Energy Resources Of Australia

Ranger Mine Closure Plan 2025

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1 INTRODUCTION

Photo: 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 former mine is 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 NT and Commonwealth legislation. As of 1 July 2024, the key instrument that governs operations on a day-to-day basis is the Deemed Mining Licence (DML0108-18), which comprises the Ranger Authorisation 0108-18 (the Authorisation) and the latest approved Ranger Mine Closure Plan. 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 RPA.

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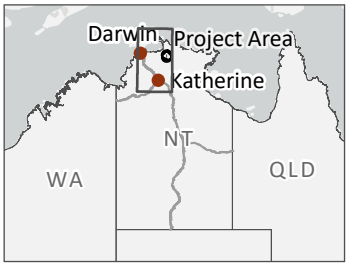
FIGURE 1-1

Location of the Ranger Project Area (RPA)

LEGEND

- Ranger Project Area
- Arnhem Land
- Kakadu National Park World Heritage Area
- National Park
- Primary Roads
- Town



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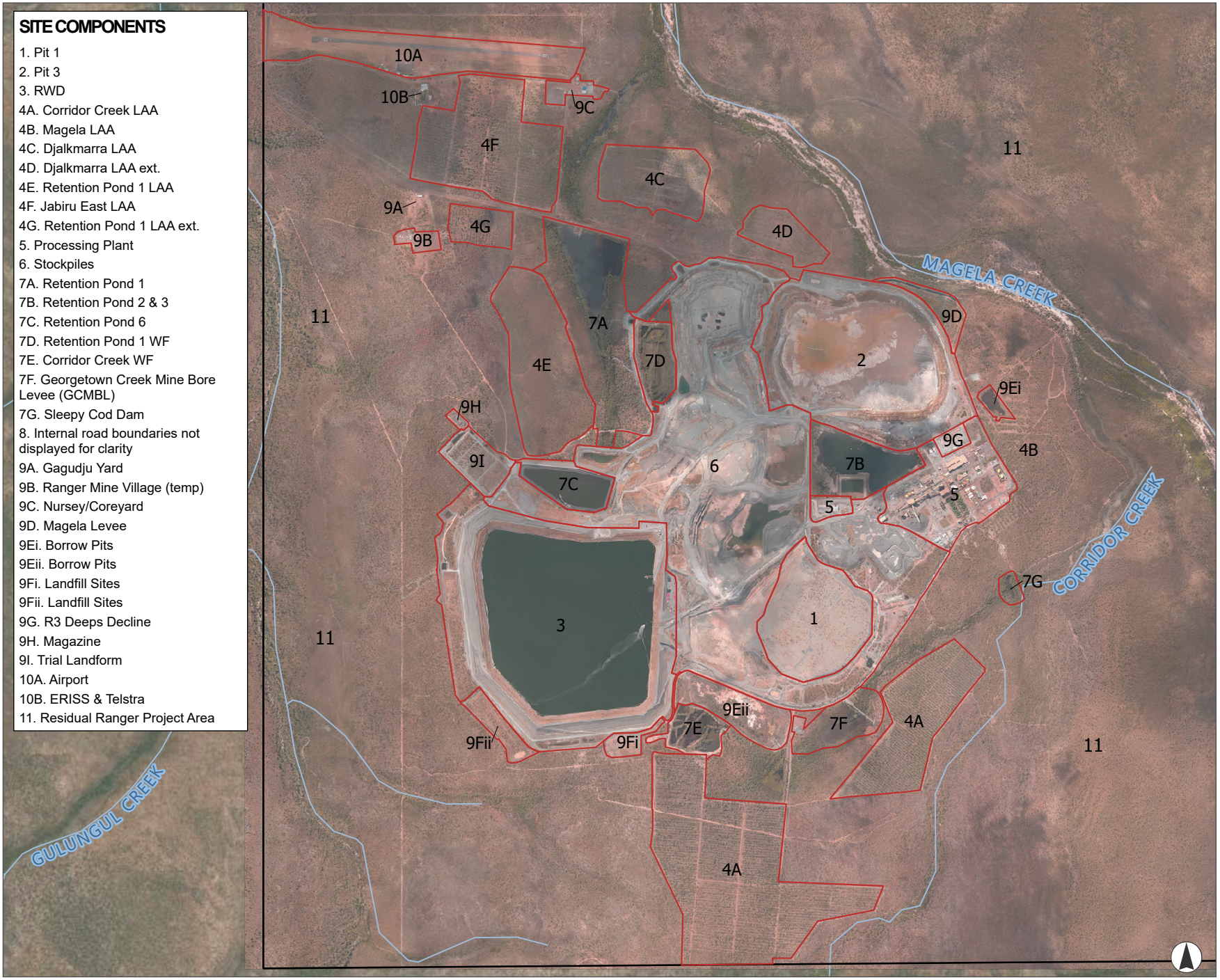

FIGURE 1-2

Ranger Mine – Closure Domains

LEGEND

- Mine closure domain
- Ranger Project Area

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

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Image Source: ESRI Basemap (2024); Aerometrex (2024) **Data source:** NT Government Data (2023)

The Ranger Environmental Requirements (ERs) are attached to the Section 41 Authority. The ERs set out the requirements that are to be satisfied to rehabilitate the former Ranger mine.

The Ranger Rehabilitation Project's mission:

Proudly restore the landscapes for those who will walk after us.

This Mine Closure Plan (MCP) is prepared by the Ranger Rehabilitation Project Team, with expertise from Rio Tinto and support from the ERA Board, to demonstrate how the proposed rehabilitation activities will achieve the ERs and support the post-mining social and economic transition of Jabiru.

The MCP is submitted for approval to both the Commonwealth Minister for Resources and Northern Australia, and the NT Minister for Lands, Planning and Environment.

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 the Ranger Rehabilitation Project Team is the comprehensive rehabilitation of the RPA.

In April 2024, ERA appointed Rio Tinto to manage the Ranger Rehabilitation Project under a Management Services Agreement (MSA). The MSA took effect on 3 June 2024. Under the MSA, Rio Tinto will manage all aspects of the rehabilitation of Ranger, on ERA's behalf, including project management and execution of all rehabilitation activities. Implementation of the MSA will allow Rio Tinto to build on ERA's work to date and combine this with Rio Tinto's technical expertise in designing, scoping and executing closure projects. The MSA follows discussions and negotiations between Rio Tinto and ERA's Independent Board Committee (IBC) in relation to a proposal to provide services and advice on the execution of the Ranger Rehabilitation Project.

The project objective is to complete the Ranger Rehabilitation Project in the safest and most efficient way, and to a standard that will establish an environment similar to the adjacent Kakadu National Park. The 'Operator' of the Ranger mine as per NT legislation remains the same as per Table 1-1. ERA maintains an organisational structure sufficient to carry out the closure and rehabilitation of the RPA.

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Table 1-1: Ranger operator details

Mining Operator Name (legal entity)	Energy Resources of Australia Ltd
Australian Company Number (ACN	008 550 865
Australian Business Number (ABN)	71 008 550 865
Postal Address	Locked Bag 1
	Jabiru NT 0886
Primary Contact	Alex Jones
Position / Title	General Manager, Ranger Rehabilitation Project
Phone	08 8924 3500
Email	info@era.riotinto.com
Activity Type	Mining

1.2 Title Details

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 1-3). Table 1-2 summarises the holder details associated with Ranger.

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.

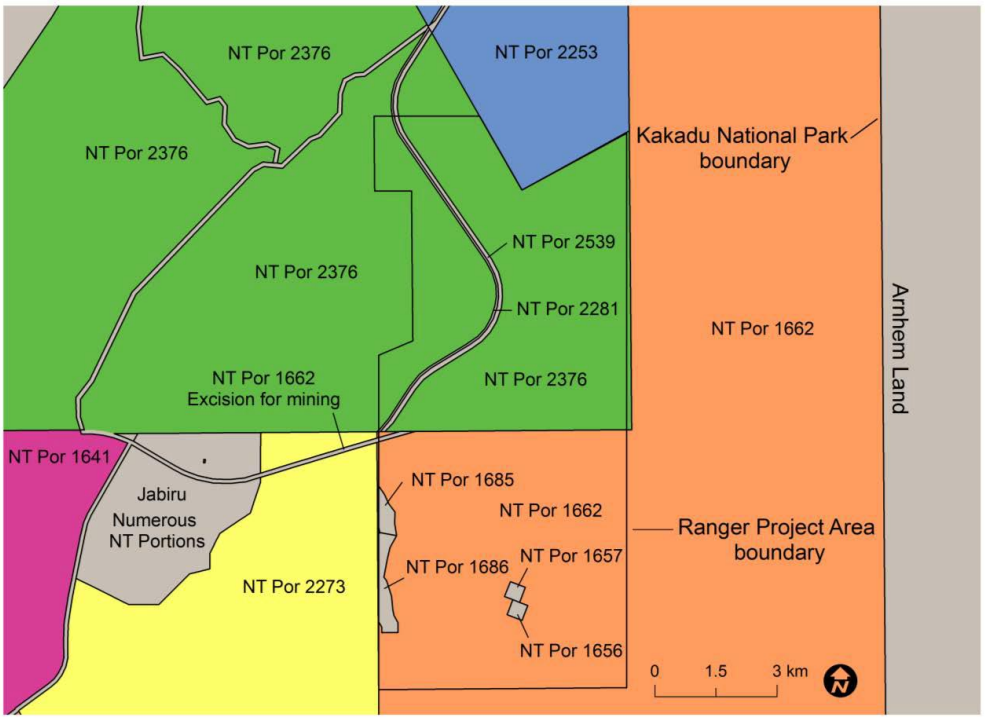

Figure 1-3: Land portions within and surrounding the RPA

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Table 1-2: Ranger mine title holder details

Name of Mining Site	Ranger Uranium Mine
Mineral Title	Section 41 Authority
Title Holder (legal entity)	Energy Resources of Australia Ltd
Australian Company Number (ACN)	ACN: 008 550 865
Australian Business Number (ABN)	ABN: 71 008 550 865
Mining interests	Uranium mining
Administration act	*Atomic Energy Act 1953* (Cth)
Authorisation number	0108-18 (now Deemed Mining Licence – DML0108-18)
Operator to whom Authorisation was granted	Energy Resources of Australia Ltd

1.3 Purpose of this MCP

The submission of an annual MCP is required under the Ranger Authorisation (Annex B: Submission and Assessment of the Mine Closure Plan). This MCP is prepared by the Ranger Rehabilitation Project Team to demonstrate how the proposed closure activities will achieve the ERs and the role of the Ranger Rehabilitation Project 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 into the rehabilitation of the RPA.

1.4 Scope of this MCP

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

- Ranger's decommissioned ore processing infrastructure, former mine pit voids, Ranger Water Dam (RWD: formerly known as the Tailings Dam), the Ranger 3 Deeps exploration decline and all associated utilities within the operational area of Ranger.
- Land application areas (LAAs), wetland filters, water management areas (e.g. sumps) and other infrastructure associated with Ranger, including monitoring infrastructure such as groundwater bores.
- Jabiru Airport and associated infrastructure and utilities: noting that discussions are progressing with Traditional Owner representatives and relevant government agencies regarding the potential future use of the airport.

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

- the town of Jabiru (with the exception of activities to support the post-mining 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.

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Closure and rehabilitation activity phases are outlined in Table 1-3. Table 1-3 is to 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 the Closure Phase	Completion criteria monitoring (and maintenance rehabilitation works as required).
Close-out / Relinquishment	Issue of close-out-certificate(s), relinquishment of RPA to the Commonwealth	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).

This MCP provides information current to the end of June 2025. The 2024 MCP was subject to stakeholder review and feedback. Appendix 1.1 provides the stakeholder review comments and a cross-reference to the relevant section of the MCP for the Ranger Rehabilitation Project Team's response. 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, and as such, not all stakeholder feedback has been addressed in this 2025 MCP (see Appendix 1.1 for details). Table 1-4 summarises the sections of the MCP that have changed between the 2024 and 2025 MCP.

Table 1-4: Updates/changes between the 2024 and the 2025 MCP

Section Number	Description of update / change	Update
Introduction		
1	Minor word changes only.	Minor
Statutory, Cultural and Climatic Context		
2	Minor word changes only.	Minor
Stakeholder Engagement		
3	Strengthened the commitment to engage with the Mirarr People.	Minor
3.1	Update to the relevant committees and forums.	Minor
Description of Closure Activities		
4	Updated to reflect the revised timeline for capping, bulk material movement and Phase 1 demolition. Planned end date for the creation of the final landform (Q4, 2034) remains unchanged at this point in time, recognising that further work is occurring to reduce uncertainties.	Minor
4.1.8	Seeking approval via the 2025 MCP to place grade 1 material within the broader Pit 1 domain, construction of a second erosion and sediment trial area (in addition to Stage 52) and infill the Pit 1 perimeter drain.	Minor

Section Number	Description of update / change	Update
4.2	Included a table to track the status of the Ministerial approval conditions from the Pit 3 Capping, Waste Disposal and Bulk Material Movement application.	Minor
4.2	Updated various progress metrics with regards to Pit 3 dewatering and capping.	Minor
4.3.1	Updated the Ranger water class descriptions to manage water in accordance with its quality rather than where it is spatially generated on site.	Minor
4.4	Provided further detail of the planned Phase 1 Demolition activities.	Minor
Landform		
6	Updated landform-related studies progress and monitoring results.	Minor
6.1	Added, are seeking approval for two additional Closure Criteria, which relate to Environmental Requirements 2.3 (retained facilities) and 11.2 (tailings placed in mined out pits).	Minor
6.3.1.3	Continued controlled release of runoff from the rehabilitated Pit 1.	Minor
Water and Sediment		
7.3.1	Progressed studies to inform the Ranger conceptual groundwater model including data analysis from new and existing Gulungul Creek bores, and improved modelling of the complex interaction between groundwater and surface water systems.	Minor
7.3.2	Progressed studies to inform the groundwater source terms including sampling results from 20 new monitoring bores and an improved understanding of solute movement from the backfilled Pit 1.	Minor
7.3.5	Progressed the development of the surface water transport model.	Minor
7.3.8	Progressed studies to inform the Vulnerability Assessment Framework including additional sampling in the late wet season across billabongs and artificial waterbodies on the RPA and reference billabongs in Kakadu National Park.	Minor
Soils		
8	Updated based on the findings of contaminated soils site investigations completed to help inform the Phase 1 Demolition activities in the vicinity of the processing plant.	Minor
Ecosystems		
9.3	Progressed studies to inform closure criteria metrics, including reference ecosystems.	Minor
9.3.3	Progressed studies to inform the ecosystem establishment strategy, including a controlled burn on the Trial landform (TLF), invertebrate survey, the plant mortality event on Pit 1, late dry season substrate and leaf sampling, and surveys of the TLF, Stage 13, Stage 52, Ranger Mine Village and the Magazine laydown area.	Minor
Radiation		
10	Minor word changes only.	Minor
Cultural		
11	Strengthened the commitment to engage with the Mirarr People.	Minor
Consolidated Risk Assessment		
12.2	Incorporated the environmental risks within the Rio Tinto Archer risk register into the Umwelt bow-tie risk assessment.	Minor
Timing and Financial Provision for Closure		
13.1	Minor changes only.	Minor

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2 STATUTORY, CULTURAL AND CLIMATIC CONTEXT

Photo: Water quality monitoring at Coonjimba Billabong

2.1 Statutory Context

Rehabilitation and closure of Ranger are governed by both Commonwealth and NT legislation. The Ranger Rehabilitation Project Team maintain a compliance register that identifies the legislative Acts and regulatory obligations relevant to the closure and rehabilitation of Ranger. Twelve Acts and several hundred obligations are relevant. 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).

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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 allows for a process for the progressive relinquishment (close-out) of parts of the RPA. Work continues with the Commonwealth Government, Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) (on behalf of the Mirarr Traditional Owners), to negotiate the new Section 41 Authority for the RPA (a 'Rehabilitation Authority' as defined in Section 41CA of the Atomic Energy Act). ERA applied for a new Authority on 27 May 2024.

Opportunities have been identified 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 NLC and GAC to date has indicated support for responsibility for this area to be transferred to the final landowners as early as possible. These conversations are progressing, alongside the range of instruments that are being negotiated following the amendments to the Atomic Energy Act.

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.

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Aboriginal Land Rights (Northern Territory) Act 1976

Title to the RPA was granted to the Kakadu Aboriginal Land Trust in 1978 (southern portion) and 1986 (northern portion), in accordance with the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976* ("Land Rights Act"). Activities on the land are subject to the terms of access contained in the Section 44 Agreement with the NLC under the Land Rights Act. The post-mining land use of the RPA will be 'Aboriginal land', which means freehold ownership held by the Aboriginal Land Trust free of any other interest.

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.

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2.1.3 Northern Territory Government Legislation

Environment Protection Act 2019

The *Environment Protection Act 2019* (EP Act) repealed and replaced the *Mining Management Act 2001* commencing on 1 July 2024.

As a result of the new legislative requirements, the previous Authorisation 0108-18 now operates as an 'environmental (mining) licence (Deemed Mining Licence – DML0108-08)' under the EP Act. As a consequence, this 2025 MCP is submitted to the Minister responsible for the agency administering the EP Act (i.e. the Department of Lands, Planning and Environment). Under the new arrangements, ERA must apply for an environmental (mining) licence for the duration of the project by no later than 1 July 2028.

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 sacred sites, during the conduct of works. ERA currently hold an authority certificate for mining activities at Ranger and are planning to apply for an authority certificate for rehabilitation.

2.1.4 Closure Objectives and Closure Criteria

A set of closure objectives have been developed based on the rehabilitation objectives described in the ERs which continue to apply as Rehabilitation Requirements under the proposed future authority. The objectives have been developed in consultation with stakeholders over many years and 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 criteria for measuring progress to achieving the objectives are intended to be measurable and quantifiable, and include 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 the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. 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).

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2.2 Cultural Context

The landscape in which the RPA is situated has high cultural values to the Mirrar People. Recent research conducted at Madjedbebe rock shelter, which is on the Mirarr Estate to the north of the RPA, has found evidence of human occupation for at least 65,000 years (Clarkson *et al*., 2015, 2017). The entire area has many tangible cultural heritage places, and equally rich intangible cultural heritage values, which link the landscape and peoples with the wider West Arnhem community.

The post mining land use is freehold 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 1,553 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 (32.1 degrees Celsius (°C)) and highest in October (37.8°C). The average minimum temperature ranges from 18.8°C in June to 25°C in November and December. Annual evaporation is approximately 2,594 mm and relative humidity (at 9 am) 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.

