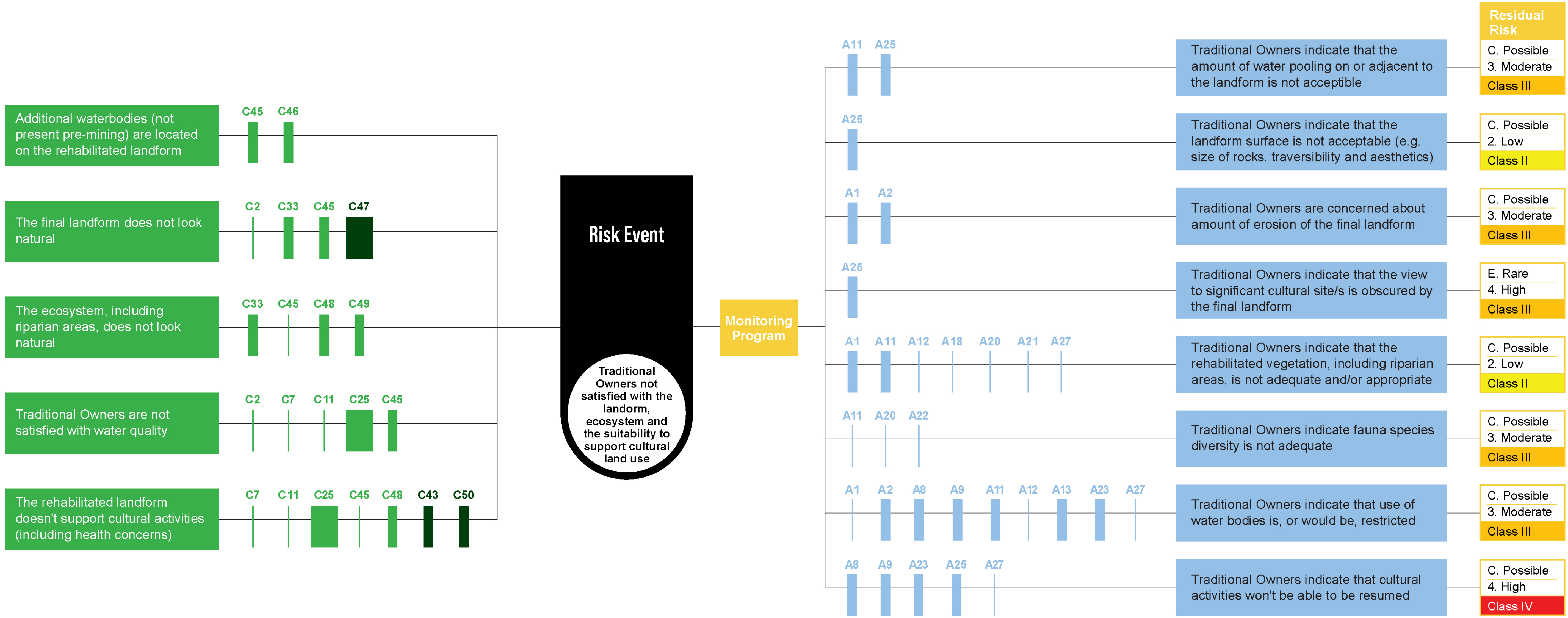


Figure 11-1: Bow-tie diagram for closure criteria – creating a landform that meets Traditional Owner requirements (CL1)

Preventative Controls

C1 Final landform design and construction
Marginal

C2 Erosion control measures including preparation of final landform surface
Marginal

C3 Sediment control measures including sediment basins
Satisfactory

C5 Revegetation of the final landform surface
Satisfactory

C7 All tailings deposited into Pits 1 and 3
Marginal - Strong

C11 Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met
Satisfactory

C12 Brine injected into Pit 3 underfill
Marginal - Satisfactory

C13 No water released from mine site unless it meets defined criteria and sufficient creek flow
Satisfactory

C44 Maintain tailings in near saturated state, and active dust control (water trucks, water cannons) prior to capping tailings and during movement of higher grade material
Satisfactory

C51 Implement Cultural Heritage Management System
Marginal

Corrective Actions

A28 Early notification and consultation with Traditional Owners and implementation of agreed mitigation
Satisfactory

A29 Initial response to prevent further damage
Satisfactory

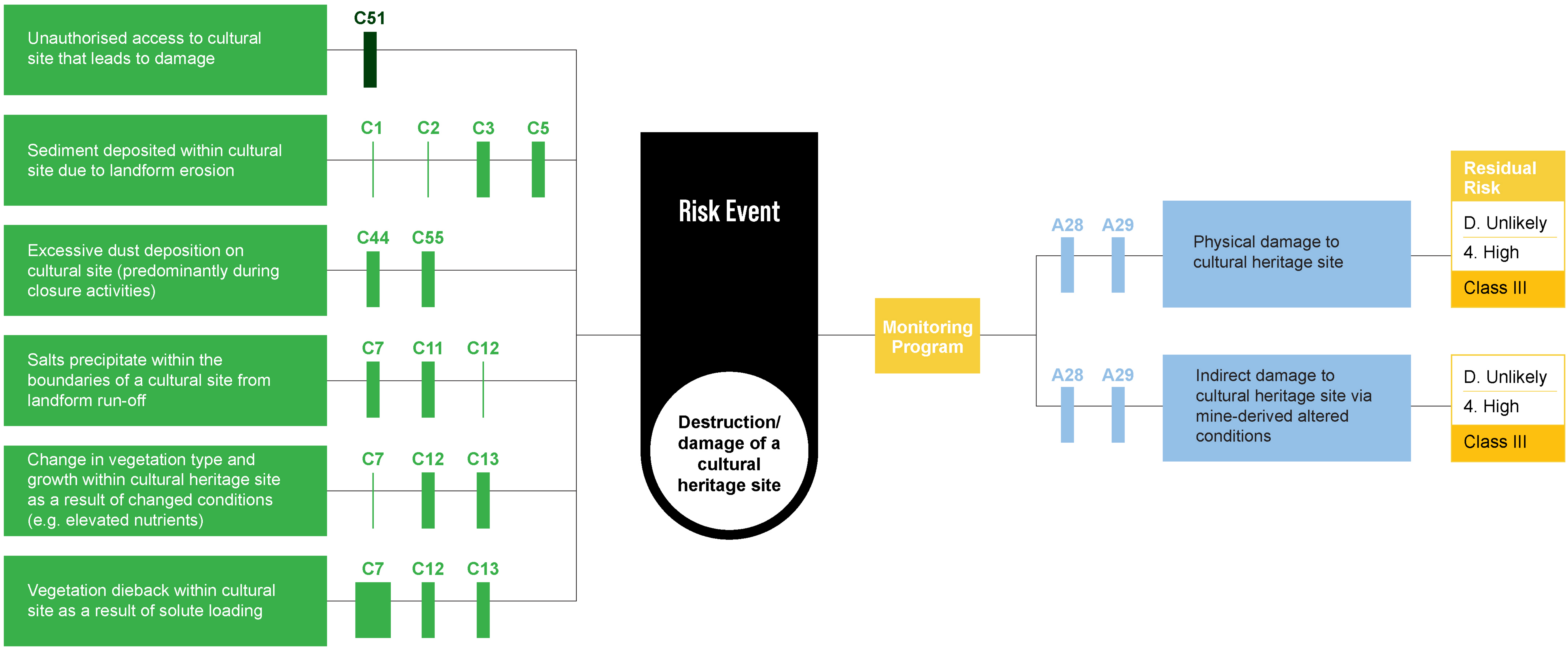


Figure 11-2: Bow-tie diagram for cultural management – to avoid destruction or damage to a cultural site (CL2)

11.5 Preventative controls and their effectiveness

The spider web diagram at the beginning of this chapter assigns a subjective 60% complete for the progress status relating to preventative controls.

As can be seen in the bow-tie diagram provided as Figure 11-1, the preventative controls relating to threats to the Traditional Owners' requirements are largely related to activities and processes that are described in the other themes in this MCP. As such, they are not repeated here and are summarised in Table 11-3. It is simply reiterated that ERA acknowledges the importance of open and transparent communication with the Traditional Owners to maintain a clear understanding of their expectations for the creation of the final landform.

With regards to the protection of cultural sites (bow-tie diagram Figure 11-2), specific preventative controls have been developed and these are described below.

There are nine cultural sites located within 200 m of where the final landform will tie-in to the existing landscape, with the closest being 30 m. It is considered that these sites have the highest potential to be impacted during the execution of the final landform construction, through accidental direct impact or indirect impact from excessive dust settling within the cultural site.

The preventative controls that are in place to manage direct damage to cultural heritage sites as a result of unauthorised access include the implementation of the CHMS and land disturbance permit process, consideration of cultural heritage in BPT assessments, physical demarcation and signage of all known cultural heritage sites, training and inductions, and a regular site condition audit program carried out in partnership with GAC. These controls range in effectiveness from 'Marginal' to 'Satisfactory' (Figure 11-2).

In addition, there are a number of cultural heritage sites within the RPA that are in close proximity to auxiliary access tracks. In addition to the physical demarcation and signage of known sites, Ranger project rules are in place, such as no driving off formed access tracks, to assist in mitigating against unauthorised vehicle access to a cultural heritage site. Any team or works program that requires access to areas off formed access tracks is assessed on a case-by-case basis with additional training in place to ensure team members are aware of the location of known cultural heritage sites.

The preventative controls in place to prevent indirect damage to cultural heritage sites relating to excessive dust deposition within a cultural site during construction relate to on-site dust management processes. These include dust suppression by water trucks especially in areas where conditions lead to a higher risk of dust production and dispersion, limiting vehicle speeds along site roads and regular track maintenance. Dust monitoring and review of predicted daily weather conditions will guide dust management activities. These preventative controls have been assigned a 'Satisfactory' effectiveness as they are common practice at Ranger. Isolated dusting incidents have occurred, and ongoing vigilance will be required when undertaking bulk material movement activities upwind of the culturally significant sites.

The threat of salt precipitation within a cultural heritage site relates to surface water run-off and the potential interactions with groundwater. The controls that are in place, or will be in place, to manage water contaminants are the same for the protection of cultural heritage. That is, there are no additional controls that can be implemented to specifically protect cultural heritage sites beyond those already identified in the Water and Sediment bow-ties (refer Chapter 7). The controls include: burying tailings and higher-grade materials in the lower levels of Pit 1 and Pit 3; pumping and treating water from Pit 1 and Pit 3 until the agreed criteria is met; and the brine injected into the Pit 3 underfill.

For the Mirarr Traditional Owners, maintaining the visual aesthetic and the environmental health within a cultural site is also very important. Any changes to the vegetation within a cultural heritage site as a result of project activities would be considered indirect impact. Changes may include changes to flora species type, vegetation growth affected or loss of vegetation. The most likely cause of changes to tree health and composition relate to water contamination. Thus, the preventative controls to manage water will also mitigate against indirect damage to cultural sites.

Table 11-3: Preventative Controls for Cultural

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C1	Final landform design and construction	Marginal	Modelling has demonstrated effectiveness of current final landform design. However, further work is planned to refine the final landform design and further reduce erosion and denudation rate. For more details on landform preventative controls refer to Section 6.5.
C2	Erosion control measures including preparation of final landform surface	Marginal	Currently at preliminary design with general consensus of the core principles, however further work is planned to incorporate catchment specific erosion and sediment control structures based on the assessments proposed to develop the *Erosion, Sediment and Water Control Plan.* For further details refer to Section 6.5.
C7	All tailings deposited into Pits 1 and 3	Marginal to Strong	All tailings gave been deposited at depth into both Pits 1 and 3 and reduces the risk of CoPC to the downstream environment (utilised for by Traditional Owners) through solute movement and/or mobilisation through erosion (Strong). The overall level of control for some CoPC is lower (Marginal) and requires complementary preventative controls to reduce loads and concentrations of these CoPC entering shallow groundwater and surface water systems in the receiving catchment. For further details refer to Section 7.5.
C11	Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met	Marginal to Strong	Pumping and treating CoPC at Ranger is a proven and effective method and is therefore a strong control for most CoPC. However, this control is assessed as having marginal effectiveness for manganese, ammonia and sulfate. For further details refer to Section 7.5
C25	Excavate and dispose contaminated soil/sediments into Pit 3 and RP2	Strong	Strong because considerable data is available, well established and proven method, more than sufficient void space is available and the validation sampling to identified contaminated soils will be completed well before Pit 3 is backfilled up to the grade 2 material cap. For further details refer to Section 8.5.
C33	Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application	Satisfactory	Establishment of the majority of dominant and important species has been demonstrated on waste rock and other substrates. However, there are remaining uncertainties for some species and particular methods for propagation and establishment. Understanding and effectiveness will increase with continued monitoring of current trials, and additional targeted trials for particular species. For more details refer to Section 9.5.

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
C45	Final landform designed and constructed to meet Traditional Owner requirements	Marginal to Satisfactory	Modelling has demonstrated effectiveness of current final landform design. However, further work is planned to refine the final landform design and further reduce erosion and denudation rate. Feedback from Traditional Owners through the Cultural Reconnection Steering Committee has led to changes to final landform design and surface and consultation will be ongoing throughout final landform construction. For more details on landform preventative controls refer to Section 6.5.
C46	All sediment basins will be removed and rehabilitated	Satisfactory	The plan to remove sediment basins required for water and sediment management to ensure no unnatural water bodies remain on the final landform is sufficient.
C48	Management of the rehabilitated landform for weeds, exotic fauna, fire pests and natural disturbances	Satisfactory	Compared to remnant vegetation, ERA has less experience with weed management in revegetated areas, where selective and species-specific application of herbicides is more important. Effectiveness will be increased with further planning, including methods for removal of existing weed cover, resourcing and implementation at scale. Fire management on the RPA surrounding the final landform is well understood and has been implemented over many years and offers protection to the rehabilitated areas. With respect to introduction of fire to the rehabilitated areas, there have been two trial burns applied to the Trial Landform that has provided a good understanding of this control and is expected to further improve with long-term implementation and monitoring. There is an active, accepted and successful exotic and threatening fauna management program in place on the RPA. The effectiveness of this program is expected to improve with increased understanding and resourcing. For further details refer to Section 9.5.
C49	Clean-up of all existing infrastructure and rubbish	Satisfactory	There is an annual general lease clean-up which has been ongoing throughout operations and closure and will continue throughout the rehabilitation phase. Additional targeted clean-up programs will be required to remove old infrastructure, including within areas of cultural significance. These clean-up efforts will be completed in partnership with Traditional Owners.
C3	Sediment control measures including sediment basins	Satisfactory	As above for erosion control structures and the proposed sediment basins are also currently at preliminary design. The location and size of these basins will be determined as part of the *Erosion, Sediment and Water Control Plan*. For further details refer to Section 6.5.
C5	Revegetation of the final landform surface	Satisfactory	ERA has demonstrated successful rehabilitation (~70% planting success rate) on Pit 1 after ~2 years and on the TLF after ~13 years. Monitoring data is available but further work is planned to finalise the species selection and demonstrate long-term sustainability of ecosystems on the final landform. For further details refer to Section 6.5.
C12	Brine injected into Pit 3 underfill	Marginal to Satisfactory	‘Satisfactory’ because the directionally drilled injection wells can be worked-over to unblock if required, and the capacity of the underfill has been calculated at 2.5 GL against the planned production of 1.9–2.1 GL of brine. Refer to Section 7.5 for more details.

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
C13	No water released from mine site unless it meets defined criteria and sufficient creek flow	Satisfactory	The ability to capture surface water runoff on-site provides an effectiveness rating of 'strong' for this control, however the 'satisfactory' effectiveness rating is considered relevant in terms of being able to achieve long-term post-closure management of water. Refer to Section 7.5 for more details.
C44	Maintain tailings in near saturated state and active dust control (water trucks, water cannons) prior to capping tailings and during movement of higher grade material	Satisfactory	This is a proven method and has been applied previously at Ranger with success. The effectiveness rating of Satisfactory rather than Strong has been applied recognising that there have been isolated dusting incidents. For further details refer to Section 6.5.
'Knowledge-based / Administrative' controls			
C43	Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bush foods	Satisfactory	The work by Garde (2015) established post-closure occupancy and verified dietary intakes first developed by Ryan and others (2011). These occupancy and dietary intake values are widely accepted. Considerable work by OSS (Doering *et al*., 2016, 2019) has established transfer factors in bushfoods and further studies are underway. For more details refer to Section 10.5.
C47	Line of site assessment for cultural landscape features undertaken and incorporated into final landform design and execution	Strong	A line of site assessment has been completed for the current design of the final landform that indicates that there will be visual connection between key cultural areas across the landscape.
C50	Final land use consultation with Traditional Owners	Satisfactory	The work by Garde (2015) established the nature and timing of post-closure occupancy by Mirarr Traditional Owners. These occupancy details are widely accepted. Further ongoing consultation is required throughout execution to ensure the final landform will meet these expectations.
C51	Implement Cultural Heritage Management System	Marginal	ERA has a Cultural Heritage Management System in place that provides administrative processes and procedures to ensure land disturbing activities undertaken on the RPA do not impact cultural heritage. Consideration for cultural heritage is also included in the closure/rehabilitation approvals process.

11.6 Monitoring Program

The spider web diagram at the beginning of this chapter assigns a subjective 50% complete for the progress status relating to monitoring. The monitoring program described below is based on the possible structure put forward by Murray Garde in 2015 (Garde, 2015).