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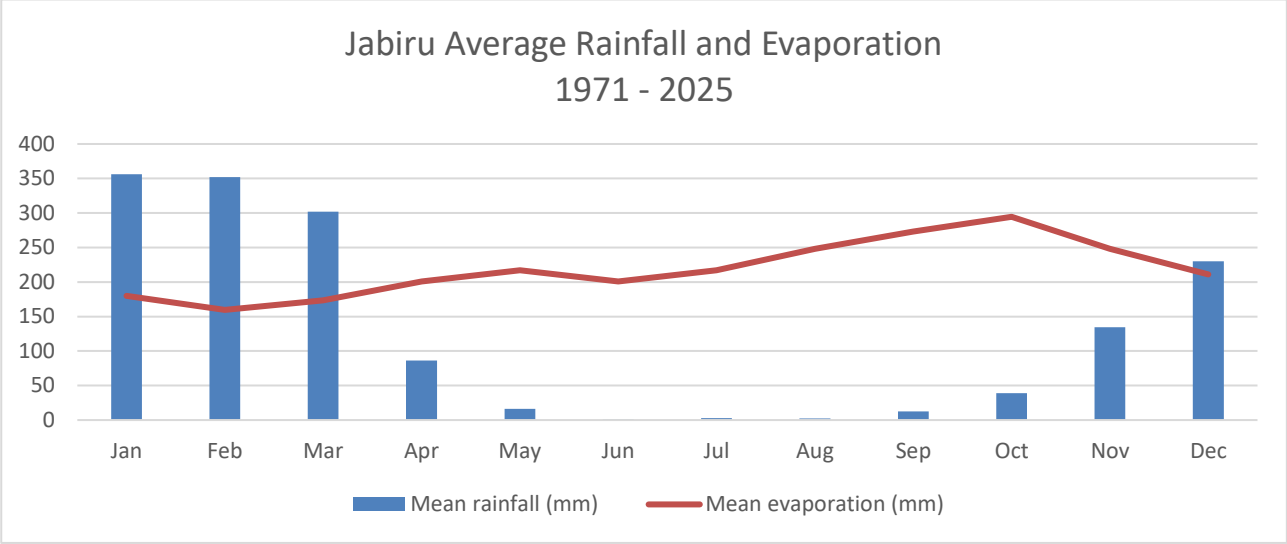

Figure 2-1: Jabiru mean monthly rainfall and evaporation (1971 to 2025: Bureau of Meteorology 2025)

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 impacts report 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) 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. In the longer term, most climate change risks are landscape in nature and would likely affect the entire Kakadu region.

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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
R10 mm: 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)

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3 STAKEHOLDER ENGAGEMENT

Photo: Harvesting of native seeds

Successful rehabilitation and relinquishment of the former Ranger mine is dependent on a consolidated and strategic approach to community and stakeholder engagement. Engagement with stakeholders is focussed on several significant aspects of the rehabilitation project, such as:

- land tenure and governance;
- planning process and schedule;
- determining post-mining land use, final landform, closure objectives and closure criteria;
- technical aspects of closure, including engineering and design criteria, to safely and efficiently complete rehabilitation to meet the Environmental Requirements;
- selection of closure strategies, technologies and methodologies for closure studies and activities;
- compliance with legal requirements and obligations in agreements related to Ranger and Jabiru;
- facilitating information sharing and review processes; and
- managing applications, approvals and verification processes.

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3.1 Stakeholders and Engagement Mechanisms

There are a range of stakeholders that influence, or are interested in, the Ranger Rehabilitation Project. The Mirarr are the Traditional Owners of the area that includes the Ranger Project Area, who exercise rights as the owners of the Ranger Project Area under the Land Rights Act. They are the post-mining landowners via the freehold title vested in the Kakadu Aboriginal Land Trust and also assert native title over the area. Gundjeihmi Aboriginal Corporation (GAC) is their local administrative corporation.

Engagement undertaken by the Ranger Rehabilitation Project Team is mostly coordinated through the forums and committees listed in Table 3-1. These committees oversee and/or contribute to the Ranger Rehabilitation Project's approval processes, mandatory reporting obligations and the scientific integrity of studies, research trials and projects. The different forums and committees facilitate feedback and information sharing between the Ranger Rehabilitation Project and a variety of different stakeholders.

For a more detailed understanding of the regulatory framework, refer to Chapter 2.

Where there are specific issues of interest that arise, various engagement mechanisms are utilised to address these objectives. Table 3-2 lists the engagement mechanisms and the related activities undertaken by the Ranger Rehabilitation Project Team that support engagement with community and stakeholders.

The Ranger Rehabilitation Project has developed a stakeholder engagement plan in accordance with an engagement framework that is reviewed annually and updated to align with Rio Tinto's Community & Social Performance Standard.

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Table 3-1: Committees and forums

Forum / Committee	Description	Members / Attendees	Frequency
Minesite Technical Committee (MTC)	The MTC is a forum established under the Working Arrangements between the Commonwealth and NT Government. Members discuss and resolve technical environmental management matters (assessments (including assessments of Best Practicable Technology (BPT), inspections, audits and rehabilitation activities), and regulatory matters related to the former Ranger mine.	Chairperson, Department of Lands, Planning and Environment (DLPE), OSS, ERA, GAC and the NLC The Commonwealth Department of Industry Science and Resources (DISR) is an observer to the MTC	At least 1 meeting is required every 12 months
Alligator Rivers Region Technical Committee (ARRTC)	The ARRTC is an independent scientific statutory committee that oversees scientific study programs undertaken to protect the environment in the Alligator Rivers Region from effects of uranium mining. These study programs 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 uranium mining in the Alligator Rivers Region.	An independent chairperson, OSS, independent scientific members, NLC, representatives for DLPE, 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 Approvals and Studies Forum (RASF)	The RASF was stood up in March 2025 as a key collaborative forum for sharing information on Ranger project approvals and studies. It supports engagement on approval applications and study scopes, outcomes and decisions; identifies technical issues for resolution by working groups; and receives updates from those groups.	Ranger Rehabilitation Project Approvals and Studies teams, OSS, GAC, NLC, DPLE and DISR	Quarterly
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.	MTC Members: DLPE, OSS, ERA, GAC and the NLC	Monthly
Relationship Committee	The committee was established by the Mining Agreement 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	Currently paused – last meeting September 2023
Cultural Reconnection Steering Committee (CRSC)	The CRSC was established by the NLC in 2021 to provide a forum for Traditional Owners to discuss the process and implications of mine closure from their perspective and facilitate reconnection with areas impacted by the mine. The NLC has not confirmed further funding for CRSC going forward.	Traditional Owners, GAC, NLC and ERA	Currently not meeting with ERA

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Forum / Committee	Description	Members / Attendees	Frequency
On Country Forum (TBD)	The On Country Forum would provide a platform for Traditional Owners to actively participate in closure planning and execution. The forum would provide transparency and make technical information accessible, aiding decision-making and skill development, and foster relationships to support involvement in rehabilitation processes.	Traditional Owners, GAC, RRP and invited observers	TBC
Working Groups (WG) of the MTC	Several targeted working groups have been formed to address matters related to specific closure themes and KKNs. (e.g. Water, Landform and Ecosystem Restoration).	ERA, OSS, NLC and various subject matter experts undertaking work in the relevant area	As required
Future of Jabiru MoU Parties Forum	The Jabiru MoU Parties 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.	GAC JT, GAC, Department of the Housing Local Government and Community Development (DHLGCD), Parks Australia, and ERA.	Quarterly
Future of Jabiru & Kakadu Program Steering Group (Jabiru PSG)	The Jabiru PSG drive forward initiatives agreed under the Future of Jabiru MoU agreement.	GAC JT, GAC, NLC, Jabiru Property Services, DHLGCD, Department of Infrastructure, Planning and Logistics (DIPL), Department of Climate Change, Energy, the Environment and Water (DCCEEW), ERA, West Arnhem Regional Council, Jabiru Police, and Parks Australia.	Monthly

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Table 3-2: Other Stakeholder Engagement Mechanisms

Engagement mechanism	Description	Frequency
Informal meetings	One-on-one impromptu discussions and informal conversations, either face-to-face or via email or phone.	As required or as occurs
Formal meetings	Formal briefings to key stakeholders and government agencies, to provide updates on the rehabilitation project and business strategy.	As required
Site visits / tours	Scheduled site visits for key stakeholder groups i.e., closure activities and studies and special interest groups to tell the story of the Ranger mine closure and rehabilitation.	As required for closure activities
ERA Website	ERA maintain a project website to provide project information and updates on work being undertaken at the RPA and within Jabiru township. The public can access a range of reports and publications on the website including ASX Announcements and the Ranger MCP.	Ongoing
Mine Closure Plan	A Mine Closure Plan (MCP) is submitted to the relevant NT and Commonwealth ministers for an approval decision 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 and the closure criteria. ERA also choose to make the MCP publicly available on the ERA website.	Annual
Industry conferences	From time to time, the Ranger Rehabilitation Project Team may select to attend and contribute to presentations, key-note speeches, panel discussions, etc. to share knowledge, network, and learn about the latest trends and developments – where aligned with the Ranger Rehabilitation Project's communication plan.	Ongoing
Media briefings session	Briefings are provided to regional and national media to provide updates on business decisions, mine closure and onsite rehabilitation.	As required
Media releases	Project updates are provided in regional newspapers, and broadcast on local radio networks.	As required
Audio-visual material in language	Ranger Rehabilitation Project Team plans to work with local organisations to create audio-visual material in (Bininj) language to provide project information to Traditional Owners and local Aboriginal communities.	As required
Project Town Office	Ranger Rehabilitation Project Team members are based at the old Jabiru Sports and Social Club (JSSC) and are available for face-to-face interactions.	Every Wednesday
Ministerial briefings	Briefings are provided to both Commonwealth and Northern Territory Ministers and senior advisors on Ranger Rehabilitation operations, including on site rehabilitation and Jabiru township.	Milestone dependent
Community briefings/meetings	Attend community held meetings and provide project briefings and information tailored to meet the information needs and interest of the stakeholders.	Quarterly
Kakadu Board of Management Meetings	Ranger Rehabilitation Project Team to provide operational updates, including mine rehabilitations status. The meeting also provides an opportunity to consult with the broader Indigenous population of the park.	Meetings occur quarterly, as invited

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3.2 Engagement with Traditional Owners

The Mirarr Traditional Owners are represented by GAC and the NLC at the various forums and committees (refer Table 3-1).

In 2024, the Mirarr Traditional Owners expressed their concerns regarding ERA's ability to fund the rehabilitation of Ranger and ERA's decision to apply for the Jabiluka lease extension. This resulted in the deterioration of the relationship between ERA and the Mirarr People.

Improved funding certainty and Rio Tinto's management of the Ranger Rehabilitation Project, under a Management Services Agreement with ERA, presents an opportunity to reset relationships and reactivate engagement with Mirarr Traditional Owners and their representatives on all Project matters. In recognition of the importance of re-establishing trust between the Project and Mirarr People, the relationship reset has been established as a strategic issue for engagement.

The Leadership Team of the Ranger Rehabilitation Project values ongoing consultation with the Mirarr Traditional Owners and their representatives, as this is essential to achieving the best outcomes at Ranger. The Leadership Team of the Ranger Rehabilitation Project are working to re-activate engagement with GAC, NLC, and the Mirarr Traditional Owners on all Project matters of interest.

3.3 Current Engagement Context

In 2024–2025 a range of engagement improvements were integrated into the Ranger Rehabilitation Project, including:

- improving understanding by staff of Indigenous knowledge and culture as it relates to the Ranger Rehabilitation Project via the Bininj Kunwok Cultural Induction Course;
- consolidating record keeping across stakeholder interactions and forums into a stakeholder management system;
- continue stakeholder engagement planning into the Ranger Rehabilitation Project's execution schedule;
- building internal capacity and capability, and local and regional participation;
- increasing consultation and touchpoints with the broader community to gain a deeper understanding of the concerns and perceptions raised via various engagement channels.

Since the last MCP, stakeholders have been consulted on a range of topics and issues, including:

- negotiations for consent to continued access to the RPA as required under the Land Rights Act;
- negotiations to progress a new Section 41CA Authority (Rehabilitation Authority);
- Jabiru housing rectification works and transfers;
- Jabiru town centre revitalisation work;
- applications to progress closure activities;

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- progress with Ranger Rehabilitation Project activities; and
- progressing a formal Cultural Heritage Management Agreement.

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

3.4 Future Priorities for Engagement

The Ranger Rehabilitation Project Team will continue to work with the Department of Lands, Planning and Environment, GAC, NLC, and other relevant government departments to secure a new Section 41 Authority (and associated agreements) to allow additional time to complete the rehabilitation, long-term monitoring, and maintenance of the RPA.

Over the next 12 months, the primary focus for the Ranger Rehabilitation Project will be to substantially progress initial capping of Pit 3, commence the secondary capping of Pit 3, and progress decommissioning and decontamination to support Phase 1 demolition. At the same time, the studies and assessments will inform Key Knowledge Needs (KNNs) (see Appendix 5.1) and support the future major approval applications to be progressed. Regular updates will be provided to stakeholders on these topics, primarily through the forums and committees listed in Table 3-1.

Other important topics for stakeholder engagement include:

- subject to terms being agreed and accepted by the parties, finalisation and implementation of the Cultural Heritage Management Agreement;
- planning for the intended retention, if agreed, or decommissioning of the Jabiru Airport in 2027, if no third-party operator is identified by stakeholders;
- Jabiru housing rectification and infrastructure works;
- execution activities, schedule and progressive rehabilitation;
- agreement on the meaning of ALARA with Traditional Owners;
- planning with regards to onsite waterways and billabongs;
- local and Indigenous participation in rehabilitation, land management and post-closure monitoring;
- processes and options for partial relinquishment or transfer of management responsibility of the RPA;
- Traditional Owner business opportunities in Ranger Rehabilitation scopes of works; and
- continued delivery of Cultural Awareness training via the Bininj Kunwok Regional Language and Culture Centre Induction Course.

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3.5 Supporting the Jabiru Community Transition

The RRP is committed to working with Traditional Owners, the local community and key stakeholders to support the social transition of Jabiru town in line with the Mirarr People's vision, which is outlined in the Jabiru Masterplan.

In 2023, The Social Transition Framework for Jabiru (Table 3-3) was developed, following a range of social impact identification and social risk analysis by ERA. It is best practice in mine closure to have a transition framework (ICMM, 2019). Due to the multi-stakeholder and multi-faceted social transition process, the framework provides an overarching structure and identifies objectives to guide the RRP's role and activities relating to the social transition of Jabiru.

The programs that RRP are focused on to support sustainable transition include:

- the housing rectification and transfer of third-party properties to Jabiru Property Services;
- the ERA Community Partnerships Fund (CPF);
- collaborating with stakeholders on the future of Jabiru Airport; and
- accommodating the RRP temporary workforce.

The Ranger Rehabilitation Project Team remains committed to its role in supporting the social and economic transition of Jabiru through the goal and objectives listed in the Jabiru Transition Framework (Table 3-3).

Table 3-3: Jabiru transition framework

Goal	Objectives	Success Measures
The Ranger Rehabilitation Project supports the objectives set by the Mirarr Traditional Owners for the future of Jabiru, and the Ranger Rehabilitation Project Team 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 Ranger Rehabilitation Project. • Ranger Rehabilitation Project Team's discretionary effort aligns with the vision of the Mirarr People.	1. Ranger Rehabilitation Project meets commitments regarding third-party housing rectification and other infrastructure work as agreed and to the agreed standards. 2. The Ranger Rehabilitation Project Team will engage with stakeholders on the future of the Jabiru Airport and support for any identified future operator. 3. The Ranger Rehabilitation Project Team believes in the development of safe and sustainable Indigenous-owned enterprises and intends to use these service providers and businesses throughout the Ranger Rehabilitation Project. 4. The Ranger Rehabilitation Project Team will actively support the Future of Jabiru governance structures that support the town's successful transition. 5. Ranger Rehabilitation Project 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.

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3.6 Community and Social Performance Plan (2024–2027)

In 2024, the Ranger Rehabilitation Project constructed a Community and Social Performance Plan (CSP Plan), which outlines strategies to mitigate social impacts and risks, and enhance identified opportunities. This CSP Plan has been developed to support the implementation and achievement of Rio Tinto HSEC and Human Rights policies, in line with the Rio Tinto Communities and Social Performance Standard (2022). The four focus areas of the CSP Plan include:

- Supporting the social transition of Jabiru in line with the Mirarr People's vision;
- Embedding Indigenous knowledge and culture throughout the Ranger Rehabilitation Project;
- Engaging meaningfully with stakeholders and the community; and
- Maximising regional development opportunities.

These focus areas are underpinned by maintaining good governance in community practices (RT CSP and Closure Standards).

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4 DESCRIPTION OF CLOSURE ACTIVITIES

Photo: Processing plant and administration area left, RP2 in centre, and Pit 3 right (2025)

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. The Ranger Rehabilitation Project Team are seeking opportunities to accelerate the schedule.

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 Ranger Rehabilitation 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 calculated via GIS, 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 and the subsequent planting of that 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.