Part of the scope for the consultation carried out by Garde (2015) was to understand the rehabilitation trajectory and its suitability for Traditional Owners cultural land use. Garde (2015) noted that there are "*very few established models or methodologies*" to inform long term periodic assessments of the attitudes and opinions of Traditional Owners "*in relation to the dynamics of rehabilitation over time*". In the absence of existing models to draw on, he proposed potential indicators that could be used to reflect Traditional Owners' attitudes towards the progress of rehabilitation. These indicators were largely based on visual and aesthetic factors. Garde provided various set of bilingual scalar measurement tools for monitoring the Traditional Owner attitudes towards aspects of the cultural closure criteria.

As noted by Garde, the program will "*involve long-term periodic assessment of attitudes and opinions of Traditional Owners and their kin in relation to the dynamics of rehabilitation over time".* These assessments will be undertaken annually (as a minimum) and will determine whether or not the Traditional Owners feel that rehabilitation in the RPA is progressing towards a desirable trajectory.

A scalar measurement tool for Traditional Owners impressionistic responses to closure with bilingual descriptive data to provide the rationale has been suggested (Table 11-4), which links back to the summary criteria presented in Table 11-1.

However, the ultimate method for monitoring will be determined in consultation with GAC and NLC.

Table 11-4: Example of scalar measurement tool for cultural criteria monitoring

1 | 2	3 | 4	5 | 6	7 | 8	9 | 10
ka-djalbolkwarre yerre	ka-bolkwarre yika ka-bolkmakmen kun-yahwurd	kareh ka-bolkmakmen kare lark	ka-bolkmakmen wurd	bon, ba-bolkmakminj wanjh
no improvement yet noticed	some minor improvements	some areas improved, some areas not	noticeable return to healthy state in most areas	satisfactory return to natural state

It is proposed that the Cultural Reconnection Steering Committee will be the instrument for monitoring the cultural closure criteria following the rehabilitation of the final landform. The steering committee was established by the NLC, in partnership with Mirarr Traditional Owners, the GAC and ERA. The Cultural Reconnection Steering Committee meets periodically, usually once a quarter, for on-site visits to view the rehabilitated areas and other areas of interest to progress ERA's understanding of the Traditional Owners' expectations and facilitate their reconnection to areas of the RPA. The steering committee allows Traditional Owners to raise concerns early during the planning and execution process, which in turn allows ERA to modify designs and processes if needed.

During the rehabilitation phase, further work and consultation to develop a culturally appropriate monitoring program will be conducted. The suitability of any measurement tool for the monitoring process (if one exists) will be confirmed with the Traditional Owners to ensure that the questions and the visual/aesthetic descriptions will assist in identifying where interventions and improvements are required to meet the cultural closure criteria.

Work is continuing to ensure the final landform delivers the appropriate cultural outcome, and ensure the right species are planted in the right places. This includes overlaying the final landform design with the Kundjeyhmi system of ecological zones (an-kabo, an-labbarl etc.), and then within each of these zones prescribing the layout/placement of various flora species. The Cultural Reconnection Steering Committee is progressing this work, with several visits to Ranger having already been held to provide feedback on the rehabilitation, revegetation and habitat recreation plans.

Consultation with the Cultural Reconnection Steering Committee will be ongoing throughout the execution phase and will be a key aspect of the cultural criteria monitoring program. Closure monitoring for cultural criteria will be conducted at a number of sites that collectively provide a cross section of the range of site types where rehabilitation has been undertaken or where the rehabilitation work has the potential for indirect impact. These sites will be identified in consultation with the Cultural Reconnection Steering Committee.

In addition to the monitoring for cultural closure criteria, a robust monitoring program of cultural heritage sites is in place to ensure that sites are protected from direct and indirect impact from the rehabilitation project. During the rehabilitation phase, the cultural heritage monitoring program will follow a similar structure to the established operations process at ERA. This will include:

- Audits and in-field checks as part of the land disturbance process.
- Triennial condition audit of cultural heritage sites by an external cultural heritage specialist engaged by ERA on behalf of GAC. ERA will not engage an external cultural heritage specialist to carry out this work who has not first been approved by GAC. A cultural heritage report will be produced and provided to ERA and the Relationship Committee by the external cultural heritage specialist.
- Rio Tinto Business Conformance Audits will also be completed every two years, which includes an assessment of the effectiveness of the Cultural Heritage Management System.

In 2019, prior to the cessation of operations in 2021, a comprehensive site audit was carried out to determine the baseline condition for closure. This audit was conducted by an external cultural heritage specialist engaged by ERA on behalf of GAC, Mirarr Traditional Owners and supported by ERA's Specialist Cultural Heritage. If at any stage of monitoring, damage to a cultural heritage site or the protective measures (i.e. demarcation and signage) is found, corrective action will be taken.

The cultural heritage monitoring program will provide a good opportunity for engagement and employment for local Aboriginal people.

11.7 Corrective Actions

As shown in Figure 11-1, the corrective actions to recover a deviated state for the final landform not meeting the requirements of the Traditional Owners are the same actions described in other themes of this MCP (particularly Landform, Water and Sediment, Radiation and Ecosystems). These corrective actions are summarised in Table 11-5.

Table 11-5: Corrective Actions for Cultural

Unique Identifier	Corrective Actions	Current Effectiveness	Status of Effectiveness
'Active' corrective actions			
A1	Maintenance of erosion and sediment control measures	Satisfactory	Erosion and sediment control measures will be maintained in a working and proper order throughout the closure and post-closure periods up until relinquishment.
A2	Undertaking earthworks to repair significant gullying or eroded areas	Satisfactory	These activities will occur prior to relinquishment if greater than predicted gullying is observed. Material erosion and gullying that occurs throughout the closure and post-closure periods will be actively managed.
A5	Removing any contaminated or impacted material (water and sediment)	Marginal	If monitoring detects contaminated material has been transported from the mine disturbance area it will be remediated up until relinquishment. Should this corrective action be required after relinquishment, there is uncertainty regarding resources available to execute this corrective action.
A8	Planned duration of pump and treat extended to further reduce peak contaminant loads	Satisfactory	The base case prediction is that active pump and treat will finish in 2034. Should monitoring determine the agreed water and sediment guideline values would not be met, pump and treat would be extended.
A9	Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels	Satisfactory	The effectiveness of this control is currently rated as 'marginal' based on uncertainties around requirements, potential impacts associated with implementation of these controls and uncertainty around the success of such interventions. Consultation required with Traditional Owners to understand their preferences.
A11	Infill planting and seeding to maintain suitable vegetative cover on final landform	Satisfactory	Infill planting may be required if unexpected impacts on vegetation associated with solutes in groundwater are observed. Control effectiveness for this corrective action is assessed as being 'satisfactory' due to some uncertainty regarding impacts associated with solute transport in the shallow groundwater.
A12	Additional interception system (e.g. passive reactive barrier)	Marginal	As these controls are still under investigation, they are rated as having a 'marginal' effectiveness.
A13	Discontinue use/change pesticide	Satisfactory	The effectiveness of this control is rated as 'strong' given its ability to avoid ongoing impacts.
A18	Targeted weed management	Marginal	Although this action is well understood, demonstrated effectiveness is poor for weed dominated areas such as those at the TLF. Effectiveness is expected to improve with further implementation.
A20	Addition of organic material/s and or fertiliser beyond that planned	Marginal	This action is understood to be potentially beneficial for a range of scenarios. Effectiveness will be improved with implementation at scale, if required.
A21	Targeted pest and disease management	Marginal	With fauna return expected to take some time, this action will only be considered in extreme circumstances, and is expected to improve with further planning and implementation, if required.

Unique Identifier	Corrective Actions	Current Effectiveness	Status of Effectiveness
A22	Supplementation of habitat features and/or migration corridors	Marginal	With fauna return expected to take some time, this action will only be considered in extreme circumstances, and is expected to improve with further planning and implementation, if required.
A23	Remediation (as required) of surface radiation following construction and rehabilitation of final landform	Satisfactory	Monitoring will occur progressively as the different stages of the final landform are established and higher-grade material (grade 2s and 3s) will be removed and replaced with lower grade material (grade 1s) if monitoring detects higher grade material at the surface.
A25	Reshape landform	Satisfactory	Landform reshaping is a common operational practice and although rework after several years of establishment is not an appealing option, it is well understood. Consultation with Mirarr Traditional Owners is key in understanding landscape aesthetics.
A26	Modified fire management	Marginal	The strategic introduction of fire is well understood and expected to be further improved with long-term implementation and monitoring. Exclusion of fire from rehabilitated areas (if needed) is well understood, proven and will be implemented as required.
A27	Remediation of surface sediment or salt deposition	Marginal	Remediation works to be undertaken where Traditional Owners identify areas that affect the general aesthetics of the landform or health of the ecosystem. The effectiveness will depend on the timing of the intervention.
‘Knowledge-based / Administrative’ corrective actions			
A28	Early notification and consultation with Traditional Owners and implementation of agreed mitigation	Satisfactory	Implementation of agreed mitigation in a timely fashion is considered satisfactory, mitigation includes remediation activities (if required) and legislative requirements.
A29	Initial response to prevent further damage	Satisfactory	This is key to ensure that continued damage does not occur to cultural heritage site and is undertaken in consultation with GAC.

With regards to cultural sites, the Cultural Heritage Management System has been developed as multi-layered protection against impact to cultural heritage sites. However, in the unlikely event that a cultural heritage site is damaged during closure, an agreed process is needed to manage the site remediation in accordance with NT legislative requirements and Traditional Owner requirements. This process is documented in Standard Operating Procedure *PRO043 Action damage or disturbance to cultural heritage site (or suspected site)*. The corrective action for damage to cultural heritage has four stages:

1. initial in-field management;
2. stakeholder consultation;
3. reporting; and
4. agreed mitigation.

The focus of the initial in-field management is to ensure that further damage to the cultural heritage site (or suspected site) is prevented if it is safe to do so. Following the initial discovery of damage or suspected damage to a cultural heritage site, the Specialist Cultural Heritage (or delegate) will review the cultural heritage GIS database to ascertain if any known sites are in the location and physically assess the area to determine the nature and extent of the damage, if any. GAC will also be notified immediately and provided the opportunity to visit the site with Traditional Owners. This approach will assist in developing an effective plan of management which allows for clear, informed and timely consultation with Traditional Owners.

Once the nature and extent of the damage is confirmed, a documented plan to manage the site remediation or salvage will be completed on a case-by-case basis. Generally, the following questions will be asked to understand the appropriate management:

- Can the damage be repaired, restored or stabilised?
- Can the works be continued as designed?
- Are additional protection measures needed?
- If the site cannot be protected from future damage, will Traditional Owners support an application for a permit from the Heritage Branch?
- What mitigation, if any, is required? (e.g. surface artefact collection, excavation, artefact storage or repatriation).

Once documented, the damage will be reported as required by NT legislation. A permit application will outline the nature of the damage and any proposed repair, restoration, stabilisation or other mitigation such as surface collection.

Concurrent to this process, an ERA representative, in consultation with GAC's cultural heritage representative, will establish an appropriate exclusion zone (which may be larger than the standard demarcation) to ensure the site is adequately protected prior to mitigation measures being completed.

11.8 Trigger, Action, Response Plan

Table 11-6 consolidates the monitoring and adaptive management programs described above into the form of a TARP for the cultural closure criteria and cultural heritage. The below TARP is based on our current understanding and may change or be further refined depending on the outcomes of future works as they evolve. This TARP will be updated as required in future iterations of the MCP.

Table 11-6: Trigger, Action, Response Plan for Cultural and Cultural Heritage

	Normal State	Level 1 Trigger	Level 2 Trigger
Trigger Action Response Plan	Triennial Audit program and Land Disturbance Permit follow up (as relevant) indicate adequate protection measures are in place and no direct or indirect damage has occurred.	Audit shows adequate protection measures are not in place.	Audit shows direct or indirect impact has occurred within cultural heritage site boundary.
	Input from Traditional Owners is provided on an ongoing basis in the planning, design and execution of the final landform and rehabilitation.	Traditional Owners identify potential future issue through Cultural Reconnection Steering Committee and monitoring program.	Traditional Owners identify an issue through Cultural Reconnection Steering Committee and monitoring program.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Site Cultural Heritage Officer (or delegate)	No action	Update site protection measures in line with site protocols and as outlined in the *Cultural Heritage Management Plan.*	Initial response to prevent further damage to cultural heritage sites, early notification and consultation with Traditional Owners, implementation of agreed mitigation/remediation, review of practices and procedures relating to cultural heritage protection and payment of fines for legislative breach (if applicable).
Senior Manager Approvals and Heritage	No action	Assess issue to determine appropriate actions. May require re-design or changes to execution plan.	The preventative controls associated with Traditional Owners not being satisfied with different aspects of the final landform and rehabilitation are generally related to other themes such as landform, water and sediment. Each Level 2 Trigger will be assessed and the appropriate corrective actions from the relevant theme will be implemented.

11.9 Future Work

The spider web diagram at the beginning of this chapter provided a subjective progress status for the cultural theme. Where <100% is indicated, future work is occurring, planned and/or required. The future work listed is based on our current understanding. These work programs may change or be further refined, removed or added to depending on the outcomes of the ongoing consultation with Traditional Owners.

Future work for the Cultural theme will consist of five discrete work packages. The work packages include consultation with Traditional Owners on formal agreement for cultural heritage for rehabilitation and post-closure; finalising the draft *Cultural Heritage Management Plan*; applying for an updated Aboriginal Areas Protection Authority (AAPA) Certificate; ongoing cultural heritage management; and the cultural closure criteria monitoring program and ongoing consultation.

Consultation on a formal cultural heritage agreement

As discussed in Section 11.3.1, ERA does not have a formal cultural heritage agreement with the Mirarr Traditional Owners. In 2006, an interim cultural heritage protocol was developed with the view that it would be replaced by a Cultural Heritage Management Plan (CHMP). However, the interim agreement remains the guiding document on cultural heritage management at Ranger. There have been some discussions with GAC regarding a formal cultural heritage agreement for rehabilitation; however, further consultation will be undertaken.

Finalise the draft Cultural Heritage Management Plan (CHMP)

The second work package is to finalise the draft CHMP. It is proposed that this is completed following the consultation regarding a cultural heritage agreement. The CHMP will be reviewed and revised based on the outcome of the cultural heritage agreement consultation.

Apply for an updated Aboriginal Areas Protection Authority (AAPA) Certificate

In 2023, as part of the recommendations from the 2023 Cultural Heritage site audit, GAC recommended that ERA apply for an updated AAPA certification for the RPA. ERA will consult with AAPA to obtain an updated AAPA Certificate. Following receipt of a new certificate a review of current systems and procedures will be undertaken to ensure they are compliant with any stipulations in the new AAPA certificate. The application for a new AAPA certificate is forecast for early 2024.

Ongoing cultural heritage management

Cultural heritage management will be ongoing on the RPA and will continue as outlined in the CHMP. This includes the consideration of cultural heritage as part of the land disturbance and approvals processes, the triennial audit program, mitigation works identified through the audits, and any survey work that may be undertaken to support rehabilitation works.

Monitoring programs and ongoing consultation

The consultation with the Cultural Reconnection Steering Committee will be ongoing throughout the execution phase and will be a key aspect of the cultural criteria monitoring program. During the rehabilitation phase, further consultation to finalise the monitoring program will be undertaken. The finalised monitoring program will assist in identifying where interventions and improvements are required to meet the cultural closure criteria.

ERA, NLC, GAC and the Mirarr Traditional Owners are aligned on the desire to upskill Traditional Owners to undertake some of the monitoring described in this MCP. The exact nature of this transition is currently being discussed; however, the Cultural Reconnection Steering Committee will be key in the planning to transition the management responsibility to the Mirarr Traditional Owners at final site relinquishment.

12 CONSOLIDATED RISK ASSESSMENT

Photo: Ranger Processing Plant and RP2 (2022)

There are three primary risk assessments that inform Ranger closure activities and the MCP:

1. The Ranger rehabilitation and closure risk assessment facilitated by CSIRO in 2013, which was based on sources, pathways, receptors and their interactions (Bartolo *et al.,* 2013), and identified key knowledge needs (KKNs). Investigations, studies, assessments and modelling exercises undertaken by ERA and OSS over the last decade have sought to address these KKNs and other knowledge gaps as they have arisen. Section 12.1 provides further discussion on this process.
2. The ERA risk management framework (hosted by the Rio Tinto risk platform called 'Archer'), which consolidates strategic, technical, commercial, safety and environmental risks into a single master register. This is a live process that is updated regularly, most recently in 2023 as part of the 2022 Feasibility Study. Section 12.2 provides further discussion on this process.
3. The Ranger Mine Closure Environmental Risk Analysis undertaken by Umwelt (2023), which assigned the ERs to the six Ranger themes and developed bow-tie diagrams to communicate the current risk to achieving the ERs. In other words, what are the threats to achieving the ER, what preventative controls are planned, what corrective actions are plausible, should these fail, what is the consequence and likelihood (and thus residual risk) that would result. This is a live process that will be updated annually and reported in each iteration of the MCP. Section 12.3 provides further discussion on this process.

12.1 CSIRO led 2013 risk assessment

The 2013 Ranger Rehabilitation and Closure Risk Assessment was completed in three phases commencing with problem definition and risk screening using conceptual models, through to the development of qualitative systems models to capture existing knowledge of key ecosystem processes, followed by detailed quantitative risk modelling using available data. The conceptual risk model identified sources and stressors, pathways, receptors/measurement endpoints, assessment endpoints and management goals.