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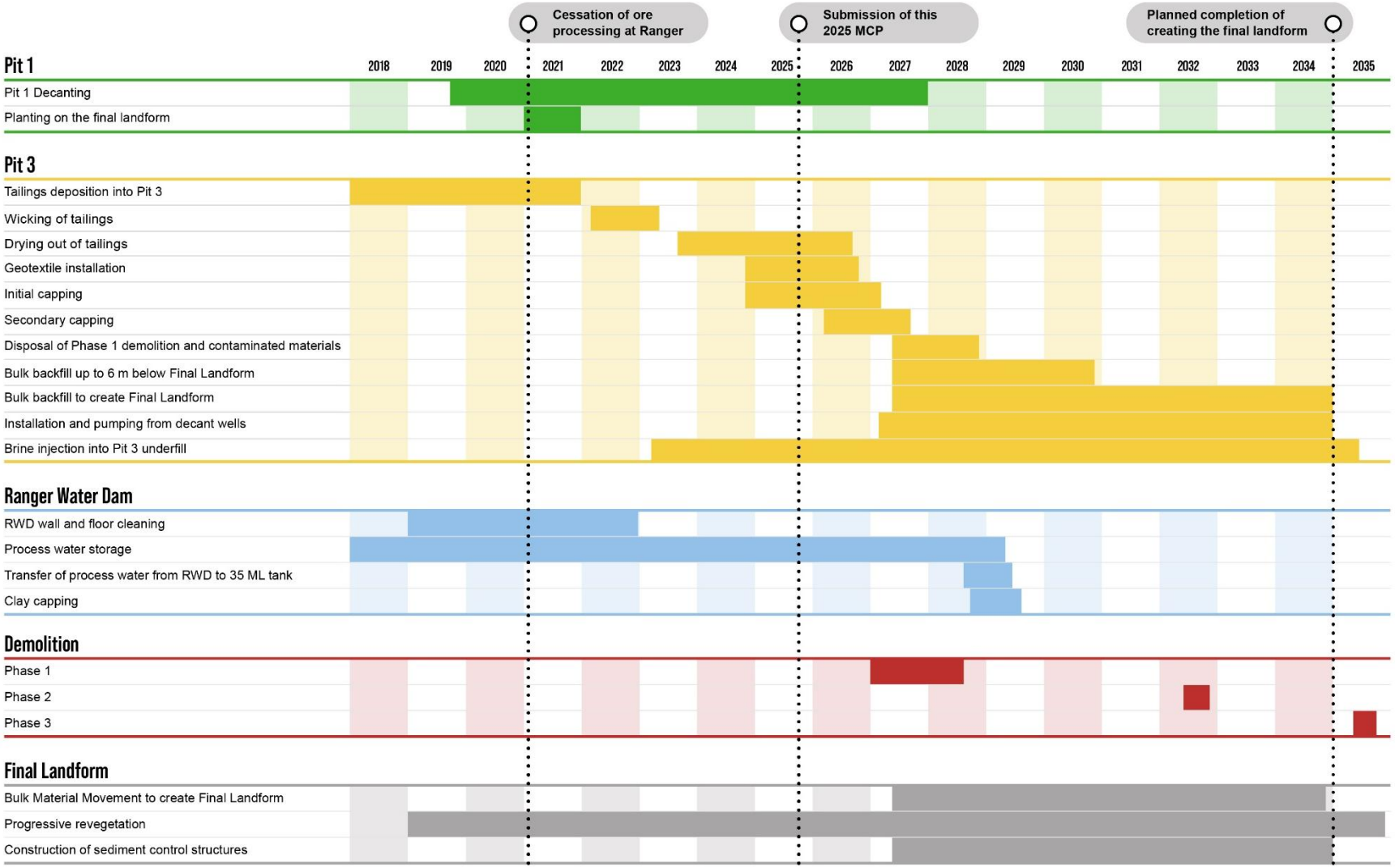

Figure 4-1: Indicative timeline of planned activities

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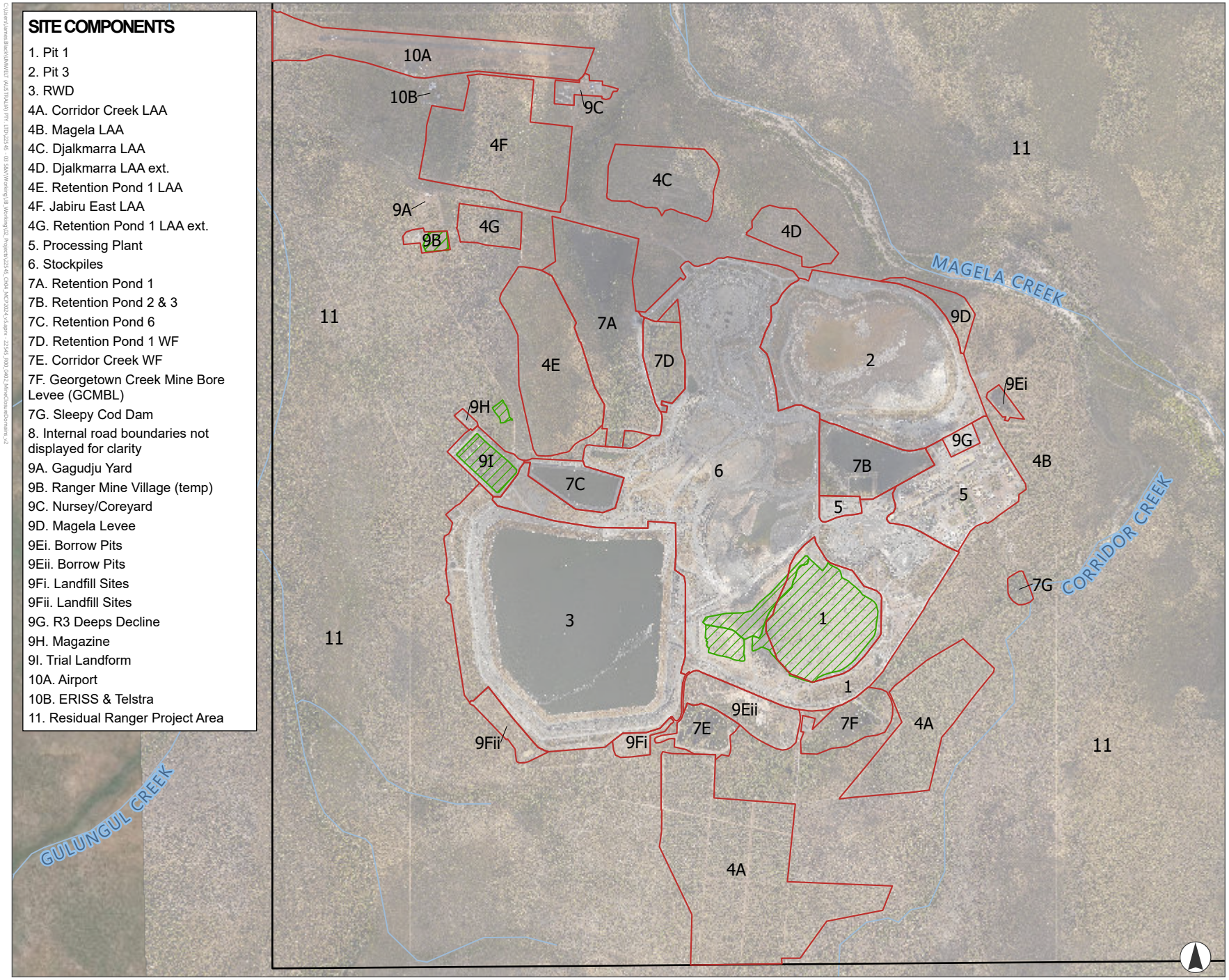

FIGURE 4-2

Ranger Mine – Closure Domains

LEGEND

- Mine closure domain
- Progressive rehabilitation
- Ranger Project Area

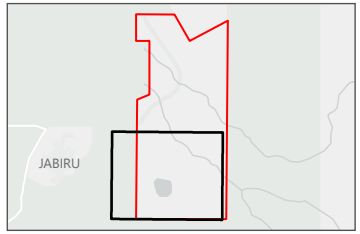

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Image Source: ESRI Basemap (2022); Propeller (2025) **Data source:** ERA (2025)

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

Domain Number	Domain description	Area	Area subject to vegetation establishment
1	Pit 1	41.4	39
2	Pit 3	107.12	-
3	Ranger Water Dam (formerly the Tailings Dam)	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	1.4
9C	Nursery/Core yard	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

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Domain Number	Domain description	Area	Area subject to vegetation establishment
10 A & B	Airport and ERISS	44.08	-
11	Residual RPA	TBC[2]	2.93[3]
	TOTAL	**1,064.98**	**61.9**

[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 (Photo 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).

Photo 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.

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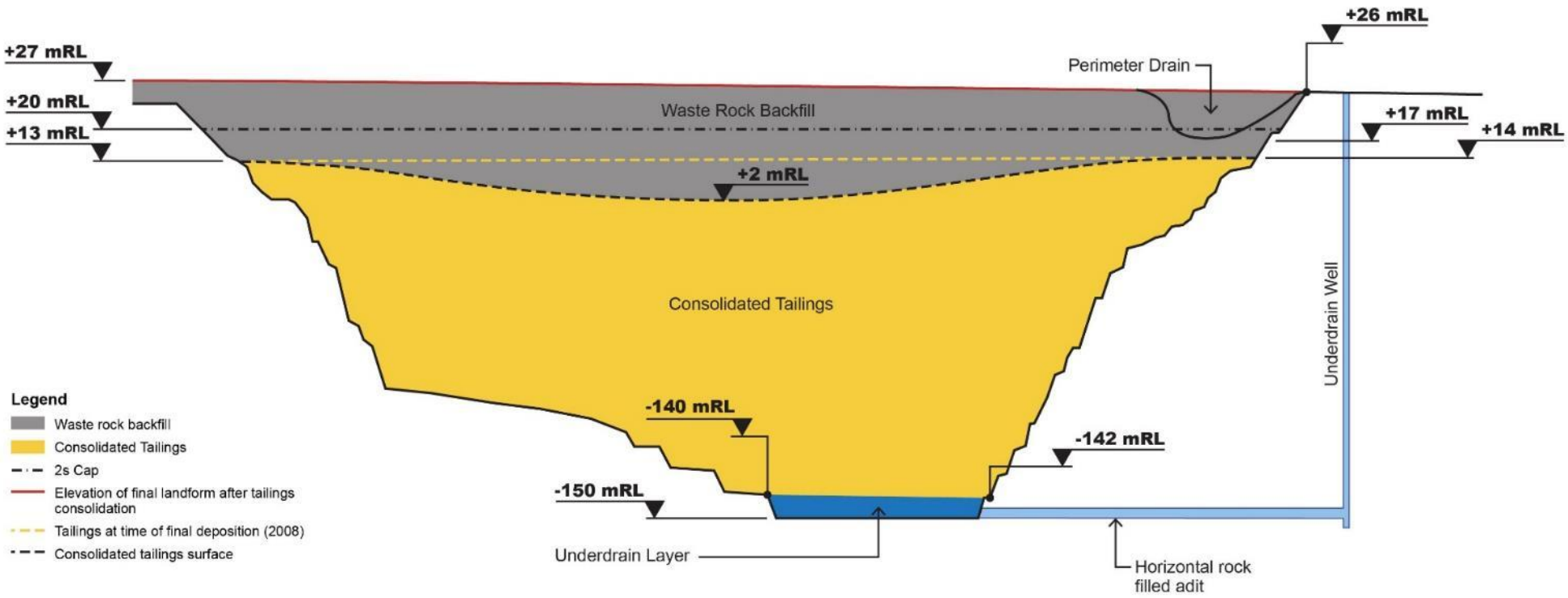

Figure 4-3: Schematic of Pit 1 with key elevations (not to scale)

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A horizontal adit was installed to connect the base of the pit to a vertical dewatering bore that pumped process water to the Tailings Dam. 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 south-east 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 was measured using settlement monitoring plates fitted with standpipes (Photo 4-2), and it proceeded as predicted, reaching approximately 98% to 99% consolidation by 2021 (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).

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

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With consolidation practically complete in July 2021, most of 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 truncated pipes were surveyed, so the monitoring system could be reinstated should the need arise. Annual surveys of the landform surface are used to monitor total settlement (waste rock and tailings) across Pit 1.

4.1.2 Wicking

Prefabricated vertical drains or wicks (Photo 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.

Photo 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).

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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.

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.

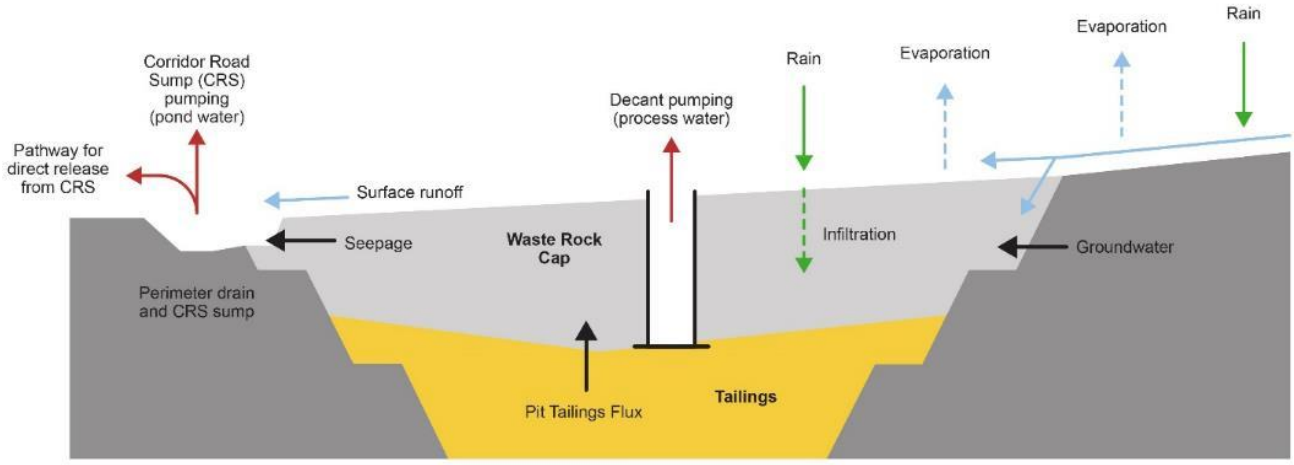

Figure 4-4: Pit 1 water balance schematic

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 (Photo 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.

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Photo 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 (Photo 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 (Photo 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, and 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; Photo 4-7) is undertaken as required. To date, no remediation activities have been required on parts of the catchment considered as final landform. The first release of rainfall runoff from the surface of the rehabilitated Pit 1 landform to Corridor Creek via the CRS occurred on 4 March 2024 (see Chapter 6 and Chapter 7 for details), representing a significant milestone for Pit 1 rehabilitation, and Ranger closure.

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

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

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Photo 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, methods for successfully establishing vegetation and habitat supplementation for fauna.

The outcomes of the Pit 1 trial and implications for the Ecosystem Establishment Strategy are discussed further in Chapter 9.

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 (Photo 4-8). Monitoring of Pit 1 is ongoing and has informed a need for further investigation in several areas. This is discussed further in Chapter 9.

Photo 4-8: Revegetation on Pit 1 (June 2025)

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4.1.8 Planned Future Activities in the Pit 1 Closure Domain

Activity approved via the 2024 MCP

The area surrounding the perimeter of Pit 1 is scheduled for a general clean-up, which will involve the removal of any loose or unused materials. Additionally, small areas with infrastructure no longer used for their designed purpose in the vicinity will be dismantled and rehabilitated. These areas include (see Figure 4-5 for locations):

- the former Orica Explosives Storage Yard and Laydown Area (see Photo 4-9): this area is located between the RoM stockpiles and Pit 1. It was the storage location for the ammonium nitrate emulsion and workshop used during the operational phase for in-pit blasting. It now contains several demountables, the ammonium nitrate emulsion storage silo, the disused workshop with spare parts and small machinery, redundant high density polyethylene (HDPE) pipes, scrap steel, and disused equipment (e.g. an old drill rig and diesel generators);
- the former trial evaporators area (see Photo 4-10): this area supported a small trial to better understand the ability of shallow concrete channels covered with transparent roof sheets to maximise evaporation of process water;
- decommissioned pumping booster station (see Photo 4-11): this was previously used as an in-line boosting station for water before it was transferred up the RWD embankment wall and into the RWD. The area also has some piping that will be removed and electrical conduits (note: this activity is limited to the boosting station and does not include the relocation of the main HDPE pipelines that will be included in the separate Central Services Corridor application);
- the omega pumping station: this is a redundant pump that was previously used as a contingency emergency back-up system to pump water from the RWD back to the pit in the event that the water level in the RWD was at risk of overspill; and
- objects and materials from the Pit 1 Laydown Yard.

The material removed from these areas will either be sold (once cleared for radiation), repurposed or placed temporarily in the Pit 3 waste dump or laydown area prior to disposal into Pit 3 following secondary capping.

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FIGURE 4-5

Areas within the Pit 1 closure domain

LEGEND

- Area Scheduled for General Clean-Up
- Former Orica Explosives Storage Yard and Laydown Yard
- Former Trial Evaporators
- Pit 1 Laydown Area
- Omega Pump Station
- Decommissioned Pumping Station

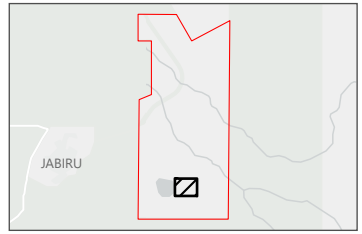

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Image Source: ESRI Basemap (2024); Aerometrex (2024) **Data source:** NT Government Data (2023)

Photo 4-9: Former Orica Explosives Storage Yard

Photo 4-10: Former trial evaporators

Photo 4-11: Decommissioned pumping booster station

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Approval of the following activities sought via this 2025 MCP

The following activities are planned in the wider Pit 1 domain beyond the clean-up activities outlined above:

- Placement of grade 1 material from the stockpiles excavated to backfill Pit 3: As backfill of Pit 3 via bulk material movement (BMM) commences (forecast for late 2027/early 2028), the RRP will be prioritising the placement of mineralised material (i.e. grade 2 and above) deeper into Pit 3 and moving that material more suitable as final landform surface material (e.g. grade 1) to other locations. This practice will minimise the amount of grade 1 waste rock being placed deep into Pit 3 and reduce the potential of double handling grade 1 waste rock. Approval is sought via this MCP to allow such paddock dumping of grade 1 material, which in the first instance is likely to occur in the wider Pit 1 domain but potentially in other areas such as the footprint of demolished processing plant and the RoM pad area/Stage 2 once depleted of material for Pit 3 capping. The general principle of water collection, monitoring, and release only if applicable criteria have been satisfied would be adopted for any areas subject to this activity.
- Construction of a second erosion and sediment trial: The first trial, Stage 52, was constructed and revegetated in 2022/23. The trial was established to improve the understanding of erosion and the resulting sedimentation from a newly constructed landform area and to help test the practicality and performance of various proposed water management methods (see Section 6.3.1.4 for details). This second trial is proposed with a similar purpose, with the exception that waste rock more representative of the final landform surface would be used (i.e. a lower proportion of lateritic clay material to that used at Stage 52). This second trial would also provide the opportunity to investigate the effectiveness in reducing erosion and sedimentation of an increased density of suitable ground cover species and/or alternative species mixes to promote early ground cover establishment. As above, the general principle of water collection, monitoring, and release only if applicable criteria have been satisfied would be adopted for any area subject to this trial.
- Infill of the Pit 1 perimeter drain: the Pit 1 perimeter drain as shown in Figure 4-3 exists because the backfilling of Pit 1 was not completed. The drain has been useful to capture runoff from Pit 1 and allow sediment to settle behind the rock check dams within the drain before entering CRS. The drain does however promote back-cutting erosion on the steeper batter slopes (see Photo 4-7). As vegetation on Pit 1 establishes and sediment laden runoff from the surface reduces, the value of retaining the perimeter drain diminishes. The drain also provides a low point for solute movement out of Pit 1. The timing of backfilling the perimeter drain has not yet been determined, but it may coincide with the paddock dumping of grade 1 material mentioned above for BMM (i.e. late 2027/early 2028). As above, the general principle of water collection, monitoring, and release only if applicable criteria have been satisfied would be adopted for this activity.

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Approval of the following activities will be sought via a future MCP

The future closure activities associated with the Pit 1 closure domain that are not seeking approval via this MCP are the removal of Corridor Creek Road, Corridor Road Sump, Pit 1 decant wells and infrastructure, and the revegetation of these areas.

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 in June 2022 recommending additional studies were undertaken prior to final submission. These studies were completed in consultation with OSS and NLC and the final Pit 3 application was submitted to the MTC members in September 2023. Ministerial approval was granted on 11 August 2024.

The conditions of approval are listed in Table 4-2, along with their status at the time of writing this MCP.