The tiered assessment approach to the risk screening and identification of KKNs was reported in three separate articles. The first article by Bartolo and others (unpublished) outlined the method and results of a screening level risk assessment using stakeholder and expert knowledge to identify and rank 41 risks for the decommissioning phase and 93 risks for the post-decommissioning phase of site rehabilitation. The second article by Harford (unpublished) demonstrated how the risk screening results were applied to undertake a process for identifying knowledge gaps and determining KKNs. The third article by Bayliss (2018) provided a framework for conducting a quantitative and cumulative risk assessment for ecological risks.

All three reports present refinements of the conceptual causal models developed in the problem formulation phase.

The risks that resulted from this work have been reviewed and included where relevant in the *Bow-tie Diagram* section of Chapter 6 to Chapter 11. The studies that resulted from this work are included, where relevant, in the *Relevant Studies / Knowledge Base* section of Chapter 6 to Chapter 11.

12.2 Archer risk assessment

The objectives of the ERA risk management framework are to improve execution and reduce risk exposure. To achieve these objectives, ERA has implemented a structured and consistent process that provides a clear indication of the most significant risks and mitigating actions.

Successful management of risks requires the implementation of a clear risk management strategy supported by adequate resources and a strong risk-aware culture. To support risk management during closure execution, specific risk management accountabilities and responsibilities are assigned to relevant project and support personnel.

Since 2008, ERA has held regular risk assessment workshops to identify key risks relating to the closure of Ranger, each of which resulted in a material update to the Archer risk register. The most recent update occurred in 2023 as part of the 2022 Feasibility Study.

The management process applied to risk assessments at Ranger is consistent with the following national and corporate management standards:

- AS/NZS ISO 14001 Environmental management systems – specification with guidance for use;
- AS48012 Occupational health and safety (OHS) management systems – specification with guidance for use;
- AS ISO 31000:2018 Risk Management– Principles and guidelines;
- Environmental risk management – Principles and processes (HB 203:2012);
- Rio Tinto Risk Policy and Risk Management Standard (2019), Rio Tinto Health, Safety and Environment (HSE) management system – Element 3 hazard identification and risk assessment; and
- Rio Tinto HSE performance standards.

Whilst the risks to achieving ERs identified in the bow-tie diagrams are captured in the Archer register, other risks that relate to the physical activities that are to occur on-site to successfully close and rehabilitate the mine site are also captured in the Archer register. These latter risks are referred to as 'project risks' and their consequence ratings are largely influenced by project cost and schedule.

12.3 Umwelt led 2023 risk assessment

The objectives of the Umwelt 2023 risk assessment were to quantify the risk of not achieving each of the ERs, and to prioritise future work based on an assessment of the current effectiveness of preventative controls and corrective actions. Section 5.4 of this MCP describes the bow-tie risk assessment process used to achieve these two objectives. The look-up tables used in this process for consequence, likelihood and risk rating are provided in Table 12-1, Table 12-2 and Table 12-3 respectively.

12.4 Findings

Table 12-4 provides a consolidated list of the risks and their ratings derived from the bow-tie diagrams provided in Chapter 6 to Chapter 11. The additional project risks are provided in Table 12-5.

Table 12-1: Risk assessment consequence table

Consequence Type	CONSEQUENCE				
	1. Very Low	2. Low	3. Moderate	4. High	5. Very High
Landform / Ecosystem Development	Natural variability in trajectory	Easily mitigated variation in trajectory	More complex but reversable trajectory changes	Significant changes in trajectory that are very difficult to resolve	Major changes in trajectory where rectification is unfeasible
Contamination	Detectable contamination or radiation dose to environment and/or biota	Noticeable change to environment and/or biota related to contamination	Significant change to environment and/or biota related to contamination; Minor tailings derived contamination or exposure	Cascading change to multiple components of environment and/or biota related to contamination; Moderate tailings derived contamination or exposure	Entire ecosystem or landscape is impacted by contamination; Significant tailings derived contamination or exposure
Human health and safety	Low-level short-term inconvenience or symptoms; measurable increase in radiation dose within acceptable limits	Injury or illness requiring medical treatment; Radiation dose above limits	Injury / illness with moderate damage or impairment to one or more persons; significant radiation dose with increased risk of cancer	Single fatality or severe permanent impairment; Significant radiation dose to multiple people and acute radiation syndrome to one individual	Multiple fatalities or severe permanent impairment to multiple people; Acute radiation dose to multiple people
Cultural	Minimal loss of trust; minimal restriction to cultural activities or occupation	Resolvable loss of trust; Restricted cultural activities or occupation at certain times in a year	Loss of trust that cannot be resolved easily; Restricted cultural activities or occupation, particularly around water bodies	Widespread, sustained loss of trust; Long term restrictions of cultural activities or occupation, particularly around water bodies	Systematic opposition that spreads to other Rio Tinto sites; Permanent restriction of cultural activities or occupation post closure
Closure scope, scope and legacy	Minimal scope change complexity/cost and/or informal disapproval from stakeholders	Minor scope change complexity, remediation costs within resources/budget and/or informal disapproval from stakeholders	Moderate scope change complexity, remediation costs above planned resources/budget, formal disapproval and/or reputational damage	Significantly scope change complexity, remediation costs well above resources/budget and/or national reputational damage	Unfeasible changes to scope, unfeasible additional cost and/or international reputational damage
Spatial extent (if applicable)	Near source and confined, single point	Localised, multiple points	Largely localised but unconfined	Unconfined, entire system catchment	Unconfined and widespread, regional/landscape scale

Note: whilst not specifically included above, the response time for recovery from a deviated trajectory to a desired trajectory is considered when assessing the consequence of a corrective action.

Table 12-2: Risk assessment likelihood table

	LIKELIHOOD				
	A. Almost Certain	**B. Likely**	**C. Possible**	**D. Unlikely**	**E. Rare**
Frequency / probability of detected deviations	Detected deviations in more than 75% of monitoring events over proposed timeframe*	Detected deviations in 50–75% of monitoring events over proposed timeframe*	Detected deviations in 25-50% of monitoring events over proposed timeframe*	Detected deviations in 5–25% of monitoring events over proposed timeframe*	Detected deviations in less than 5% of monitoring events over proposed timeframe*
General description	Almost certainly occurs in every scenario	Occurs in most scenarios	Occurs in some scenarios	Occurs in very few scenarios	Difficult to predict any scenario with an occurrence

* the proposed timeframe over which the likelihood is determined necessarily varies for different aspects. For the purpose of the MCP:

- 10,000 year timeframe is relevant to the bow-ties identified as L1, WS1, WS2 and WS3;
- 300 year timeframe (or 7 generations from Traditional Owner viewpoint) is relevant to the bow-ties identified as CL1, ES1, ES2, ES5, ES6 and ES7;
- 50 year timeframe is relevant to the bow-ties identified as ES3, ES4, L2, R1 and R2; and
- 10 year timeframe is relevant to the bow-ties identified as CL2 and S1.

Table 12-3: Risk assessment risk rating table and associated response

Likelihood	Consequence				
	1. Very Low	2. Low	3. Moderate	4. High	5. Very High
A. Almost Certain	Class II	Class III	Class IV	Class IV	Class IV
B. Likely	Class II	Class III	Class III	Class IV	Class IV
C. Possible	Class I	Class II	Class III	Class IV	Class IV
D. Unlikely	Class I	Class I	Class II	Class III	Class IV
E. Rare	Class I	Class I	Class II	Class III	Class III

Risk Classification	Response
Class I	Risks that are below the risk acceptance threshold and do not require further controls or studies
Class II	Risks that lie on the risk acceptance threshold and require some development of controls details or studies to address uncertainty
Class III	Risks that exceed the risk acceptance threshold and require further investment in controls and study development, with classification of uncertainty
Class IV	Risks that significantly exceed the risk acceptance threshold and require investment in a complete suite of suitable best practice controls and detailed studies to classify uncertainty

Table 12-4: Consolidated risks from bow-tie diagrams (see relevant chapters for details)

Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
WS1 and WS2 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (Djalkmarra Catchment and Coonjimba Catchment)	Above criteria concentrations of manganese result in health impacts	B. Likely	3. Moderate	Class IV
WS1 and WS2 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (Djalkmarra Catchment and Coonjimba Catchment)	Above criteria concentrations of manganese, sulfate and/or nutrients result in environmental impacts	B. Likely	3. Moderate	Class IV
WS1 and WS2 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (Djalkmarra Catchment and Coonjimba Catchment)	Above criteria concentrations result in land access and cultural restrictions	C. Possible	4. High	Class IV
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Elevated concentrations of sulfate result in increased ASS formation and acidification processes	B. Likely	3. Moderate	Class IV
ES4 (Ecosystems) – Significant presence or abundance of weeds	Stakeholders are not satisfied with the presence of weeds – relinquishment is delayed	B. Likely	4. High	Class IV
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners indicate that cultural activities won't be able to be resumed	C. Possible	4. High	Class IV
L2 (Landform) – Tailings are exposed within 10,000 years	Environmental and health impacts at the point of exposure	D. Unlikely	4. High	Class III
L2 (Landform) – Tailings are exposed within 10,000 years	Tailings are transported out of the pits	D. Unlikely	4. High	Class III
S1 (Soils) – Contaminated soils are not remediated to ALARA	Treatment at Coonjimba Billabong is unable to achieve target levels, requiring access and/or land use restrictions unacceptable to the Mirarr people	D. Unlikely	4. High	Class III
ES1 (Ecosystems) – Vegetation composition, abundance or community structure are on a deviated trajectory	Stakeholders are not satisfied with vegetation, composition, abundance and/or structure – relinquishment is delayed	C. Possible	3. Moderate	Class III
ES2 (Ecosystems) – Fauna composition, abundance or habitat formation are on a deviated trajectory	Stakeholders are not satisfied with fauna composition, abundance and/or formation of habitat – relinquishment is delayed	C. Possible	3. Moderate	Class III
ES3 (Ecosystems) – Evidence that nutrient cycling will not sustain ecological processes	Stakeholders are not satisfied with evidence of nutrient cycling – relinquishment is delayed	C. Possible	3. Moderate	Class III
R1 (Radiation) – Radiation doses to humans are not ALARA	Above baseline radiation doses result in health impacts	E. Rare	5. Very High	Class III

Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
R1 (Radiation) – Radiation doses to humans are not ALARA	Access restrictions to land	E. Rare	5. High	Class III
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners indicate that the amount of water pooling on or adjacent to the landform is not acceptable	C. Possible	3. Moderate	Class III
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners are concerned about amount of erosion of the final landform	C. Possible	3. Moderate	Class III
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners indicate that the view to significant cultural site/s is obscured by the final landform	E. Rare	4. High	Class III
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners indicate fauna species diversity is not adequate	C. Possible	3. Moderate	Class III
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional owners indicate that use of water bodies is, or would be, restricted	C. Possible	3. Moderate	Class III
CL2 (Cultural) – Destruction / damage of a cultural heritage site	Physical damage to cultural heritage site	D. Unlikely	4. High	Class III
CL2 (Cultural) – Destruction / damage of a cultural heritage site	Indirect damage to cultural heritage site via mine-derived altered conditions	D. Unlikely	4. High	Class III
L1 (Landform) – Erosion characteristics of the rehabilitated landform vary significantly from comparable landforms	Impact of sediment to surrounding ecosystems	C. Possible	2. Low	Class II
L1 (Landform) – Erosion characteristics of the rehabilitated landform vary significantly from comparable landforms	Unsightly landscape and limited traversability for cultural activities	C. Possible	2. Low	Class II
L2 (Landform) – Tailings are exposed within 10,000 years	Restrictions to land access and cultural activities, reputational damage relationship with key stakeholders and community distrust	E. Rare	3. Moderate	Class II
WS1 and WS2 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (Djalkmarra Catchment and Coonjimba Catchment)	Above criteria concentrations (except manganese) result in health impacts	D. Unlikely	3. Moderate	Class II
WS1 and WS2 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (Djalkmarra Catchment and Coonjimba Catchment)	Above criteria concentrations (except manganese, sulfate and/or nutrients) result in environmental impacts	D. Unlikely	3. Moderate	Class II
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Above criteria concentrations of magnesium and sulfate result in environmental impacts	D. Unlikely	3. Moderate	Class II

Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Above criteria concentrations result in land access and cultural restrictions	D. Unlikely	3. Moderate	Class II
S1 (Soils) – Contaminated soils are not remediated to ALARA	Contaminated soils are not identified or remediated appropriately	D. Unlikely	3. Moderate	Class II
S1 (Soils) - Contaminated soils are not remediated to ALARA	Soil contamination identified, however both Pit 3 and RP2 have already been backfilled	D. Unlikely	3. Moderate	Class II
S1 (Soils) – Contaminated soils are not remediated to ALARA	The ecosystem of the RPA (plants and animals) is adversely effected by uptake of contaminants from soil	D. Unlikely	3. Moderate	Class II
ES4 (Ecosystems) – Significant presence or abundance of weeds	Further weed spread into surrounds	D. Unlikely	3. Moderate	Class II
ES6 (Ecosystems) – Ecosystems are not resilient to the appropriate fire regime	Stakeholders are not satisfied with ecosystem resilience to an appropriate fire regime – relinquishment is delayed	D. Unlikely	3. Moderate	Class II
ES7 (Ecosystems) – Ecosystems are not resilient to extreme weather events, pests or disease	Stakeholders are not satisfied with ecosystem resilience to extreme weather events, pests or disease – relinquishment is delayed	D. Unlikely	3. Moderate	Class II
R2 (Radiation) – Radiological impacts to non-human biota are not ALARA	Radiation exposure to terrestrial species has detrimental effects	E. Rare	3. Moderate	Class II
R2 (Radiation) – Radiological impacts to non-human biota are not ALARA	Radiation exposure to aquatic species has detrimental effects	E. Rare	3. Moderate	Class II
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners indicate that the landform surface is not acceptable (e.g. size of rocks, traversability, aesthetics)	C. Possible	2. Low	Class II
CL1 (Cultural) – Traditional Owners not satisfied with the landform	Traditional Owners indicate that the rehabilitated vegetation, including riparian areas, is not adequate and/or appropriate	C. Possible	2. Low	Class II
WS1 and WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (Djalkmarra Catchment and FLF/LAA catchment)	Hydrocarbons in water impact amenity or result in environmental impacts	D. Unlikely	2. Low	Class I
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Above criteria concentrations of magnesium and sulfate result in health impacts	E. Rare	2. Low	Class I

Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Elevated concentrations of pesticides have adverse environmental or health risks	D. Unlikely	2. Low	Class I
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Increased nutrients result in environmental impacts	E. Rare	2. Low	Class I
WS3 (Water and Sediment) – Surface or ground waters from the RPA do not meet relevant criteria (FLF and LAAs)	Elevated Total Suspended Solid (TSS) impacts ecosystem functioning	D. Unlikely	2. Low	Class I
S1 (Soils) – Contaminated soils are not remediated to ALARA	Additional remediation which requires destruction of planted areas and subsequent rehabilitation	D. Unlikely	2. Low	Class I
ES5 (Ecosystems) – Significant abundances of exotic fauna	Stakeholders are not satisfied with presence of exotic fauna – relinquishment is delayed	D. Unlikely	2. Low	Class I
ES5 (Ecosystems) – Significant abundances of exotic fauna	Further exotic fauna spread into surrounds	D. Unlikely	2. Low	Class I

Table 12-5: Relevant project risks from 2023 Archer register (risks captured in Table 12-4 are not duplicated in this table)

Risk	Description / Comment	Contingency / Effectiveness	Likelihood	Consequence	Rating
Insufficient capacity of underfill to accept all brine produced	Latest calculations indicate a capacity of 2.5 GL and a predicted total brine production of 1.9–2.1 GL, thus the brine would utilise 76–84% of the underfill capacity.	Reduce the volume of brine to be injected Effectiveness: Marginal	C. Possible	5. Very High	Class IV
Failure to achieve release water criteria after two consecutive wet seasons	Inadequate length of time suggested for operation of the catchment sediment basins, failure to address erosion and resulting sedimentation from source areas.	Increased maintenance of erosion and sediment controls at source areas, extension of timeframe for active management Effectiveness: Satisfactory	B. Likely	4. High	Class IV
Failure to meet production targets for process water extraction from Pit 3 / treatment	Extraction of PTF from Pit 3 and/or treatment of process water takes longer than expected (e.g. via slower than expected consolidation of tailings, inefficient decant system; insufficient capacity and/or inefficiency of BC, OBS).	Increase in extraction and/or treatment capacity, extension of timeframe for active management Effectiveness: Satisfactory	C. Possible	4. High	Class IV

Risk	Description / Comment	Contingency / Effectiveness	Likelihood	Consequence	Rating
Failure to manage weeds, including Spigelia	This risk is critically important for the FLF but also relevant to the BMM for Pit 3. Weed control and adherence to vehicle hygiene procedures will be very important during the BMM and demolition activities.	Increased weed control and adherence to procedures Effectiveness: Satisfactory (for Pit 3)	C. Possible	4. High	Class IV
Failure to achieve relinquishment after 25 year monitoring period	Longer than expected timeframe to demonstrate that closure criteria have been achieved and/or on a trajectory to being achieved.	Extension of project timeframe Effectiveness: Marginal	C. Possible	4. High	Class IV
Failure to manage Browsing Ant	This risk is critically important for the FLF but also relevant to the BMM for Pit 3. Existing programs will continue and are proving effective.	Ramp up existing program Effectiveness: Satisfactory (for Pit 3)	D. Unlikely	4. High	Class III
Failure to inject brine into the underfill	Three directionally-drilled, steel-cased injection wells with accessible headworks currently installed. The first well remains operational and effective and each well can be reworked if blocked.	Work-over rig to unblock existing three wells. Install additional brine injection wells (either directionally drilled or vertically drilled once FLF achieved over Pit 3) Effectiveness: Satisfactory	D. Unlikely	4. High	Class III
Failure to include appropriate rainfall data into water balance model leading to increased process water inventory for treatment	Rainfall exceeds that included within the water balance model, particularly if this occurs later in the closure schedule.	Conservative (last 30 year rather than last 120 year) rainfall data included in water balance model, extension of project timeframe Effectiveness: Satisfactory	C. Possible	3. Moderate	Class III
Failure to provide reliable and continuous provision of pond and process water storage and transmission	Storm events and excessive rainfall events causing over-topping of water storages, inadequate capacity.	Maintain RWD to manage water storage capacity in a conservative manner Effectiveness: Satisfactory	D. Unlikely	4. High	Class III
Failure to ensure Mine Closure Plan and activity approvals are not delayed	Many factors could contribute to this risk including engineering design not sufficiently advanced in time for approval application, technical studies not satisfactorily completed, and/or level of remaining uncertainty too high to support approval.	Incorporation of engineering studies, technical studies and conservative assessment timeframes into the master execution schedule Effectiveness: Satisfactory	C. Possible	3. Moderate	Class III
Failure to extract expressed tailings pore water	May happen if decant towers not located in lowest point of the tailings and/or collapse or otherwise fail.	Extraction from settlement towers and extension of project timeframe Effectiveness: Marginal	D. Unlikely	3. Moderate	Class II

Risk	Description / Comment	Contingency / Effectiveness	Likelihood	Consequence	Rating
Large scale failure of the capping surface	Areas of large differential settlement may occur for several reasons such as inadequate testing of capping strength, inadequate drying time, rapid fill placement, failure of geotextile.	Rectification and extension of project timeframe Effectiveness: Marginal	D. Unlikely	3. Moderate	Class II
Localised failure of geotextile or capping surface	May occur for several reasons such as inadequate testing of capping strength, inadequate drying time, rapid fill placement, failure of geotextile.	Rectification and extension of project timeframe Effectiveness: Satisfactory	C. Possible	2. Low	Class II
Failure to achieve revegetation planting rates	Insufficient seed, tubestock or resources to achieve scheduled planting rates.	Extension of planting timeframe Effectiveness: Marginal	B. Likely	2. Very Low	Class II
Tailings consolidation is slower than expected	Water treatment of pore water expressed from tailings is currently the critical path for the project timeframe – this and BMM subject to further studies.	Extension of project timeframe Effectiveness: Marginal	D. Unlikely	3. Moderate	Class II
Bio-security determination or other border restrictions impact the schedule	Changes to National, State or Territory border responses due to introduction of new pests or diseases, and/or epidemic declared that impacts operations.	Extension of project timeframe Effectiveness: Marginal	D. Unlikely	3. Moderate	Class II
Failure to manage slope failure hazard in Pit 3 and/or stockpiles during BMM	This may occur from unknown latest geotechnical conditions, vehicles entering an area of known instability, extreme flood event.	Good controls in place, remediation/rectification would occur Effectiveness: Satisfactory	D. Unlikely	1. Very Low	Class I
Loss of process water containment	Rupture of pipeline/s, failure of leak detection system and bunding.	Rectification / remediation Effectiveness: Satisfactory	D. Unlikely	2. Low	Class I
Failure to achieve planned consolidation of bulk fill	Compaction of bulk fill could be greater than planned, requiring additional material.	Material would be scavenged from other FLF volumes Effectiveness: Satisfactory	C. Possible	1. Very Low	Class I
Failure to manage source and destination of grade or mineralised material	May be caused by several factors such as inaccuracies in stockpile block model, discrimination strategy, fleet management systems.	Rehandling of material following radiation survey Effectiveness: Marginal	C. Possible	1. Very Low	Class I
Failure of demolition activities	Uncontrolled release from, and/or inadequate removal and disposal of, demolished material.	Good controls in place, remediation/rectification would occur Effectiveness: Satisfactory	D. Unlikely	2. Low	Class I

Risk	Description / Comment	Contingency / Effectiveness	Likelihood	Consequence	Rating
Failure to provide sufficient infrastructure and capability to manage offsite discharge of release water	Inappropriate pump capacity for catchments.	Controls are mature and proven Effectiveness: Satisfactory	D. Unlikely	2. Low	Class I
Failure to prevent RWD wall breach whilst still in use or during deconstruction works	May be caused by several factors such as draw down rates within the facility cause instability and slumping of the walls, excessive erosion on the walls, overtopping of the walls.	Risk decreasing in line with inventory, wall integrity monitoring and reporting to ensure stability Effectiveness: Strong	E. Rare	2. Low	Class I
Failure to manage decant and settlement monitoring towers	Management of contractors during installation of decant systems and towers required for quality control.	Contingency measure is rework and repair if required (excavate and reset) Effectiveness: Marginal	C. Possible	1. Very Low	Class I
Failure to provide a safe, secure and reliable power supply	Power supply maintenance program for aging assets and appropriate infrastructure as required for reliable continuity of service.	New facilities as and if required Effectiveness: Satisfactory	D. Unlikely	2. Low	Class I
Failure to manage cyber security threat causing system failure	May be caused by several factors resulting in need to remediate operating systems.	Preventative maintenance ongoing and recovery plan in place Effectiveness: Satisfactory	D. Unlikely	2. Low	Class I

13 TIMING AND FINANCIAL PROVISION FOR CLOSURE

13.1 Rehabilitation provision

The Energy Resources of Australia Ltd (ERA) rehabilitation provision as at 30 June 2023 was $1,446 million. The calculation of the rehabilitation provision relies on estimates of costs and their timing to rehabilitate and restore disturbed land to establish an environment similar to the adjacent Kakadu National Park in line with the Company's statutory obligations.

The costs are estimated on the basis of a closure plan, taking into account considerations of the technical closure options available to meet ERA's obligations. The provision for rehabilitation represents the net present cost as at 30 June 2023 of the preferred plan and represents managements best estimate of cost.

In determining the provision as at 30 June 2023, ERA considered initial findings from the 2022 Feasibility Study and work in preparation for the interim entitlement offer. The estimate was updated to the extent that changes reached a level that allowed ERA to determine that it was probable that cash outflows would be required to settle the obligation. The reforecast estimate is prepared in nominal terms, it has then been adjusted to real terms by removing the impacts of inflation. As the time value of money is material to value of these costs, this has then been discounted at 2.0% to calculate a closure provision.

The ultimate cost of rehabilitation is uncertain and can vary in response to many factors including legal requirements, technological change, weather events and market conditions.

ERA has received outcomes and data from the 2022 Feasibility Study in October 2023 and those matters are currently under review. ERA is unable to confirm the total rehabilitation costs and project scheduled completion at this time due to a number of significant preliminary findings emerging from the 2022 Feasibility Study process that require further analysis and studies. The separate analysis and studies are to be undertaken to investigate alternative solutions, and their outcomes will be used to verify and attempt to mitigate costs. These studies will likely proceed into 2024.

ERA expects total rehabilitation costs to materially exceed the previous estimated range of $1.6 billion to $2.2 billion, and final completion date will also be delayed.

13.2 Cash flow timing

The company estimates the presentation of its rehabilitation provision between current and non-current liabilities, based on anticipated timing of expenditure from updated cash flow forecasts.

13.3 Closure Feasibility Study Update

In May 2022, ERA commenced a feasibility study update in connection with a lower technical risk rehabilitation methodology (primarily relating to the subaerial capping of Pit 3) and to further refine the Ranger Project Area rehabilitation execution scope, risks, cost and schedule. As discussed above, ERA has received outcomes and data from the 2022 Feasibility Study and those matters are currently under review. A number of significant findings emerged from the 2022 Feasibility Study requiring further analysis and studies that will likely proceed into 2024.

13.4 Government Agreement

Separate to this MCP, ERA is required to maintain the Ranger Rehabilitation Special Account (Trust Fund) with the Commonwealth Government. The Trust Fund is intended to provide security against the estimated costs of closing and rehabilitating the Ranger mine immediately. Each year, the Company is required to prepare and submit to the Commonwealth Government an Annual Plan of Rehabilitation (Annual Plan). Once accepted by the Commonwealth Government, the Annual Plan is then independently assessed and costed and the amount to be provided by the Company into the Trust Fund is then determined.