Table 4-2: Pit 3 Capping, Waste Disposal and Bulk Material Movement approval conditions

Condition	Requirement	Status
1	Before excavating stockpile material for the primary capping, ERA will obtain support of the Supervising Scientist for the following:	
1.1	Dust monitoring and management strategy	Approved 4 November 2024 for initial capping and 2 April 2025 for secondary capping
1.2	Settlement tower design	Approved 6 February 2025
1.3	Initial Material Movement Plan	Approved 4 November 2024 for initial capping and 2 April 2025 for secondary capping
1.4	Trigger Action Response Plan for dust	Approved 4 November 2024 for initial capping and 2 April 2025 for secondary capping
1.5	Updated radiation monitoring and management strategy	Approved 4 November 2024
2	Before commencing bulk backfill works, ERA will obtain approval from the Supervising Authority for the following:	
2.1	Tailings Settlement Monitoring Plan	In progress
2.2	Bulk Material Movement Plan	In progress
2.3	Inclusion of a Pit 3 Monitoring Plan within the Ranger Water Monitoring Strategy	In progress
2.4	Pit 3 Water Treatment Plan	In progress

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Condition	Requirement	Status
3	All Grade 2 and above waste rock will be placed in Pit 3 below the 2s cap of +8 mRL, ensuring there is adequate room by minimising the volume of Grade 1 waste rock placed below this cap. *Note: ERA is required to meet this condition unless this approval is varied. Any request for variation must provide supporting evidence showing how any Grade 2 and above waste rock which is not proposed to be placed in Pit 3 will be managed in a manner which does not result in increased environmental risk.*	Noted
4	Before commencing bulk backfill works or disposing of any material in Retention Pond 2, ERA will complete all contaminated site characterisation work and obtain Supervising Authority approval for a Contaminated Material Disposal Plan	In progress
5	ERA will continue to operate the Pit 3 decant system until it can be demonstrated to the satisfaction of the Supervising Authority that it is no longer required to meet agreed closure criteria.	Noted
5.1	Before the Pit 3 decant operation begins, ERA will update the Ranger Water Monitoring Strategy to include a commitment to annual radiation monitoring of drinking water from Magela Creek for the duration of the operation.	Future activity to be discussed
5.2	During the period of the Pit 3 decant operation, ERA will maintain groundwater in Pit 3 not less than two metres below the surrounding groundwater levels as measured in monitoring bores NWOB003 and MS4, or similar bores accepted by the Supervising Authority to fulfill that purpose.	Noted
5.3	Pit 3 is not to be converted to a pond water catchment without the approval of the Supervising Authority.	Noted

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.

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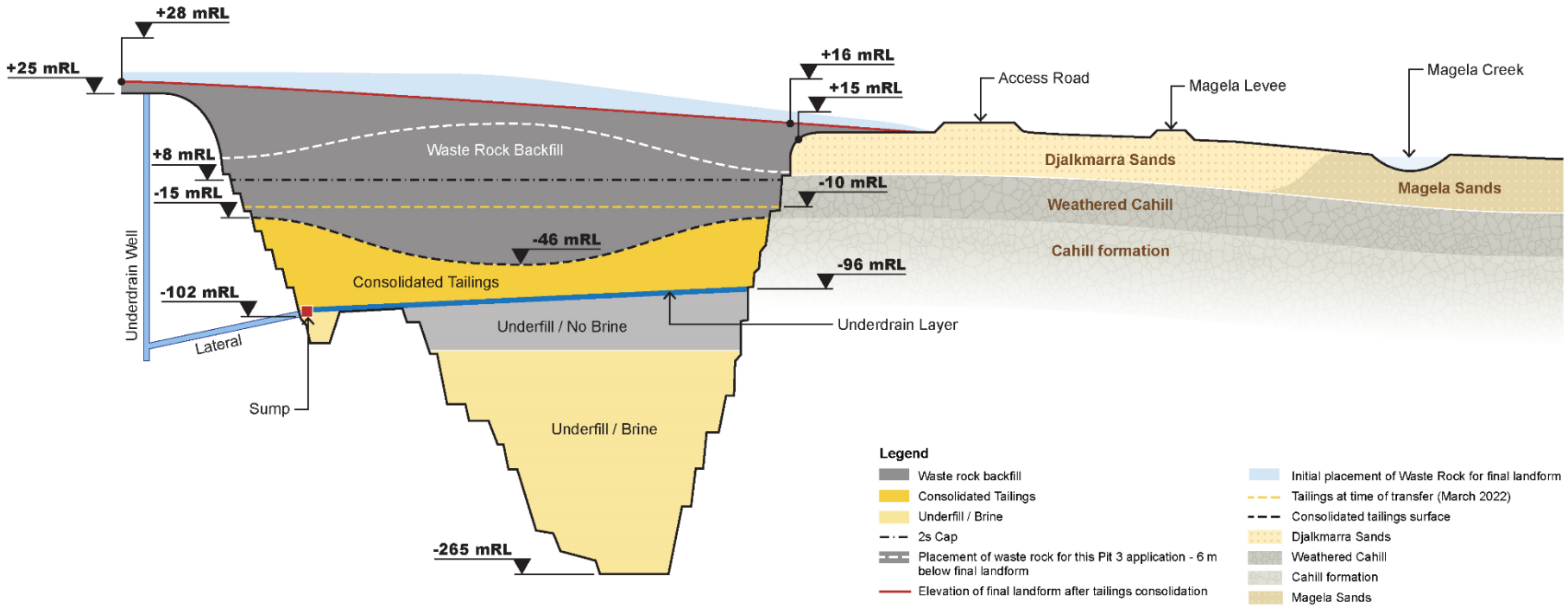

Figure 4-6: Schematic of Pit 3 with key elevations (not to scale)

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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); 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.

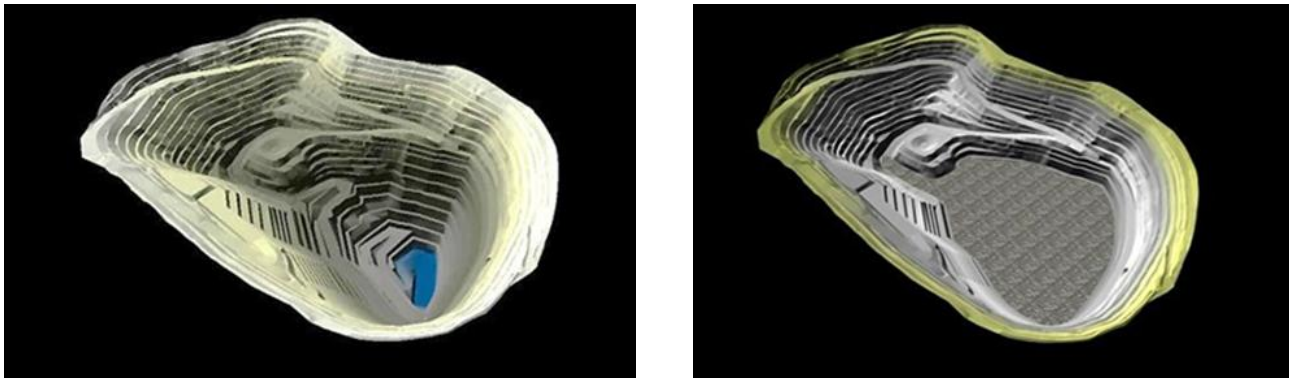

Figure 4-7: Pit 3 in 2014 (left) and after construction of the underfill in 2021 (right)

The underfill was constructed by placing 32 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 and create void space between the waste rock for brine to be injected. 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 south-west 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 is pumped from the underdrain bore to the process water circuit via piping infrastructure.

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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.

Earlier estimates (from 2013 onward) projected total volume of brine requiring disposal to be approximately 1.8 GL. The 2022/23 feasibility reforecast reassessed total brine volume and revised this slightly upward to a range of 1.9–2.1 GL.

To improve predictive accuracy, brine volumes are currently under review through:

- calibration of the site-wide GoldSim water balance model;
- additional sampling and analysis to confirm concentration of specific process water sources; and
- integration of salt tracking to enable refined brine volume forecasting.

In parallel, strategies for optimising process water treatment are under active investigation or ready to be implemented (such as commissioning the Brine Squeezer to treat process water in accordance with the existing approval).

A best practicable technology (BPT) assessment in 2013 (see Appendix 4.2) evaluated twenty-seven brine disposal methods. Eight options were assessed in detail across three common disposal approaches: brine injection, crystallisation and thermal distillation. Injection of brine into the Pit 3 waste rock underfill was chosen as the preferred disposal method at Ranger.

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.

The storage capacity of the underfill has been investigated over many years (Brown, 2013 and Coghill, 2016), both identified a void space of approximately 2.48 GL.

The 2022 Feasibility Reforecast, reviewed the capacity of the underfill to accept brine 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 estimated brine capacity of the underfill in Pit 3 is calculated by multiplying the total volume of the pit between -265 mRL and -102 mRL by the applied effective porosity (0.182). At an elevation of -102 mRL, applying the adjustment factor for inaccessible voids, Pit 3 can hold up to 2.48 GL of brine.

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In November 2022, ERA successfully installed three directionally drilled injection bores located on the perimeter of the pit (Figure 4-8). One bore is used at a time with the second and third bores to be used to manage down-time and as contingency in the event of well failure. Brine injection has continued successfully from a single bore since 31 May 2023 with the underfill accepting an average of 0.85 ML of brine per day. At the time of writing, approximately 736 megalitres (ML) of brine has been injected into the underfill to date. Designs for additional injection wells will be advanced to ensure they are ready if additional contingent bores are needed, with construction only proceeding if performance issues arise in the existing wells.

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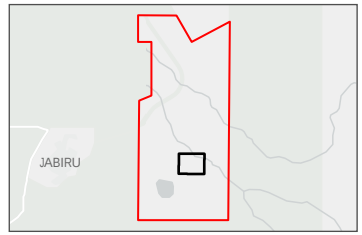
FIGURE 4-8

Location of Well Heads of the Directionally Drilled Brine Injection Wells

LEGEND

Brine Injection Well



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4.2.3 Tailings Deposition

Tailings deposition into Pit 3 involved pumping mill tailings and dredged tailings from the Tailings Dam into the pit which resulted in coarser tailings accumulating at the eastern end and finer tailings settling in the decant pond at the western end. This segregation formed a slope in the tailings surface from east to west. The finer tailings in the decant pond at the western end will take longer to consolidate and therefore longer before it reaches the geotechnical strength to enable geotextile installation and capping.

Approximately 1.77 million cubic metres (M m^3) of remnant tailings, including gravel and rock, were also transferred to Pit 3 using dump trucks by December 2021. For the transfer, a HDPE liner was installed to assist with material placement, though some of this material - referred to as 'Pit 3 tip head material' - adhered to the south-west wall. This residual material, along with the liner, was mostly removed from August - September 2024 (Photo 4-12 and Photo 4-13) with the tailings placed on the Pit 3 tailings surface below the approved final tailings level of -10 mRL. A small quantity of tailings remained beneath the pipes shown in Photo 4-12 and Photo 4-13, with final removal completed in August 2025 (Photo 4-14).

Photo 4-12: Tailings hung up on the tip head

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Photo 4-13: Pit 3 tip head during removal of tailings (August 2024)

Photo 4-14: Pit 3 tip head following tailings removal (August 2025)

4.2.4 Activities Occurring at Present

4.2.4.1 Pit 3 Dewatering and Drying out of Tailings

Tailings consolidation and drying activities in Pit 3 have advanced to support safe geotextile installation and initial capping. Approximately 39,755 prefabricated vertical drains were installed by April 2023 to accelerate tailings consolidation and strengthen the tailings surface, similar to previous efforts in Pit 1. As consolidation progresses, the tailings release pit tailings flux (PTF) which is collected via the underdrain system (described in Section 4.2.2) or from just above the tailings surface. Dewatering of the pit commenced on 3 August 2023 to facilitate drying of the tailings surface.

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The extracted water from the underdrain system and from the tailings surface is directed to the RWD ahead of treatment via the Brine Concentrator.

An exemption to dry the tailings - departing from the Ranger Authorisation requirement to keep them saturated - was approved in June 2023 along with appropriate dust management controls.

To enhance the geotechnical strength of the tailings and prepare for capping, the tailings surface must be dried out to a suitable weight bearing strength. Amphibious excavators (Photo 4-15) and amphirol machines (Photo 4-16) are used to mechanically accelerate drying the surface of the tailings in the non-wicked areas (Photo 4-17), by overturning the tailings and creating a crust up to approximately 1 to 1.5 metres thick.

Five zones were established within Pit 3 (Figure 4-9) to demarcate the progressive drying of the tailings. The wicked zones (zone 3A, 3B and 4) are anticipated to be the last zones to dry.

During the 2024-25 wet season, a trial in zone 1 tested the effectiveness of placing fine mineralised material sourced from the ROM ore stockpile into the tailings surface. The area received the fines and was covered with geotextile and the first lift of initial capping material. Post-placement monitoring indicated a notable increase in shear strength alongside reduced surface deformation and enhanced overall stability. A second method for increasing the bearing strength of the tailings to accelerate initial capping has also been used. This method places a geofabric onto the tailings prior to a thin layer of waste rock, and then the geotextile and initial capping layer. This method has also been shown to be effective.

Photo 4-15: Amphibious excavator

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Photo 4-16: Amphirol machines on Pit 3

Photo 4-17: Amphirol overturning tailings in Pit 3

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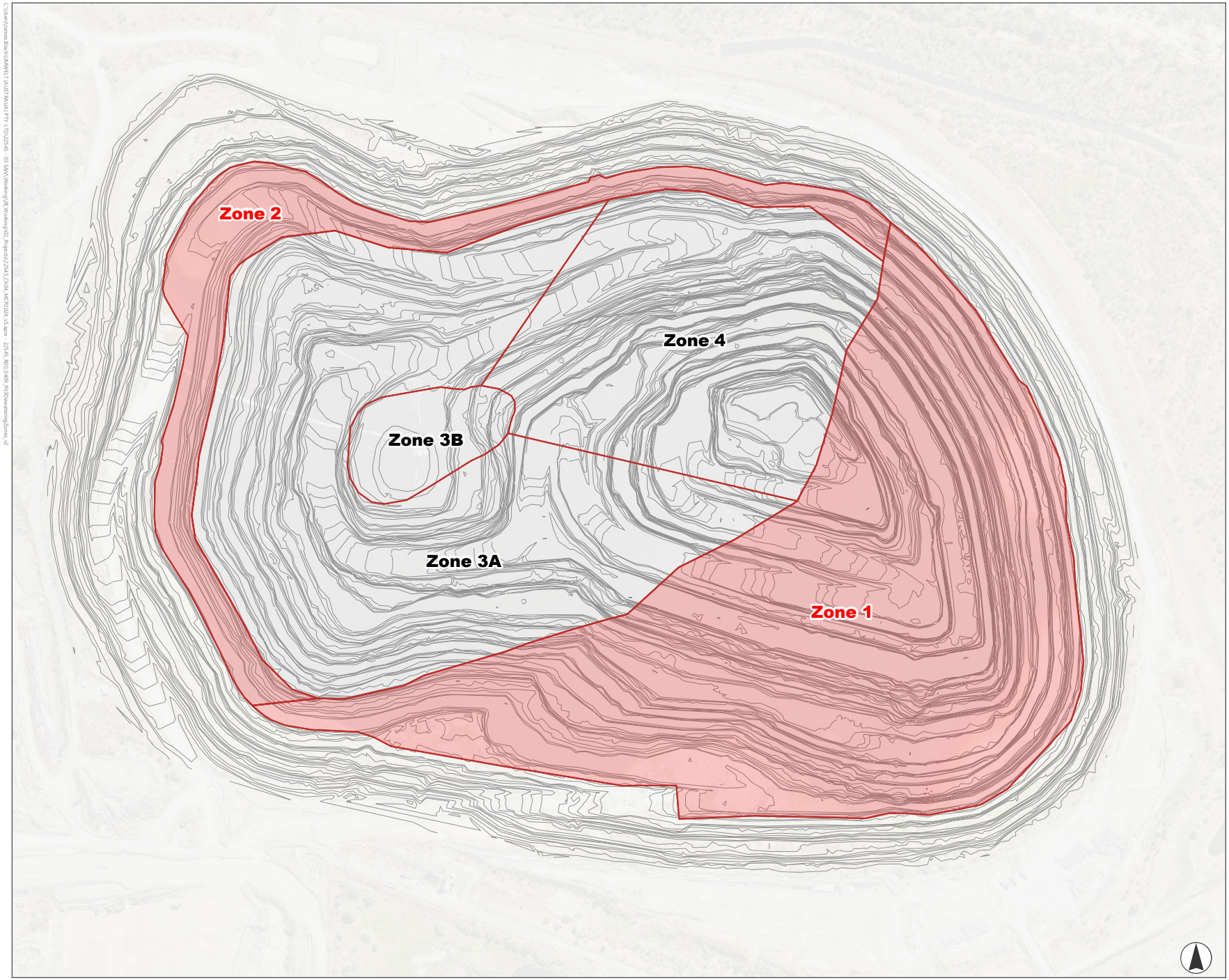
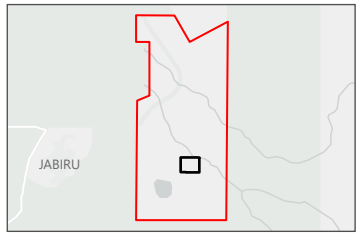


FIGURE 4-9

Pit 3 Dewatering Zones

LEGEND

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



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4.2.4.2 Geotextile Placement and Initial Capping

Placement of geotextile and the initial capping layer began in zone 1 in December 2024 and zone 2 in May 2025, and is progressing (Photo 4-18). The initial capping layer is approximately 3 m thick and installed in two lifts of about 1.5 m each (Figure 4-10).

The initial placement of waste rock over the geotextile layer is carried out slowly across the tailings surface to minimise heave and avoid overstressing the geotextile. This controlled approach allows the underlying tailings to settle progressively, reducing the risk of geotextile failure and heave. The weight of the capping material exerts downward pressure, displacing the PTF and promoting consolidation of the tailings, which in turn improves the stability of the surface for subsequent capping layers and construction activities.

Photo 4-18: Installation of geotextile and construction of initial capping on Pit 3 (June 2025)

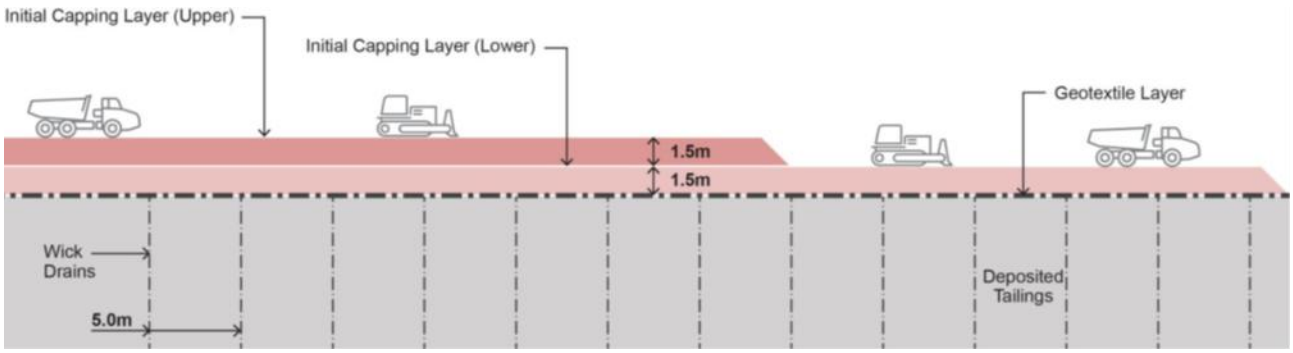

Figure 4-10: Schematic of the initial capping construction method

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Construction of the initial capping layer prioritises the use of stockpiled material with the highest proportion of mineralised waste rock (i.e. grade 2 and above). This approach ensures that the most mineralised material is buried at greatest depth within the pit. Initial capping (and secondary capping) material may be sourced from the ROM pad area and/ or from the southern stockpile areas of Stages 2, 71, 81 and 82 (see Figure 4-11).

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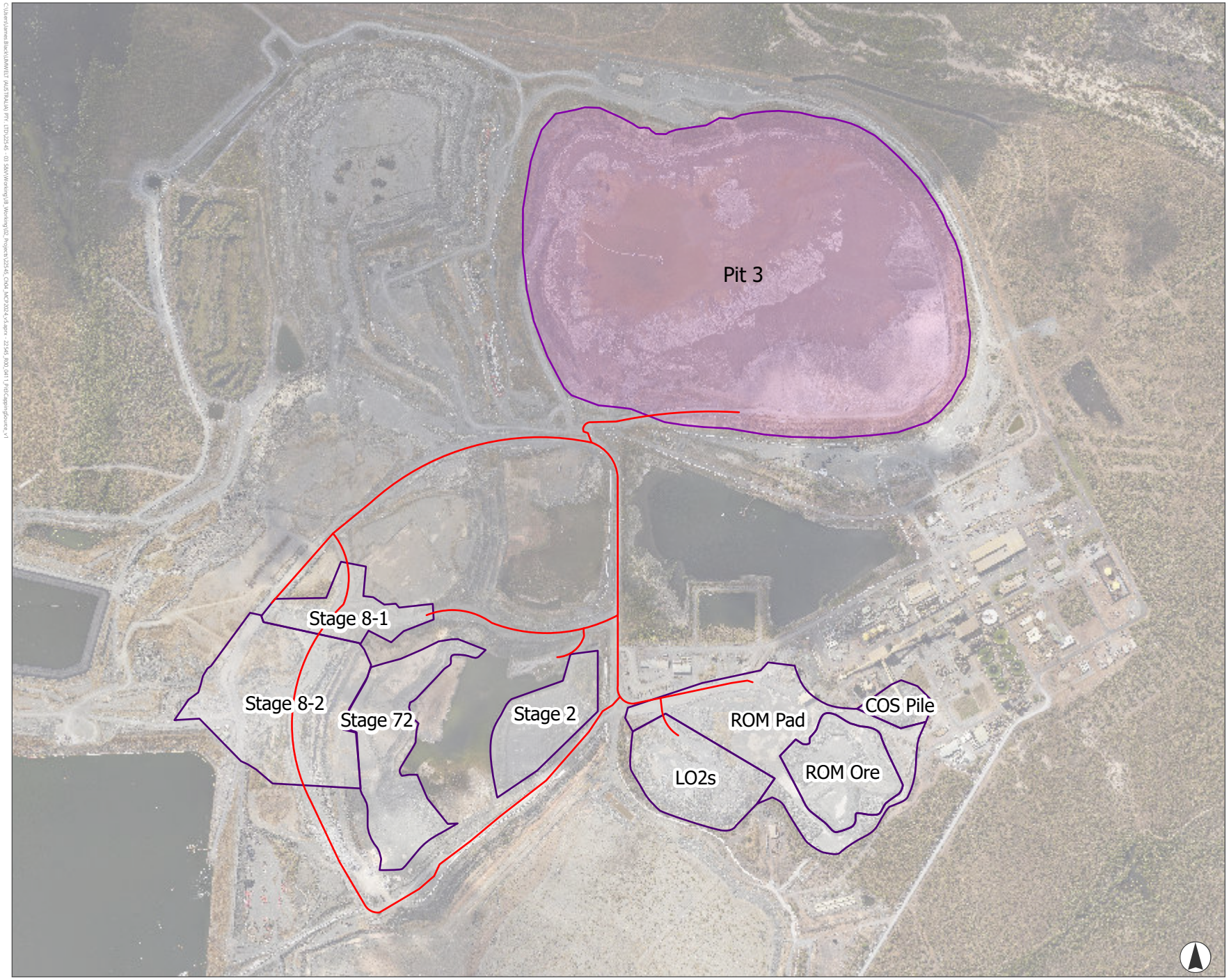
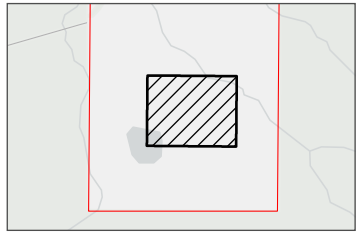


FIGURE 4-11

Pit 3 Capping Source Material Location

LEGEND

- Pit 3 area
- Source Stockpile
- Potential Haul Route



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As capping material is placed over the geotextile the weight of the material forces water out from the underlying tailings and helps with consolidation. Surface water management during the geotextile installation and capping phase includes natural evaporation and active removal of water via low flow/turret pumps, with extracted water transferred back to the RWD. To prevent fine tailings material being pumped back to the RWD, a visual inspection and testing occurs. If the water appears clear and within acceptable turbidity limits, the low flow pumps transfer the water to holding tanks. These tanks serve as a secondary checkpoint, where the water is again visually inspected for turbidity, and based on the results, is either returned to the pit (if turbid) or pumped to the RWD (if clear). Pumping operations are suspended if turbidity levels exceed acceptable limits.

All water pumped from the central pond during this initial capping phase is categorised as process water.

The capping material creates opportunities to capture rainfall runoff before it infiltrates and contacts with tailings and becomes categorised as process water. In accordance with existing approval conditions, and at the appropriate time, the Ranger Rehabilitation Project Team will seek approval to convert all or part of Pit 3 into a pond water catchment.

During initial capping, the decant and monitoring towers will be installed. The decant towers and associated pumps, along with the underdrain bore, will assume the primary role in process water extraction from Pit 3.

4.2.5 Planned Future Activities

The activities described in this section were included in the Pit 3 Capping, Waste Disposal and Bulk Material Movement application submitted in September 2023 to the Commonwealth and NT ministers' and received conditional approval on 11 August 2024.

4.2.5.1 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 layer to accommodate the construction equipment.

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. This will maximise the recovery of the PTF enabling the contaminated water to be removed from the pit, transferred to the process water circuit, and treated. A fit for purpose design of the decant wells is complete and been approved by the Office of the Supervising Scientist as per Condition 1.2 of the Pit 3 Capping and Backfill approval (Figure 4-12 provides an illustration of the main design components).

Slotted/perforated concrete pipes will be positioned directly above a reinforced pre-cast concrete base (the footing) to enable water migration into the well, followed by stacked concrete pipe sections. Mine waste rockfill will then be placed as the decant well is constructed in stages, until the final level is above the final landform. Figure 4-13 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.

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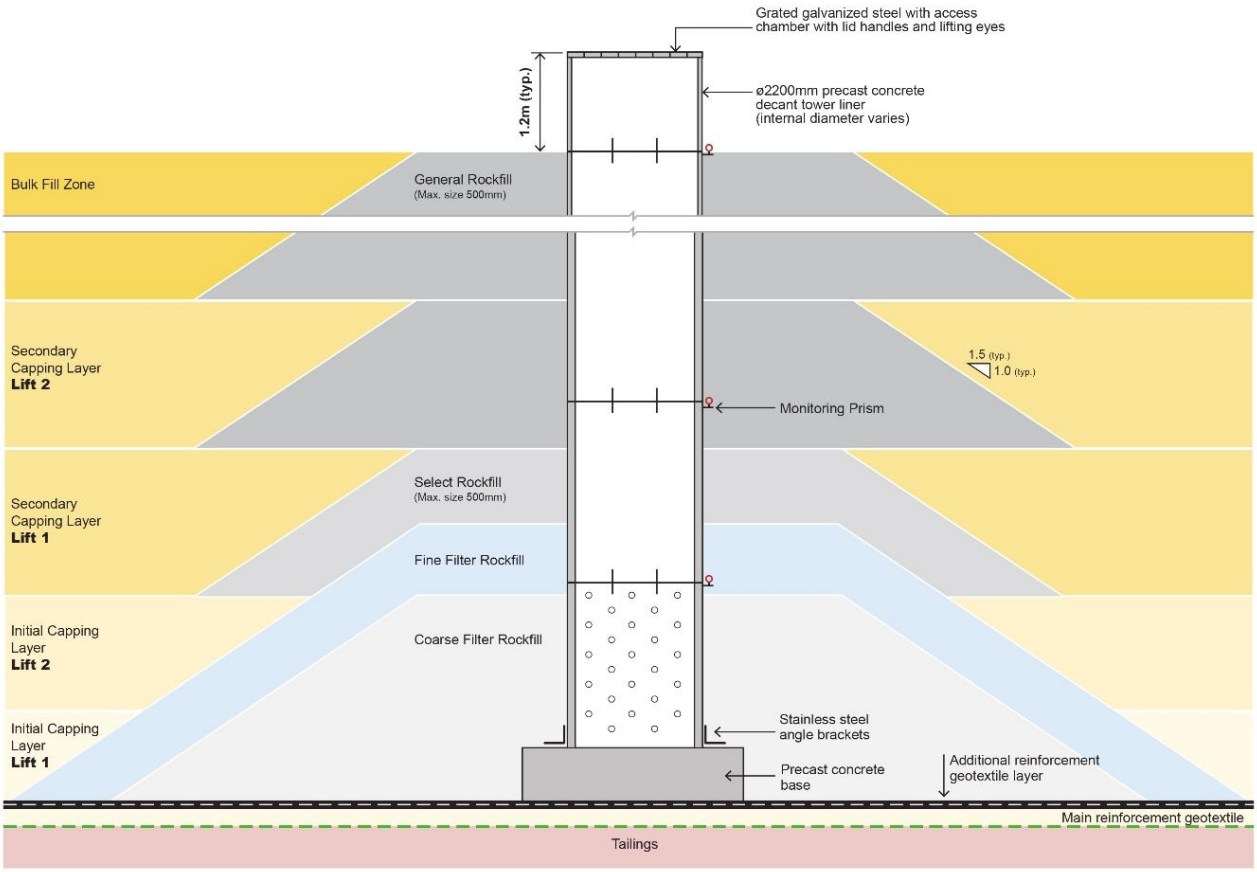

Figure 4-12: Decant well typical section (indicative only –not to scale)

The system will pump process water from the base of the decant well, and via an overland HDPE pipeline starting at the western ramp of Pit 3. The system 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 4-13 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.

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.

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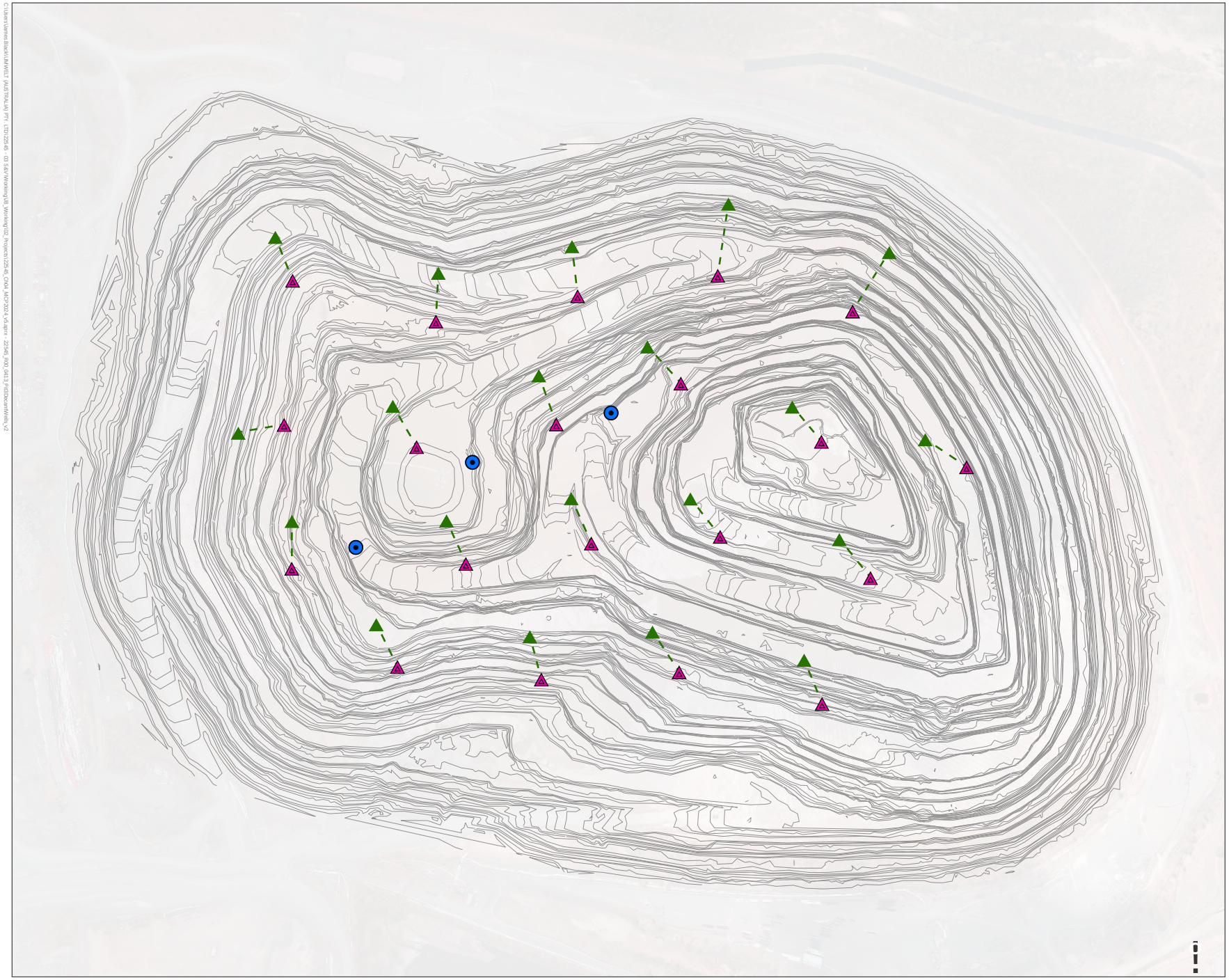

FIGURE 4-13

Nominal Location of Decant Wells and Monitoring Towers

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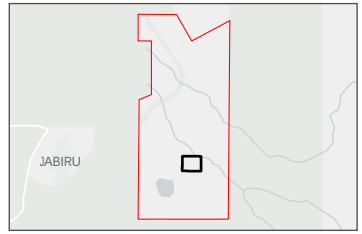
- Decant Well
- Vibrating Wire Piezometer
- Monitoring Tower
- Cable
- Bathmyetric Countours (2m)



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4.2.5.2 Secondary Capping

The secondary capping layer will be added on top of the initial capping layer. Dozers and dump trucks will be used to place approximately 4 m of waste rock material on top of the initial capping layer (Figure 4-14). It is expected that this will be placed in 2 m lifts, depending upon the geotechnical strength of the underlying layer. This activity is standard earthworks practice and will create a working surface with sufficient strength to enable larger mining fleet equipment to traffic the area for bulk material movement activities.

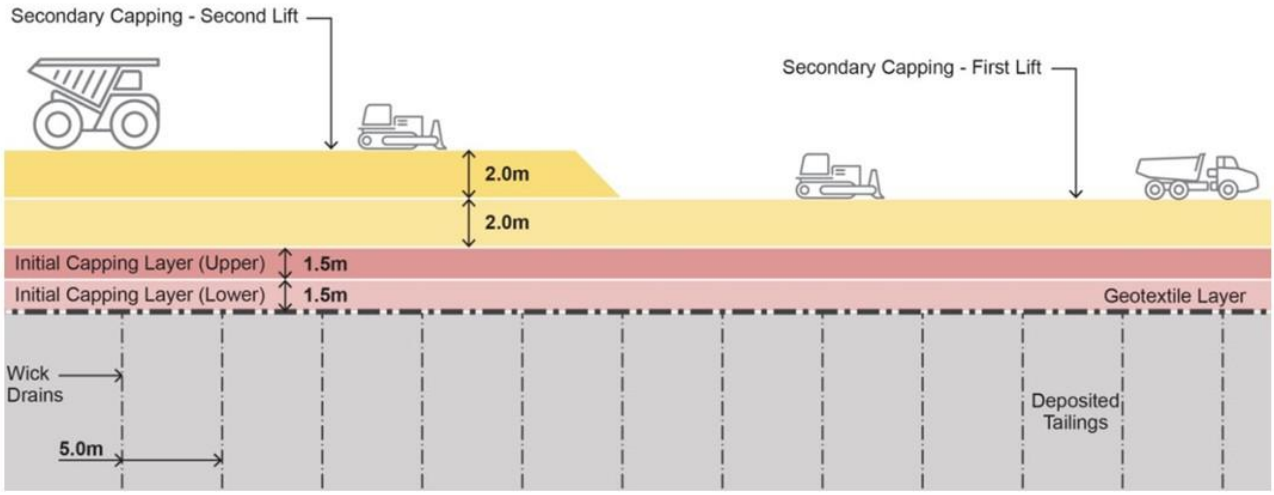

Figure 4-14: Schematic of secondary capping method

A *Secondary Capping Material Movement and Dust Strategy* was submitted on 7 March 2025 and approved on 2 April 2025. As per that approval, grade 2 and above material will be selectively excavated from Stages 2, 71, 81 and 82 to maximise the amount of this material, and minimise the amount of grade 1 material, being placed deeper into the pit.

To enable precise excavation, machine guidance technology will be used on each excavator, supported by detailed 3D excavation designs provided to contractors. Figure 4-15 illustrates the excavation design and Figure 4-11 shows the stockpile sources for the initial and secondary capping material.

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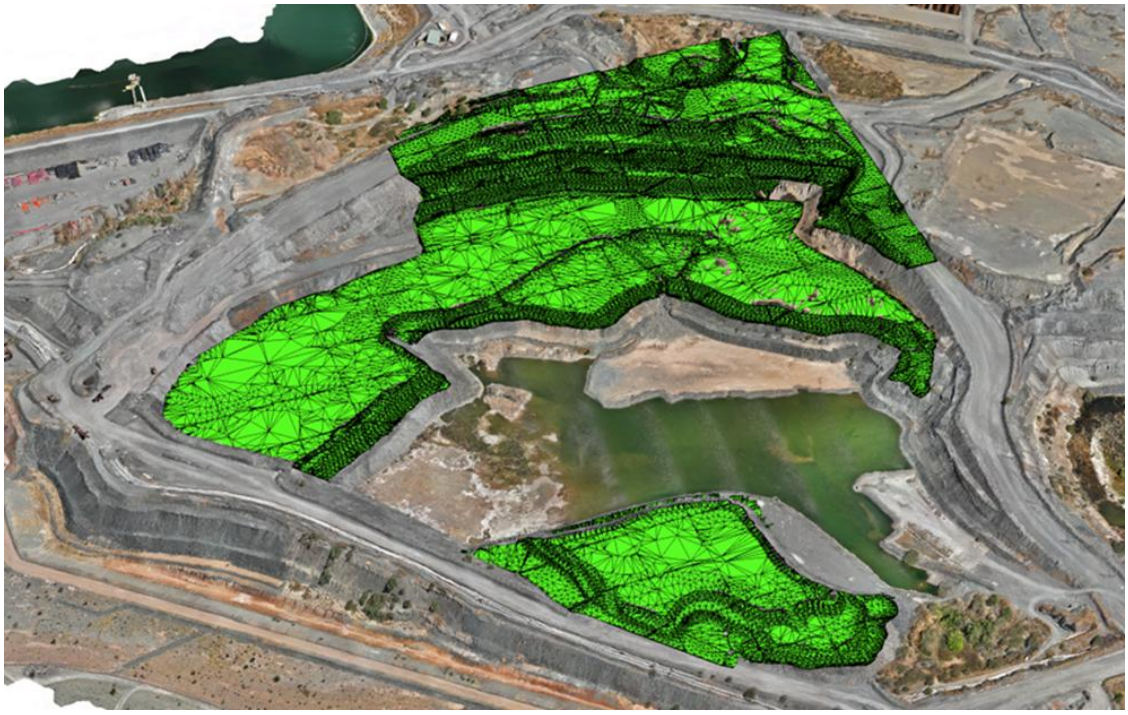

Figure 4-15: Example of 3D design files used to convert into machine guidance files for contractors

4.2.5.3 Backfilling

Following initial and secondary capping, stockpiled waste rock will be used to backfill Pit 3, with the mineralised material (grade 2 and above) placed below the water table to minimise future solute transport risk. 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, the Ranger Rehabilitation Project Team plan to allow for an offset buffer of approximately 6 m. Therefore, the Ranger Rehabilitation Project Team aim to dispose contaminated and mineralised material 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).