As at 30 June 2023, ERA had $496 million in cash currently held by the Commonwealth Government as part of the Ranger Rehabilitation Special Account (Trust Fund). In addition, bank guarantees procured by ERA totalling $125 million are held by the Commonwealth as additional security for ERA's Ranger rehabilitation obligations (an additional $1 million is held as an allowance for Jabiluka rehabilitation).

These bank guarantees were provided to the Commonwealth Government based on its review in February 2020 of the 44th Annual Plan of Rehabilitation submitted by ERA (i.e. prior to the Reforecast of the cost of Ranger Project Area rehabilitation).

ERA has agreed amendments to its Government Agreement with the Commonwealth to introduce a clearer framework for managing the amount of security held by the Commonwealth and releasing funds from the Trust Fund for completed rehabilitation works. However, drawdown of funds under this framework will first require revaluation of the security following ERA's internal cost review.

Given the expected increase in the cost of rehabilitating the Ranger Project Area, ERA may be required to provide additional security.

Under this new framework, ERA was entitled to submit a one-off interim payment request for the release from the Trust Fund of an amount representing a portion of the cost of rehabilitation works performed at Ranger between 9 January 2021 and 30 June 2022. An application for a drawdown of $57 million was submitted and approved, and funds were received in November 2022.

ERA does not consider that it can rely upon drawdown of further cash from the Trust Fund before the internal cost review is completed as part of the 2022 Feasibility Study.

14 MANAGEMENT OF INFORMATION AND DATA

This chapter provides an overview of the information management systems used by ERA to manage closure related data. The accessibility and retention of multi-disciplinary closure related data is imperative for confirming the successful achievement of mine closure and rehabilitation activities at Ranger. The monitoring, recording and documentation of closure processes is also key for auditing and the capacity for adaptive management.

To support closure activities and provide confidence in the strategy, ERA has identified three key components for closure knowledge to be retained:

- validation of site conceptual/numerical models;
- landform design and construction, and
- progressive rehabilitation.

The retention and management of this information is important to demonstrate the appropriateness of, and adherence to, approved closure activities. Further specifics on post-closure data retention and handover requirements at relinquishment will be determined in consultation with the relevant government agencies.

14.1 Data collection and management

ERA has maintained accreditation to ISO 14001:2015 environmental management systems since 2003. The management system provides for consistent performance indicators (including appropriate backup measures for electronic data and document control). The system also provides for compliance self-assessment, which is routinely verified through mechanisms such as periodic inspections and audits by stakeholders including Rio Tinto, regulators and committees.

Records and data are managed according to a range of policies, standards and work instructions to ensure data is secure, maintained, accurate and retrievable. Information is kept in approved data management systems.

To support closure operations, a program of ongoing works is being undertaken to ensure critical information is available. In accordance with the prescribed legal requirements, the aim of the program is to ensure that the information systems can be maintained and, where necessary, relocated efficiently and effectively without disrupting the activities of business units, and to handover appropriate materials at relinquishment for ongoing monitoring. The program includes:

- review of the retention schedule to ensure alignment with current legislation and to address specific business needs and document control;
- risk assessment to determine future potential information retrieval scenarios in order to inform current retention procedures;
- identification and classification of data sources against current and future needs, including the potential for addressing historical datasets on redundant media to ensure they are retrievable, if necessary;
- evaluation of digital delivery platforms to ensure alignment of systems and increased collaboration with partners for innovation and improved outcomes; and
- development of a progressive handover specification detailing data source and type, nominating handover recipient, reason for handover and indicative timelines.

14.2 Data availability and reporting

Long-term obligations towards data and information management are represented in various legislative requirements. A specific example is Schedule 7.5 of the Ranger Authorisation requiring ERA to:

"… maintain to the satisfaction of the NT Minister and for examination by a Mining Officer, all records and data associated with the operation and monitoring of the water management system for the life of the mine up to and including rehabilitation and post closure."

Further to the above requirement:

- The environmental monitoring requirements provided under Schedule 13 of the ERs states that the company must ensure data and reports are available to major stakeholders (Schedule 13.2a) and reports, other than commercial-in-confidence matters, are available to members of the ARRAC (Schedule 13.2b).

- Research undertaken, plans and results must be provided to AARTC as per Schedule 15.1 of the ERs, to enable the Committee to co-ordinate research in the broader region.
- Under the *Work Health and Safety (National Uniform Legislation) Act 2011*, health monitoring records, air monitoring results and hazardous substances exposure records must be available as required by the business or in response to approved stakeholder request, up to and including post closure in accordance with specific retention needs.

The types of data collected by ERA is provided in Table 14-1. New/expanded data sets will continue to inform and/or validate the various conceptual and numerical models on which the closure strategy and design criteria are developed, as well as other aspects of the overall design and construction of the final landform. This is an iterative process and ERA maintains these datasets within its various document management systems.

Table 14-1: Indicative data collection types

Type	Storage / software	Reporting	Objective (s)
As built records (drawings)	• Data viewer. • ERA server and centralised data storage systems (includes ProjectWise).	• As built report.	• To maintain construction standards. • To inform decommissioning and remediation programs.
Documents	• Aconex, Primavera P6, Ecosys.	• Internal. • Annual report. • Rehabilitation Progress Report.	• To record project decisions. • To manage changes in strategy documents.
Ecological surveys (including related Raster, LiDAR and/or drone imagery)	• ArcGIS. • ERA server and centralised data storage systems. • DroneDeploy.	• Periodical reports (developed internally and externally). • Ranger Mine Closure Plan (MCP). • ARRTC.	• To record and demonstrate progressive remediation and rehabilitation. • To inform closure criteria. • To inform revegetation strategy.
Geochemical QA/QC	• Laboratory Information Management System (LIMS). • ERA server and centralised data storage systems.	• Periodical studies and subsequent reports.	• To inform ore grade control. • To inform closure criteria. • To validate ground and surface water models.
Geomorpho-logical surveys and data (including related Raster, LiDAR and/or drone imagery)	• Vulcan 3D Geomodelling. • ERA server and centralised data storage systems.	• Ranger MCP.	• To record and demonstrate progressive remediation, rehabilitation and erosion control. • To inform closure criteria. • To input into modelling.
Geotechnical testing	• Datamine Discover Geospatial. • ERA server and centralised data storage systems.	• Periodical reports (developed internally and externally).	• To maintain construction standards. • To input into modelling.
Hydrological data	• Acquire. • CpetIT.	• Periodical reports (developed internally and externally). • Ranger MCP. • ARRTC.	• To maintain Water Bore/Hydrology data. • To inform closure criteria. • To validate groundwater models.
Materials movement tracking	• Hexagon MineEnterprise/MineOperate.	• Periodical studies and subsequent reports.	• To monitor material tracking.
Medical records	• Cority Medical (RTBS). • HSE BioTronic.	• Internal. • Periodical studies and subsequent reports.	• To record and maintain health/medical records.

Type	Storage / software	Reporting	Objective (s)
Radiation dose (including related Raster, LiDAR and/or drone imagery)	• Labware LIMS Radiation. • ERA server and centralised data storage systems. • MapInfo.	• Periodical reports (developed internally and externally). • Ranger MCP. • Provision of dose records to ARPANSA and ANRDR.	• To validate models. • To inform closure criteria. • To maintain national dose records.
Revegetation records (including related Raster, LiDAR and/or drone imagery)	• ERA server and centralised data storage systems.	• Ranger MCP. • Annual Report. • Periodical reports (developed internally and externally). • ARRTC.	• To record and demonstrate progressive remediation and rehabilitation. • To inform closure criteria. • To inform revegetation strategy and plant growth. • To maintain construction standards.
Surface water and groundwater monitoring (including spatial data)	• LIMS Water. • Hydstra. • LoggerNet Water Telemetry. • Operation Simulation Modelling (OPSIM). • ERA server and centralised data storage systems (Map info files).	• Ranger Annual Groundwater Report. • Annual Ranger Wet Season Report. • Routine water quality reports. • Ranger MCP. • ARRTC.	• To meet operational monitoring requirements. • To validate conceptual and numerical models. • To inform closure criteria. • To maintain construction standards.
Survey records	• Vulcan. • ERA server and centralised data storage systems.	• Ranger MCP. • Annual Report. • Adherence with Joint Ore Resource Committee guidelines.	• To validate conceptual and numerical models. • To maintain construction standards.
Water treatment production (i.e. flows /volumes)	• LIMS.	• Rehabilitation Progress Report.	• To record and demonstrate progressive remediation and rehabilitation. • To meet regulatory compliance requirements.
Incident notification	• RTBS.	• Ranger MCP. • Annual Report. • Periodical reports (developed internally and externally). • ARRTC. • Minesite Technical Committee (MTC).	• To maintain and record incident related information.

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