Pit 3 has a void volume of about 20 M m^3 from the top of the tailings surface (at the end of the consolidation period) to the conservative long-term average water level. The initial and secondary capping layers will require approximately 3.9 M m^3 of backfill material, with an additional 25.1 M m^3 needed for bulk backfill, totalling 29 M m^3 to reach the final landform surface. Section 4.8 describes the backfilling process and the placement of different grades of waste rock, including the ~15.1 M m^3 of grade 2s waste rock stockpiled on the RPA, which can all fit below the conservative average long-term water level in Pit 3.

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.

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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

Water on site is managed according to its quality and suitability for release off site. Various water treatment and disposal options are utilised to achieve the release water quality.

Water management at Ranger is driven by two key inputs: rainfall runoff and process water.

Rainfall captured on site is directed into sumps, collection basins and/or water storages depending on the catchment within which it falls. Collected runoff is categorised and managed based on its water quality.

Each class of water differs according to its composition, which dictates the way it is managed. A description of the water classes is provided in Table 4-3. Each water class is managed using the water management system infrastructure which consists of various elements such as water treatment plants, transfer pipes, ponds, sumps and release points. Typically, water classes' characteristics are consistent with the catchments from which they originate.

Table 4-3: 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.
Intermediate water	Water that is derived from rainfall runoff or groundwater and has not yet been discharged into Pond water storage, or an approved release pathway. Intermediate water can include water that is waiting on water quality analysis before appropriate transfer is made or is in the process of being transferred across site and has not yet reached either pond water storages or release pathways.
Pond water	Water that is derived from rainfall runoff or groundwater and is of a quality that requires treatment before it can be released to the environment. Pond water is stored in RP2 and RP6.
Release water	Water that is of suitable quality for release to the environment. This water can be derived from rainfall runoff, water treatment or groundwater that is of a quality suitable for release to the environment. Release water storages include RP1 and the impoundments along Corridor Creek release pathway (e.g. CRS).
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.
Reject streams	Brines and residues from treatment processes.

4.3.2 Water Treatment Infrastructure

Figure 4-16 provides a diagram of the Ranger water circuit. The main components in this circuit are described in the sections that follow.

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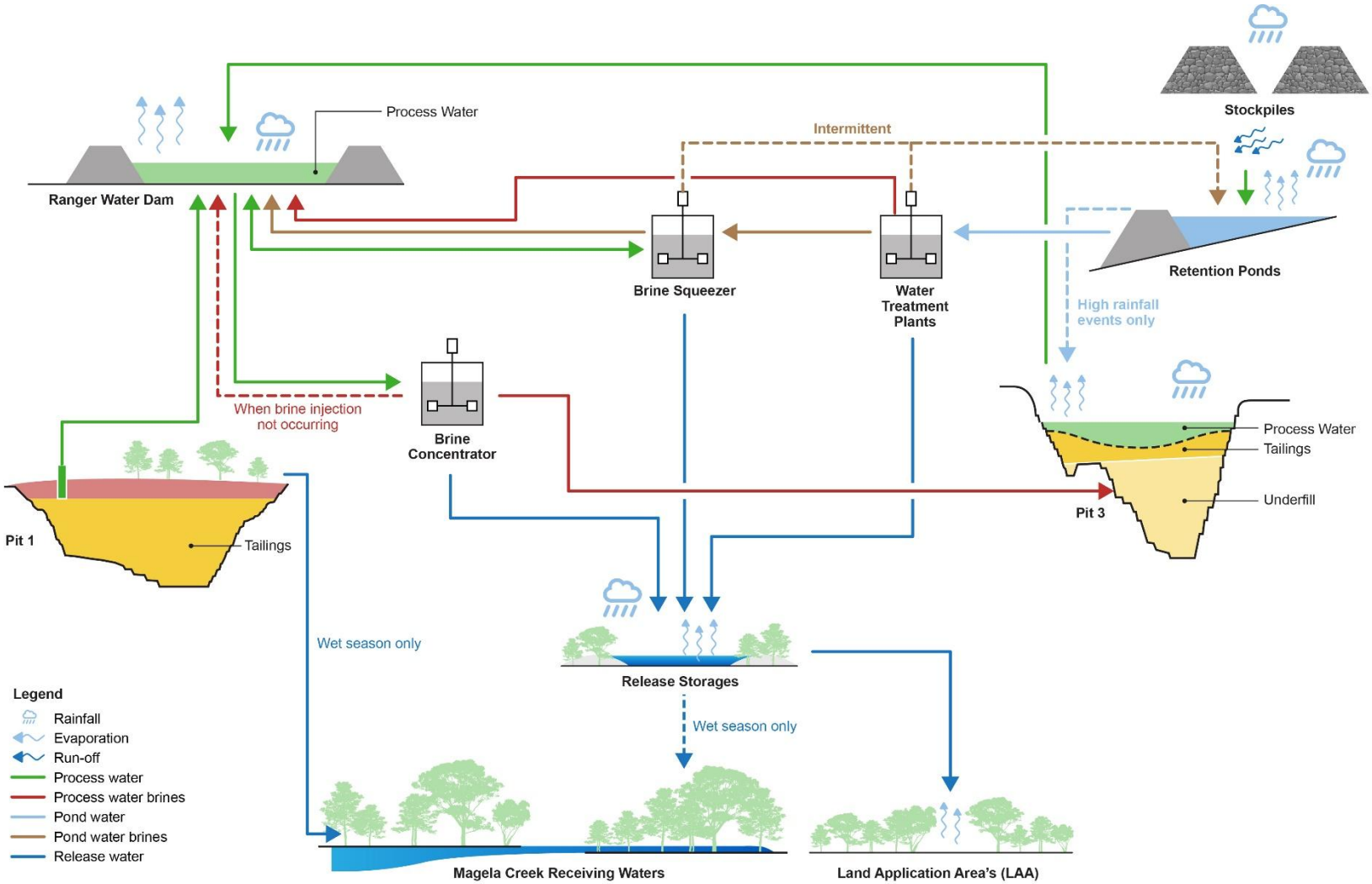

Figure 4-16: Ranger water circuit

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4.3.2.1 Brine Concentrator

The Brine Concentrator (Photo 4-19) 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 or the brine does not meet concentration specifications, it is returned to the process water inventory.

Treatment of process water and disposal of the concentrated brine are key drivers 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).

Photo 4-19: Brine Concentrator

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4.3.2.2 Brine Squeezer

The Brine Squeezer (Photo 4-20) 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 inventory.

A significant upgrade of the Brine Squeezer is now complete, and it is expected to treat around 0.5 GL of process water per year once fully operational. MTC approval for the plant to treat process water was received in November 2023 and process water treatment was anticipated to commence in 2024, following a planned testing program. However, changes in process water quality delayed the program (described in Section 4.5.3). A further trial is in progress to determine the capacity of the Brine Squeezer to treat current process water, and to enable projection of future performance as a function of changing water composition. The first part of the trial will utilise one of the three trains and will feed more dilute process water from the upper layer of the stratified RWD targeting a range of instantaneous recoveries. A sampling program will be implemented to monitor permeate quality. The second part of the trial will feed ‘intermediate’ RWD water. The intent is to transition from a successful trial to whole of plant (three train) operation, subject to demonstration of stable operation, and consistent and compliant treated water quality.

The Brine Squeezer consists of two stages of reverse osmosis treatment in series. In the first stage, high salt tolerance membranes are used to produce an intermediate 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.

Photo 4-20: Brine Squeezer

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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 is 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. Their total capacity provides 1.4 GL per annum of permeate for release, although the actual volume treated varies from year to year depending on wet season inflows and overall water inventory. 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. It is noted that a significant portion of water also evaporates naturally from the retention ponds (reducing the total volume requiring treatment) and the release water storage areas (RP1, CRS and the wetland filters).

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 4-4) 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 4-4: Capacity and description of on-site retention ponds

Name	Capacity	Description
Retention Pond 1 (RP1)	436 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.

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Name	Capacity	Description
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, though it may also be used as a temporary process water storage later in the closure sequence. The emptying of RP6 will allow the deconstruction of the central and eastern sections of the RWD north wall to commence.

It is likely that RP1, RP3 and RP6 will be deconstructed in line with Phase 2 demolition and contaminated material would 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) will be described in the Contaminated Material Disposal Plan (Condition 4 of the Pit 3 backfill approval).

Further to the retention ponds noted above, an old borrow pit (also called RP5) occurs on site (refer Figure 4-2, label 9Eii for location). This area has not been used for many years and investigations will be undertaken to determine whether to reinstate this area as an alternative water storage.

4.3.3.2 Wetland Filters

Wetland filters have been installed at Ranger to passively treat water and provide a final polishing of treated water to improve the quality prior to release.

The wetland filters used at Ranger comprise the RP1 wetland filter and the Corridor Creek wetland filter. The RP1 wetland filter, although no longer operational, served to attenuate uranium from water through biogeochemical processes before it was discharged to RP1 or used for a variety of purposes such as land application, dust suppression and construction. The Corridor Creek wetland filter (Photo 4-21) is used to treat ammonium from process and pond water permeate and uranium from surface water runoff.

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Photo 4-21: Corridor Creek Wetland Filter

Further site investigations will be undertaken to investigate the extent of any potential contamination within the wetland filters and if any remediation activities are required. If contaminated sediments are present within the wetlands, excavating and disposing of them 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 (LAAs)

The LAAs at Ranger (refer Figure 4-2 for locations and Table 4-1 for area) allow for the controlled disposal of release water using a system of pipes and sprinkler heads (Photo 4-22). 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. Magela LAA is no longer in use and has been identified for early rehabilitation.

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Photo 4-22: Corridor Creek Land Application Area

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). The LAAs contain loose materials such as general waste, fencing, redundant piping, concrete and some disused irrigation (e.g. pipes, valves, sprinkler and risers). The above ground loose materials will be collected and disposed of into Pit 3 during Phase 1 demolition. Buried disused irrigation will be left in-situ and irrigation risers will be removed to a nominal level below ground level (the risers are typically 25 mm galvanised pipe and would usually just unthread from the buried pipeline below ground). 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.

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4.3.3.4 Seepage Interception Systems

The Western Stockpile Interception System (WSIS) was installed in 2010 to intercept solute movement associated with the western stockpile and prevent it from entering RP1 and Coonjimba Creek. The GCT2 groundwater interception and recovery system was constructed between 2014 and 2015 on the western side of the RWD to intercept solute movement from the RWD wall towards Gulungul Creek. The ongoing use of the interception systems, a possible extension of the WSIS along the northern extent of the RWD, and the timing of decommissioning of the systems is being considered.

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/partially occurred. The large-scale demolition of processing plant infrastructure described in Section 4.4.2 is the subject of a separate standalone application. The disposal of contaminated material described in Section 4.4.3 is the subject of a Contaminated Material Disposal Plan (required under Condition 4 of the Pit 3 backfill approval).

4.4.1 Decommissioning

Prior to starting 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 relates to the plant, structures and buildings previously used for the mining, processing, production, storage and transport of uranium ore concentrates, and outlines 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 the processing plant was guided by the Ranger Mine Decommissioning Plan that accompanied the ASNO permit application. It is also noted that an additional ASNO permit is required prior to relocating the calciner from its currently approved location. This permit will be obtained before the calciner is relocated into Pit 3.

The decommissioning strategy focused on controlled asset shutdown, infrastructure decontamination for safe future demolition, de-energisation, isolation of demolition areas and interim management. Handover to the demolition contractor is pending.

Ongoing rehabilitation efforts mainly involve care, maintenance and preparatory works to ensure the area remains safe and that service continuity is maintained before demolition begins. These activities include managing rainwater in process area bunds through existing sump pumps, maintaining a system for pumping contaminated rainwater to the RWD, 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 involves moving service corridors, such as power and water lines, outside of the future zone of demolition.

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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. Where economically viable, infrastructure will be cleaned, cleared for radiation and stockpiled for re-use and/or sale. Infrastructure that is not re-used or sold will be disposed in Pit 3.

Some infrastructure, such as the water treatment facilities, transfer pipes, and power systems servicing the Pit 3 decant towers and the RWD, are likely to remain operational beyond the Pit 3 backfill timeframe. These components will be recycled, sold for reuse, or disposed of in RP2 (Phase 2 demolition on Figure 4-17). Any infrastructure required to support monitoring and maintenance activities after the creation of the final landform will be retained until no longer required.

The execution of mine infrastructure demolition encompasses three distinct phases:

- Phase 1: this phase includes the demolition of all facilities not required to support closure activities. Demolition of the processing plant and most of the infrastructure within the process plant area is included in this phase. Demolished materials will be cleaned and sold (after radiation clearance) or stockpiled at a temporary laydown area and disposed into Pit 3 when it is open and accessible.
- Phase 2: this phase includes the facilities required to support closure activities (e.g. water treatment facilities and some continued services including piping and power infrastructure). Demolished material will be disposed directly into Retention Pond 2 (RP2).
- Phase 3: this phase includes the remaining facilities and materials necessary to support the final water treatment (if required) and revegetation efforts on the FLF as well as monitoring and maintenance activities. These items (such as the nursery and remaining offices) will be either sold or disposed of at appropriately licenced facilities outside of the RPA.

Figure 4-17 shows the areas on the RPA included within the three demolition phases. Figure 4-18 shows the phase relevant to the processing plant and supporting infrastructure.

It is anticipated, but not yet confirmed, that Phase 1 demolition activities in the processing plant area would start approximately 6 months before Pit 3 Bulk Material Movement (BMM). The Ranger Rehabilitation Project Team continue to seek opportunities to accelerate the demolition schedule. To manage demolition material before BMM starts (and thus the ability to co-dispose demolition material with waste rock directly into the final disposal location in Pit 3), temporary laydown areas will be established to stockpile and stage demolition material until material can be transported directly into the pit. Figure 4-17 shows the current proposed temporary laydown areas, however, other areas may be proposed in consultation with the demolition and BMM contractors. The engineered ramp constructed on the southern face of Pit 3 will facilitate transportation of material into the pit.

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. This will continue until the demolished infrastructure is removed and water quality measurements confirm that water can be safely managed by other approved processes.

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Phase 2 demolition has been scheduled to commence when the Brine Concentrator and Water Treatment Plants become available for demolition and RP2 is ready to accept demolished material. Phase 3 demolition has been scheduled to commence once the final landform has been constructed and revegetated.

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;
- pavements and road surfaces (bitumen and concrete) along with associated infrastructure such as kerbs, gutters and gully pits;
- concrete slabs, piping and cabling to an appropriate depth below final landform ground level;
- concrete foundations, the treatment of which will vary depending on their size, with smaller sized foundations remaining in-situ and larger foundations being broken up to allow appropriate water movement and plant root growth;
- tyres and other contaminated material stockpiled in designated areas (noting that offsite disposal and reuse opportunities are being investigated for used tyres); and
- hazardous materials associated with demolition of structures.

In terms of demolition processing, the objective is to reduce most materials into 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 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 (offsite disposal is also being investigated as an option).

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:

- where economically viable, infrastructure will be cleaned, cleared for radiation and stockpiled for re-use and/or sale;
- demolished materials will be processed to optimise density for the disposal location and improve safety while handling;

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- designated controlled areas will be managed to ensure hazardous residues and contaminated runoff are captured and directed to the process water circuit;
- appropriate radiation management will apply throughout the activities to minimise exposure;
- biosecurity controls will be embedded in demolition and handling processes to minimise the risk of introducing or spreading pests and weeds; and
- voids created by the removal of infrastructure will be made safe.

4.4.3 Disposal of Contaminated Material

Over the 40 years of Ranger mine operations, a range of activities have resulted in some contamination of soils and sediments in various locations across the RPA. None of which have caused detrimental environmental or health impacts outside of the RPA as is evidenced by the Office of the Supervising Scientist's annual reports. 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, and seeps and spills in the plant areas.

The Ranger Rehabilitation Project Team maintain 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 of Potential Concern (AoPC) within the RPA. (discussed in Chapter 8). The CSR and AoPC continue to be reviewed and updated as contaminated land sampling programs are undertaken.

Table 4-5 provides a list of the materials, estimated volumes and potential contaminants of concern, to be disposed at Ranger. These conservative estimates have suggest that up to 455,000 m³ of contaminated or demolished material may be disposed into Pit 3, of which around 405,000 m³ (or 89%) is contaminated soil. It is noted that the volume of contaminated soils and material may change as the studies to inform remediation planning are finalised and demolition activities are underway, 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. Comparing this with the available 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.

Studies are underway to inform remediation planning. If soil removal is necessary, the volumes and characterisation of the material will be discussed in the Contaminated Material Disposal Plan.

In addition to the contaminated soils, the Ranger Rehabilitation Project Team manage hazardous materials at Ranger in accordance with:

- HMP001: Hazardous Material and Contamination Control Plan;
- ERP003 Waste Hydrocarbon Disposal Procedure;
- ERS057: ERA Standard Hazardous Substances;
- Rio Tinto E15: Hazardous materials and non-mineral waste standard; and
- Relevant legislation, standards and Codes of Practice.

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Certain materials, such as acids and ammonia will be handled separately and not disposed of into Pit 3. Blackjack (a hydrocarbon lubricant that was injected onto the spindle of the ball mill during uranium ore processing) was previously approved for offsite disposal via a BPT in 2018 (see Appendix 4.2). A 2025 reassessment confirmed the BPT option as the preferred disposal method.

All listed wastes (classified under Schedule 2 of the NT Waste Management and Pollution Control (Administration) Regulations) disposed of onsite or offsite are recorded in a waste register for regulatory compliance and auditing.

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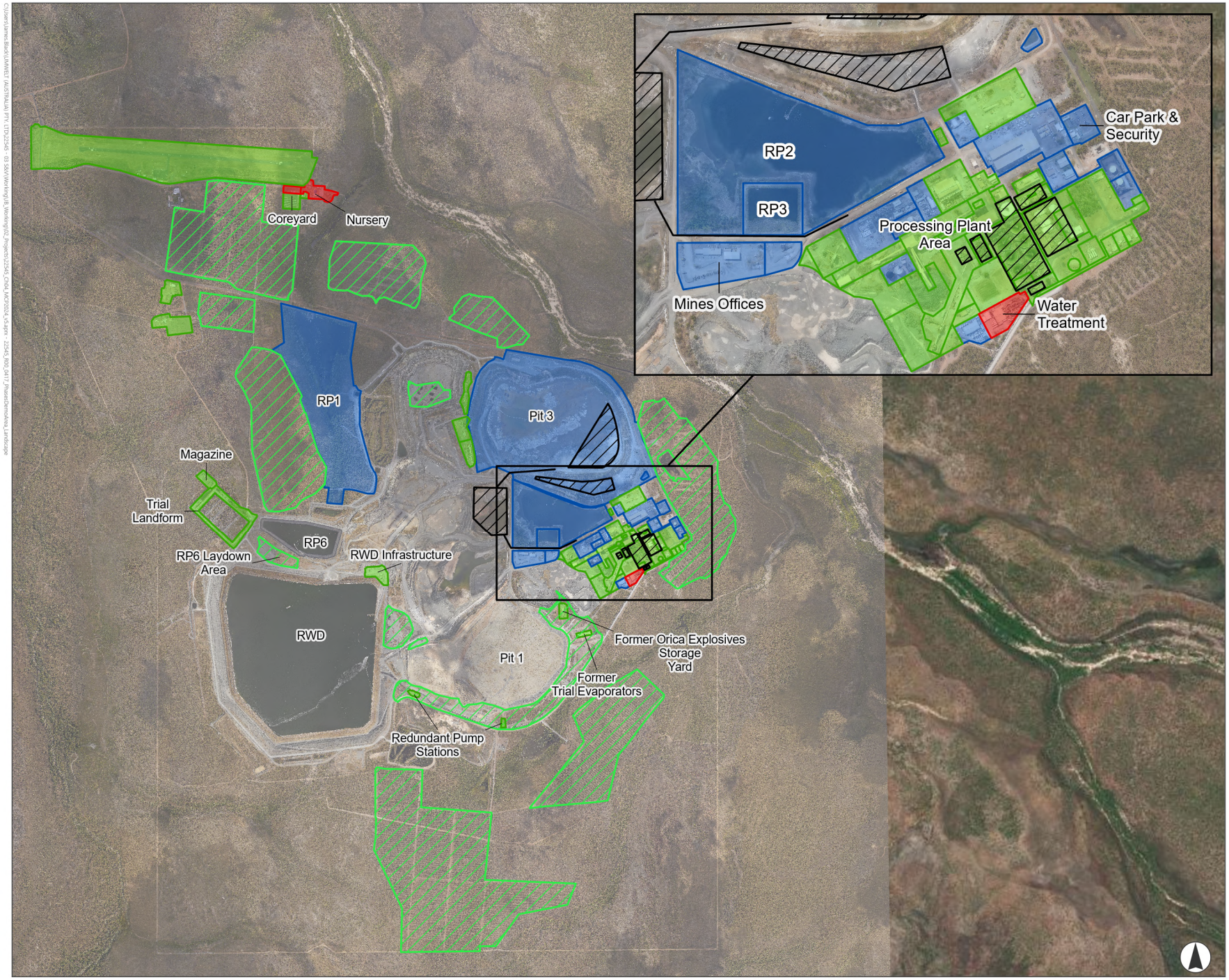

FIGURE 4-17

Demolition Phases on the RPA and proposed temporary laydown areas

LEGEND

- Phase 1
- Phase 2
- Phase 3
- Area scheduled for general clean-up (Phase 1)
- Potential sites for demolition laydown area/s
- Demolition Laydown Transport Route

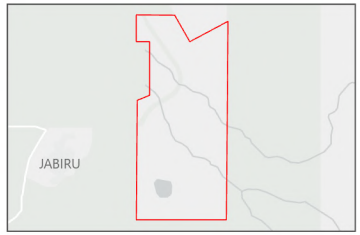

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FIGURE 4.18

Processing Plant area demolition phase

LEGEND

- Tailings 2 Sump Pumps

Demolition Phase

- Phase 1
- Phase 2
- Phase 3

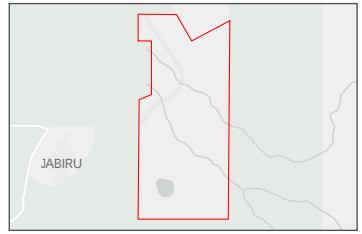

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Table 4-5: Approximate amount and destination of waste materials for disposal

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**

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4.4.3.1 Asbestos

The Ranger Rehabilitation Project Team 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 Ranger Rehabilitation Project 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 or RP2 or disposed at an appropriately licensed off-site facility.

4.4.3.2 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 (Photo 4-23).

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). Rubber waste will be disposed into Pit 3 and RP2, burying it at depth.

Two disposal options are being investigated for rubber waste:

1. cut up using hydraulic sheers prior to disposal 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; and/or
2. Rubber materials such as end-of-life tyres and conveyor belts can be transported off-site for recycling. This vendor processes the rubber by shearing, shredding and granulating it, before supplying it to bitumen manufacturers as a sustainable alternative to virgin rubber. Rio Tinto has previously adopted this recycling method at its Argyle mine and currently applies it to tyres and conveyor belts from its Weipa and Yarwun operations. All processing and recycling activities are carried out in Townsville.

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Photo 4-23: Rubber tyre dump on top of a waste rock stockpile

4.4.3.3 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. Of this, about 6,650 m^3 is expected to 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.

4.4.3.4 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 residual uranium product.

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;

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- seal the calciner apertures 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.

4.4.3.5 Buried Concrete and Other Items

The approach to managing buried concrete and other compacted surfaces is informed by key biological factors relevant to the proposed rehabilitation of the RPA, predominantly tree root structure and access to water and nutrients.

The technical guidelines for the rehabilitation of retained concrete structures on the RPA were developed and issued as OSS Technical Advice #066 (Supervising Scientist, 2024a). The guidelines for depth, dimension and spacing of retained underground infrastructure are designed to support the establishment and long-term viability of vegetation on the Ranger final landform.

The retention of concrete and other buried items will adhere to the following guidelines and principles:

- In the context of the final landform preparation, if 6 meters or more of waste rock substrate is placed on top of the remaining concrete and compacted surfaces, no further action is required. This guideline applies regardless of the size or depth of the concrete or compacted surface.
- Otherwise:
    - Linear concrete foundations will remain in place at unlimited length and depth, provided they are up to 1 m wide.
    - Columnar concrete foundations up to 3 m x 3 m in size and of unlimited depth will remain in place.
    - Horizontal concrete slabs and other compacted surfaces will be broken into fragments no larger than 3 m x 3 m.
    - Concrete foundations will be separated by at least 2 m of non-compacted substrate.
    - Retained concrete and compacted surfaces will be covered by a minimum of 1.5 m of waste rock substrate to support revegetation efforts.
    - Concrete and compacted surfaces will not interfere with the surface preparation of the final landform, specifically deep ripping.
    - Before the final substrate is deposited, an assessment of the toxicity of concrete and other compacted surfaces, including any additives, will be undertaken. If the assessment deems the material to pose an unacceptable risk to the environment or the revegetation process the material will be managed appropriately (e.g. removed and disposed into Pit 3).

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4.4.3.6 Nursery/Core Yard

During 2018 and early 2019, the old exploration area in Jabiru East, previously used as a nursery for revegetation trials, was reconverted into a nursery to support closure operations (Photo 4-24). 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.

Photo 4-24: Nursery (on right) and old core yard (on left) at Jabiru East (August 2024)

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 from exploration are currently stored at this location. As part of Phase 1 demolition, the core samples from Ranger 3 Deeps are planned to be disposed in Pit 3. Other core samples are subject to legal retention requirements and are currently planned to be securely transported to Darwin for storage, although alternative storage or disposal options may also be considered in consultation with relevant stakeholders. Subject to ministerial approval, an additional five shipping containers of core samples from the Koongarra uranium deposit may 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 and / or office space to accommodate teams prior to demolition Phase 2.

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4.4.3.7 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 and shown in Figure 4-19:

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

Contaminated sites sampling of the historic landfills and the bioremediation pads were completed during 2019 and validation sampling conducted in 2024. 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 findings of the 2024 soil sampling are finalised and remediation action plans are developed (see Chapter 8).

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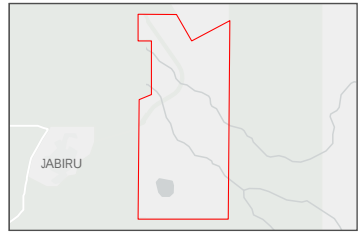
FIGURE 4.19

Existing and Current Landfill

LEGEND

- Historical Landfll
- Historic Domestc Landfll
- Historic Industrial Landfll - Pit 1
- Current General Waste Landfll
- Temporary Industrial Waste Lanfll



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4.4.4 Other Infrastructure and Services on the RPA

4.4.4.1 Airport and ERISS

Decommissioning of the airport conditionally approved via the 2023 MCP

The airport at Jabiru East and other infrastructure, such as the Environmental Research Institute for the Supervising Scientist (ERISS) and the Telstra building (Figure 4-20), 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.

Figure 4-20: Jabiru airport and ERISS buildings (August 2024)

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 the Ranger Rehabilitation Project does not 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.

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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. The Ranger Rehabilitation Project Team is committed to continue working with stakeholders to find a commercial solution. If no solution is reached in 2025 before the scope of works to support the Phase 1 demolition execution contract is tendered, the Ranger Rehabilitation Project Team will progress planning to decommission the airport infrastructure, including the ancillary buildings and infrastructure, and remediate the site in accordance with legislative requirements. Before rehabilitation activities at the airport commence, the RRP will provide prior written notice to major stakeholders and commercial users of the airport as per the Ministers' direction.

4.4.4.2 Gatehouse and Office Spaces

The main gatehouse is currently used as the primary access and egress to the mine site and will remain in use during closure, though it may be relocated at some stage in the future. The 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.

The decommissioning plan for Phase 2 demolition includes the mine office, gatehouse and the associated infrastructure (security, fire station and Inganarr) with the Ranger Rehabilitation Project Team exploring the potential for relocating or progressively demolishing these existing buildings.

4.4.4.3 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.

A temporary power generation system will be installed before or during Phase 1 demolition to ensure service continuity and support closure activities. This system will be designed to meet the site's evolving power needs, allowing for the decommissioning and demolition of the Ranger Power Station in Phase 1 demolition. The Brine Concentrator Power Station will remain for some time and be demolished and disposed of in Phase 2 demolition.

4.4.4.4 Magazine

Activity approved via the 2024 MCP

During the operational phase, more volatile explosives and the detonators were stored in the earth-walled magazine area, located to the north of the Trial Landform. All explosives and detonators have been removed from the magazine and it has been de-registered as an explosives storage facility (Photo 4-25).

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Photo 4-25: Old magazine site (August 2024)

Demolition requirements at the old explosive's magazine involve the removal of the magazine, concrete slab and associated footings, two steel framed demountable buildings and the surrounding fence. These items will be removed and placed into the Pit 3 laydown and ultimately Pit 3. The area will then be re-contoured and revegetated.

4.4.4.5 Gagudju Yard

Activity approved via the 2023 MCP

The Gagudju yard (Photo 4-26 and Photo 4-27) is no longer in use and is planned for demolition. The Ranger Rehabilitation Project team 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.

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Photo 4-26: Gagudju yard and surrounding disturbance (August 2024)

Photo 4-27: Gagudju workshop and surrounding infrastructure

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4.4.4.6 Ranger Mine Village

Activity approved via the 2023 MCP

The Ranger Mine Village has had some infrastructure and concrete removed (Photo 4-28). 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 3 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, midstorey 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.

Photo 4-28: Ranger Mine Village – with plants establishing (August 2024)

4.4.4.7 Magela Levee

Activity is the subject of a separate approval application

The Magela Levee (Photo 4-29) 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. An Erosion and Sediment Control Plan will be provided with the plan to deconstruct the levee.

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Photo 4-29: Magela Levee (August 2024)

4.4.4.8 Borrow Pits

Activity approved via the 2023 MCP

There are currently two borrow pits located on the RPA:

- one borrow pit for constructing a RWD lift, which was also the proposed location for Retention Pond 5 (never built); and
- one borrow pit for constructing the Magela Creek levee.

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

Whilst the borrow pit for the RWD lift was approved for rehabilitation via the 2023 MCP, this area may be used as an alternative water storage during closure prior to its final rehabilitation.

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 Magela levee 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.

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4.4.4.9 Central Services Corridor

Operation of the corridor is the subject of a separate approval 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 (Figure 4-21). 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.

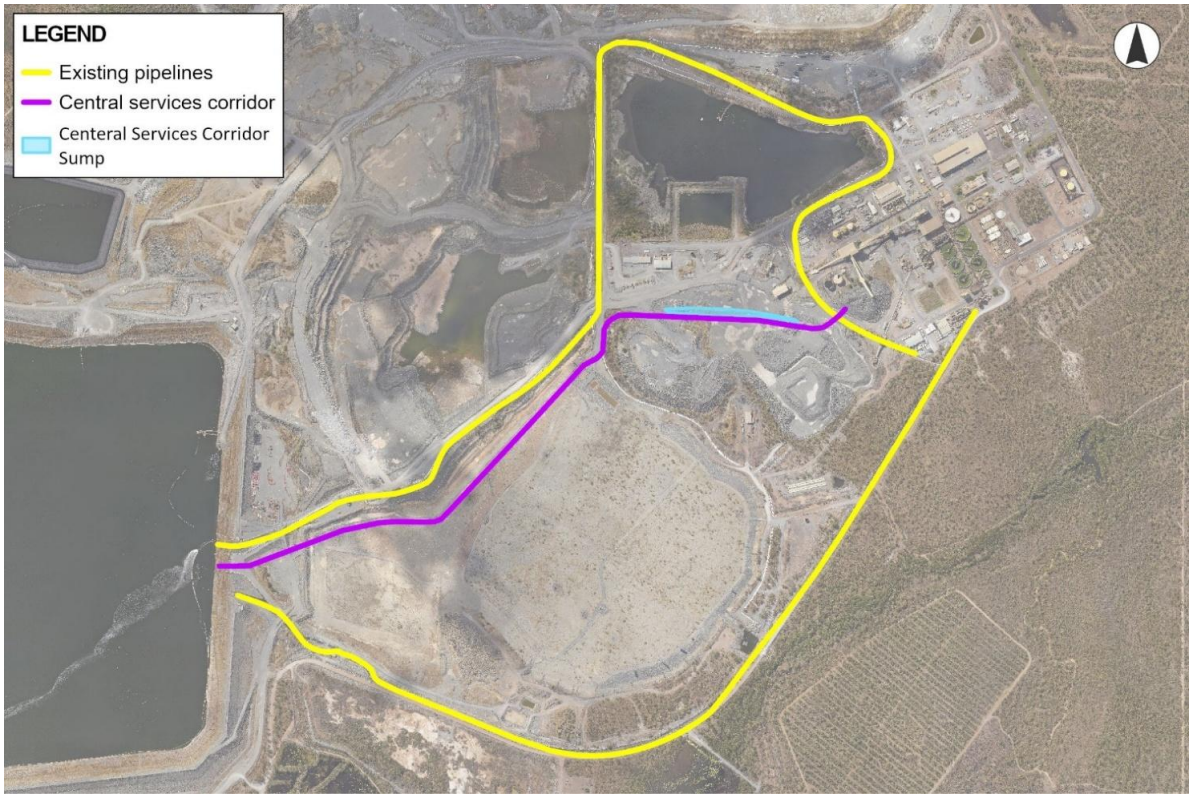

Figure 4-21: Existing pipeline corridors (yellow lines) and proposed central services corridor (purple lines)

The proposed central services corridor, approximately 1,860 m in length, is located entirely within the boundaries of the existing disturbance area of the former mine site. Its primary function is to support process water transfer between the Ranger Water Dam (RWD) and the water treatment facilities, replacing the existing pipeline corridor that runs along Corridor Creek Road.

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The corridor surface will be prepared to accommodate pipelines, light vehicle access and stormwater drainage, with the alignment generally following the layout shown in Figure 4-21. The surface will be compacted and support occasional light vehicle traffic. Drainage is directed to the Central Services Corridor sump (CSC sump), located at the corridor's low point. The CSC sump is designed to contain either a 10% annual exceedance probability (AEP) rainfall event or a pipe rupture.

Leak detection is supported by multiple measures, including conductivity monitoring sensors in the CSC sump for continuous EC and water level recording, as well as flow meters installed at both ends of all process water lines to detect leakage due to pipe rupture. In the event of a leak or spill, water will be routed to the CSC sump and pumped back to the RWD.

The corridor design includes termite control measures for HDPE pipelines, vehicle access ramps, and two heavy vehicle haul road crossings. Safety berms will be installed where required, and erosion protection will be maintained as part of ongoing operations.

Some bulk earthworks will be undertaken to align the corridor surface as closely as possible with the final landform. The connection between the central services corridor and Pit 3 will run as per the current RWD to Pit 3 corridor, with the existing pipe-in-pipe infrastructure retained rather than replaced.

Construction of the central services corridor is planned to commence in 2025. Approval to pass process water through the relocated corridor will be the subject of a separate approval 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.

4.4.4.10 Miscellaneous Infrastructure and the Groundwater Bore Network

Activity approved via the 2023 MCP, except for rehabilitation of the groundwater bore network, which will be addressed through the Ranger Water Management Strategy

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. The Ranger Rehabilitation Project Team 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. The Ranger Rehabilitation Project Team 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).

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

- Stage 1 was completed in late 2020 and involved the collation of information on the 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 is ongoing.
- Stage 3 will involve the active decommissioning of redundant infrastructure.

4.4.4.11 Communications infrastructure upgrade

In 2024, the infrastructure to support on site communications was decommissioned and removed from the Fine Ore Bins within the processing plant domain (domain 5) to allow for demolition phases. A new upgraded communications tower was constructed in the Gatehouse carpark (Photo 4-30) to support mobile phones (cellular 4G/5G), 2-Way radio, and water telemetry environmental monitoring during closure and post-closure activities.

Located on existing hard stand area, the tower does not pose any environmental impact on or off the RPA. The communications infrastructure, particularly the water telemetry environmental monitoring equipment, will be required for post-closure monitoring. A plan to decommission or potentially relocate the infrastructure will be developed in consultation with stakeholders.

Photo 4-30: Telstra communications tower upgrade

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4.5 Ranger Water Dam Deconstruction

Activity is the subject of a separate approval application

The RWD, which was known as the Tailings Dam 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 Tailings Dam. 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 Tailings Dam until the mined-out Pit 3 became available for tailings storage in 2016.

Whilst recognising that the name change from Tailings Dam 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. Following this, the process of transferring the tailings from the RWD to Pit 3 commenced via the operation of two dredges, the 'Jabiru' (Photo 4-31) and the 'Brolga I', supported by maintenance crafts. Dredged tailings were transferred to Pit 3 through dedicated overland pipelines and deposited initially subaqueously and then subaerially. Bulk dredging and transfer of tailings from the RWD to Pit 3 was completed in February 2021.

Photo 4-31: 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.

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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 is operated and managed as per the requirements of the Australian National Committee on Large Dams (ANCOLD, 2019) as well as 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.

From 21 June 2024 to 29 July 2024 limestone flour was added to the RWD in an attempt to raise the water's pH to 4.0. Historically, the water's pH was kept above 3.0 by adding lime during uranium processing. However, since the end of tailings transfer at the end of 2021 and the end of High Density Sludge operations in 2022, a gradual decrease in pH has been observed and the levels reached in 2024 were out of specification for the Brine Squeezer.

The addition of approximately 2,500 tonnes of limestone flour did not achieve a pH of 4.0. As such, trials are underway to test the Brine Squeezer's ability to treat current process water and predict future performance as water composition changes when extracted from different depths.

4.5.4 Planned Future Activities

Unless stated otherwise (e.g. the dredge demobilisation), the activities described in this section will be subject to a separate application, the RWD deconstruction application.

4.5.4.1 Dredge Demobilisation

The dredge 'Jabiru' has remained in the RWD since the completion of tailings dredging. It is planned that this dredge will be removed and sold. The 'Brolga I' dredge has already been removed from the RWD, demobilised, cleared for radiation and sold.

Prior to removal of the dredge, the north-east ramp area of the RWD will be prepared, including the creation of a pad for temporary dredge holding and equipment trafficability (Figure 4-22).

The dredge will be dismantled and hauled out via the north-east ramp to the designated laydown area (see Figure 4-22). Airbags will be used to lift and support the vessel as it moves up the slipway ramp while it is slowly towed out of the water. Once on land, the vessel will be supported with blocks to prevent damage before dismantling. The dredge will be decontaminated in a bunded area to contain waste and liquids, whilst electrics and hydraulics will be safely removed and secured following approved procedures. Once decontaminated, the dismantled and sold components will be removed from site.

Decommissioning and disposal of the dredge and the workboat will be undertaken in accordance with ERA's guidelines, policies and standards.

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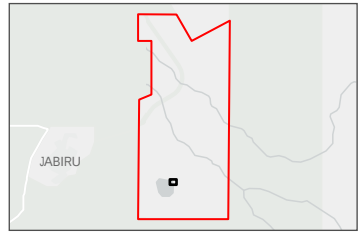
FIGURE 4-22

Jabiru dredge removal plan

LEGEND

- Laydown Area
- Temporary Dredge Holding Pad



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4.5.4.2 RWD Infrastructure demolition

The RWD offices, workshop, diesel tank and associated infrastructure located on the north-eastern corner of the RWD will be demolished (see Figure 4-23) as part of Phase 1 demolition. Additionally, the substation infrastructure will be removed and replaced with an alternative power system to support the process water treatment.

The perimeter of the RWD will undergo a clean-up, involving demolition of redundant infrastructure and removal of unused items such as signage, bollards, tyres, pallets, poles, pipelines, fittings, liner rolls, coils, pontoons, buoys, metal racks, fencing and general waste.

Deconstruction of the RWD is not a component of the Phase 1 demolition and will be subject to a separate standalone application.

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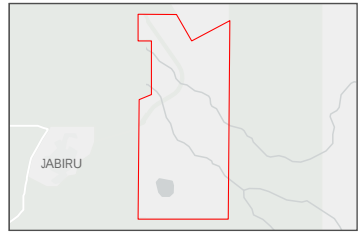
FIGURE 4.23

Phase 1 Demolition Areas in the RWD Domain

LEGEND

RWD O f ces Workshop & Associated Infrastructure



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4.5.4.3 RWD Groundwater Plume

Gradual seepage from the base of the RWD during its operational life as the Tailings Dam 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).

A BPT assessment of potential remediation options for this plume is underway and will be incorporated into the approval application that covers the RWD deconstruction and future iterations of the MCP.

4.5.4.4 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, an application was submitted to the MTC to adopt the preferred option from the BPT assessment, which was to leave the subfloor material in place. This option was found to reduce peak magnesium loads entering Magela Creek, and this approval was granted in August 2020 (see Appendix 4.2 for details). MTC approval of the BPT raised the need for plume management to be considered in the future.

The above mentioned BPT for RWD plume management is also investigating measures to minimise solute transport from the RWD subfloor, which may include in-situ management of the subfloor.

4.5.4.5 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 is reduced enough to be held in tanks or an alternative onsite pond.

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. 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 and reduce water moving up into the waste rock, 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 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 iterations of the MCP.

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4.5.4.6 Removal of HV Power Supply and Telemetry

Activity approved via the 2023 MCP

High Voltage (HV) power distribution lines (mostly aerial but some buried) will start to be decommissioned and removed across the RPA. 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) (Photo 4-32) was granted in April 2019.

Photo 4-32: 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 (Figure 4-24). 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.

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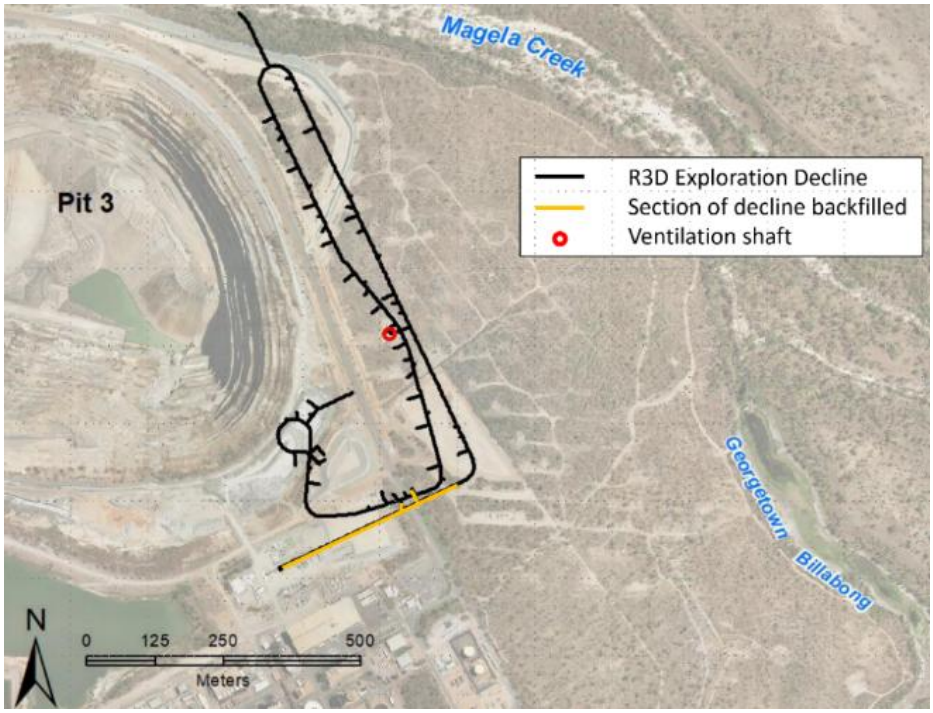

Figure 4-24: Plan view of the R3 Deeps decline

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 (Photo 4-33). 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 during the installation. A variation to the existing approval to account for this difference was lodged in September 2023 and approved in March 2024. 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.

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Photo 4-33: 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 (Photo 4-34). 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.

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Photo 4-34: Coarse rockfill placed on top of the backfilled R3 Deeps ventilation shaft

4.6.1 Planned Future Activities

The remaining infrastructure will be demolished and either sold or disposed into Pit 3. The steel multi-plate portal (Photo 4-32) will be dismantled/cut down to final ground level. The remaining infrastructure surrounding the ventilation shaft (Photo 4-34) will be removed including concrete pads, foundations, signage, fencing and other minor installations associated with controlling access to the vent shaft and portal area.

Contouring to final landform and revegetation of the R3 Deeps area will form part of the broader final landform and revegetation schedule.

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 (Photo 4-35).

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Photo 4-35: 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 (Daws and Poole, 2010).

The TLF continues to be monitored and provides ongoing and useful information to inform the Ecosystem Establishment Strategy. This is discussed further in Chapter 9.

4.7.2 Planned Future Activities

As part of Phase 1 demolition, redundant infrastructure and loose materials around the perimeter of the TLF, such as fencing, culverts, ponds and pipes, as well as research plots and associated infrastructure - including concrete edging, weirs, water and sediment monitoring equipment, and telemetry infrastructure - are scheduled for removal and disposal into Pit 3.

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.

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4.8 Final Landform

All of the activities described in this section will be the subject of a separate approval application – the Final Landform application

4.8.1 Final Landform Design Principles

The constructed final landform area will be about 800 ha (Figure 4-25). 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.

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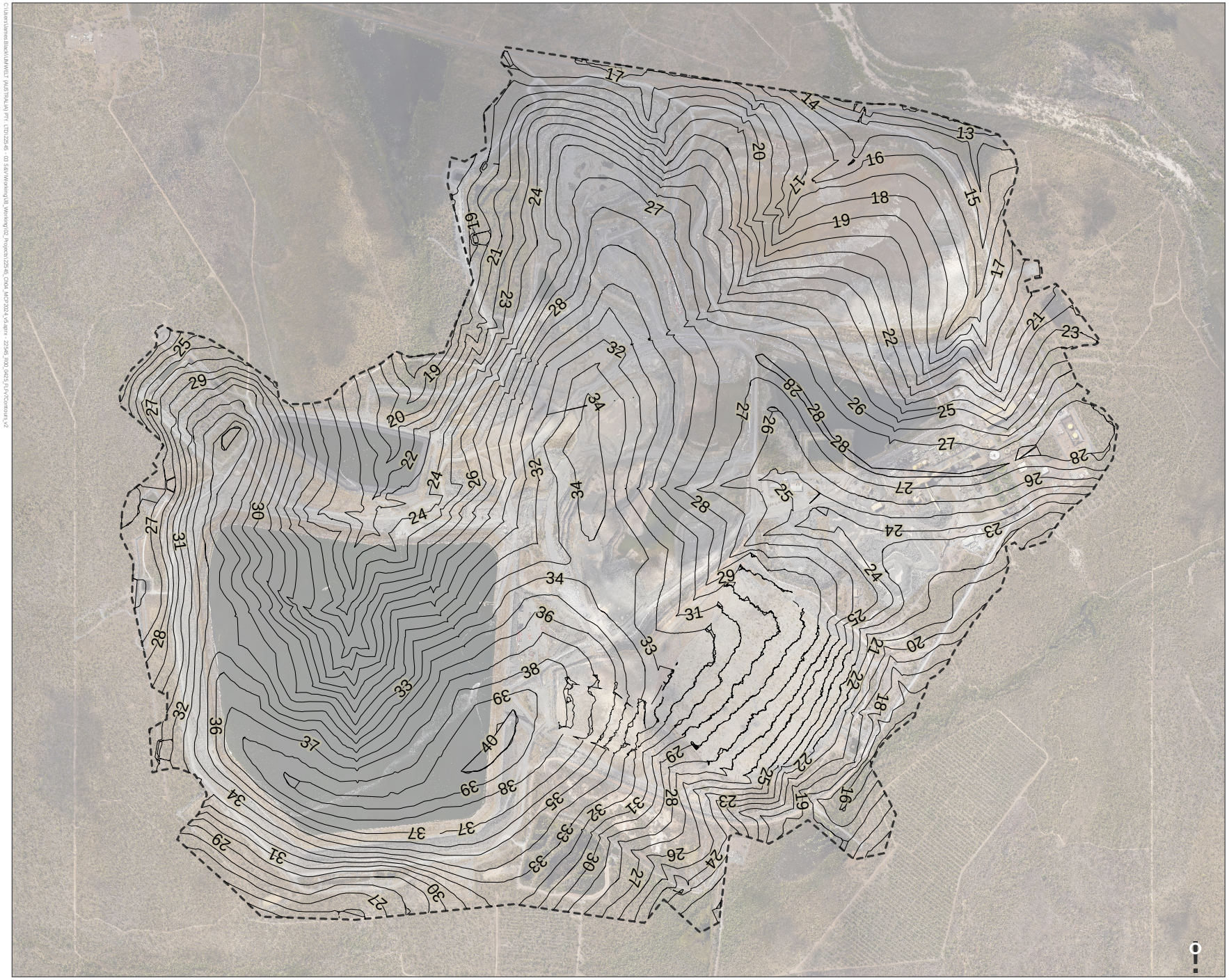

FIGURE 4-25

Final Landform Boundary and Contours

LEGEND

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

Scale 1:19,500 at A4
GDA 1994 MGA Zone 53

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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 scanned. 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). 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.

ERA maintains a stockpile block model which is partly informed by the historical discriminator data as well as a drilling and analysis program of core samples from the stockpiles.

The drilling program was originally undertaken to inform a heap leach feasibility study. In total, 430 drill holes for a combined 20,917 drill meters were sampled (gamma logged and chemically assayed at 1 m intervals) (Figure 4-26). The stockpile block model is a unique, robust and comprehensive spatial database of waste rock types and their associated chemistry. The same stockpile block model data sets have informed the backfill of Pit 1, and the backfill of Ranger 3 Deeps Exploration Decline and Ventilation Shaft. It meets the requirements of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code).

Up to the end of operations, ERA continued to actively update the stockpile block model as stockpile material was depleted and accumulated through mining activities in Pit 3, mineral processing and operation of the mill, and the backfilling of Pit 1 and the Pit 3 underfill. The stockpile block model was updated with depletion and accretion using end-of-month surveyed surface models and Tritronics data.

Verification drilling programs have since been undertaken, further validating the accuracy of sampled assay data. In May 2019, nine extra holes were drilled in representative locations and sampled for U_3O_8, calcium, magnesium, aluminium, iron, phosphorus, potassium, and sulphur.

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FIGURE 4-26

Location of Stockpile Drilling and Core Samples to Inform Grade Class

LEGEND

- 2010 Drilling
- Pre-2010 Drilling

0 250 500

Metres

Scale 1:12,500 at A4
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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
1s[1]	- <0.02%	74.6	33.6	Above and below permanent water table.
2s	>0.02 - <0.08%	28.3	14.9	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.

In addition to the stockpile block model, ERA maintains a bulk material movement model. The model includes all the material movements required to transform the current mine disturbed areas to the final landform, whilst accounting for the uranium grade of the material in the stockpiles. The model uses source and destination locations to describe where the material (waste rock) is taken from or sourced, and where the final location for that material will be. 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.

The bulk material movement model is being reviewed, and the outcomes will be provided within a Bulk Material Movement Plan, as per condition 2 of the Pit 3 backfill approval.

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, 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.

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 4-27 illustrates the height difference between current and final landform. This is provided for context only and will be further refined for the Final Landform application. Figure 4-28 and Figure 4-29 represent the lots (source and destination locations) respectively.

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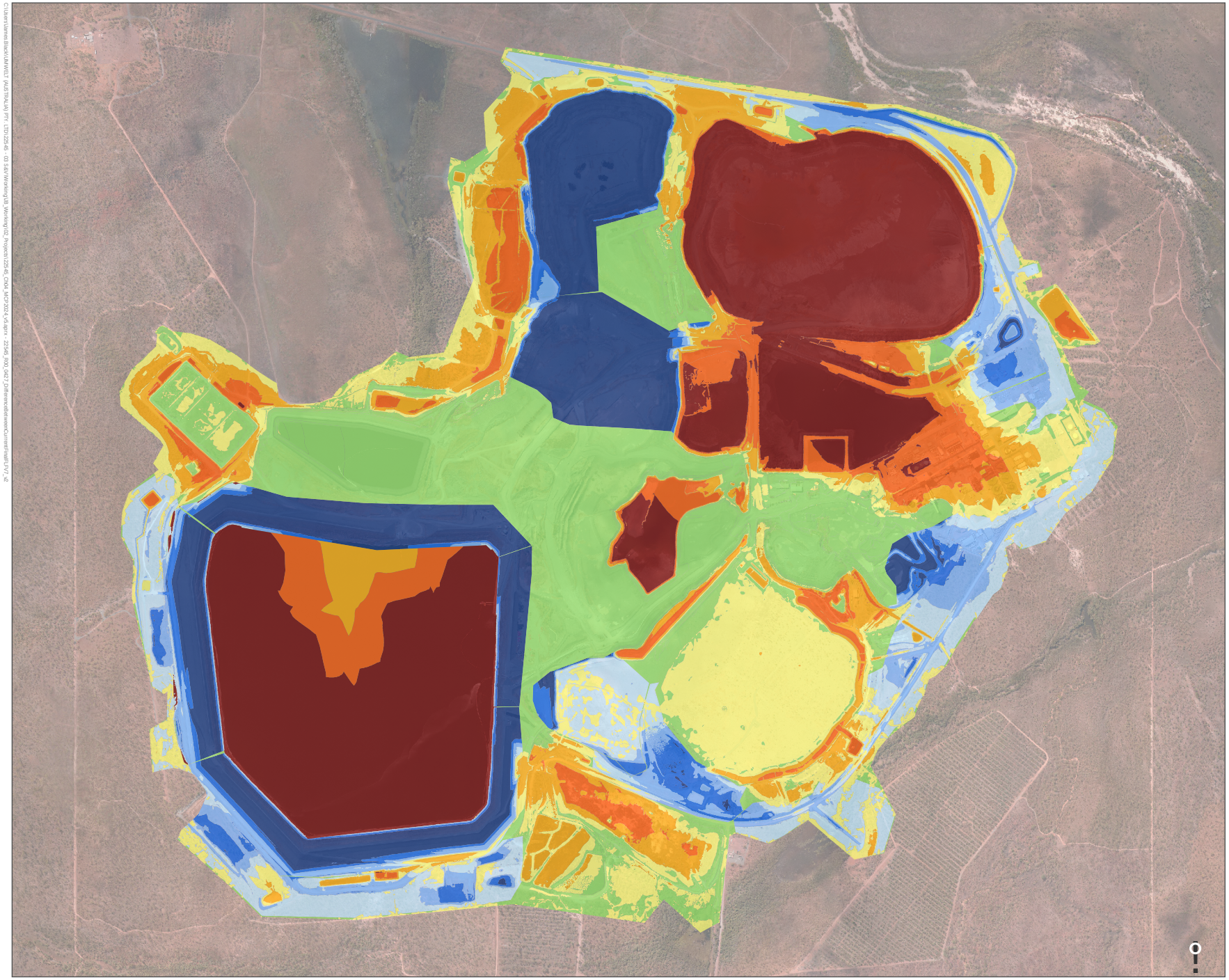


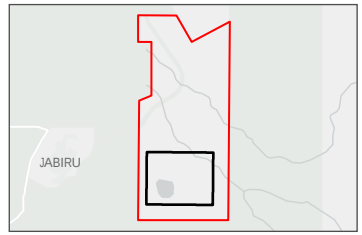
FIGURE 4-27

Illustration of the height difference between current and final landform

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



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Metres

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FIGURE 4-28

Source locations of bulk material movements

LEGEND

BMM Source Locations

0 250 500

Metres

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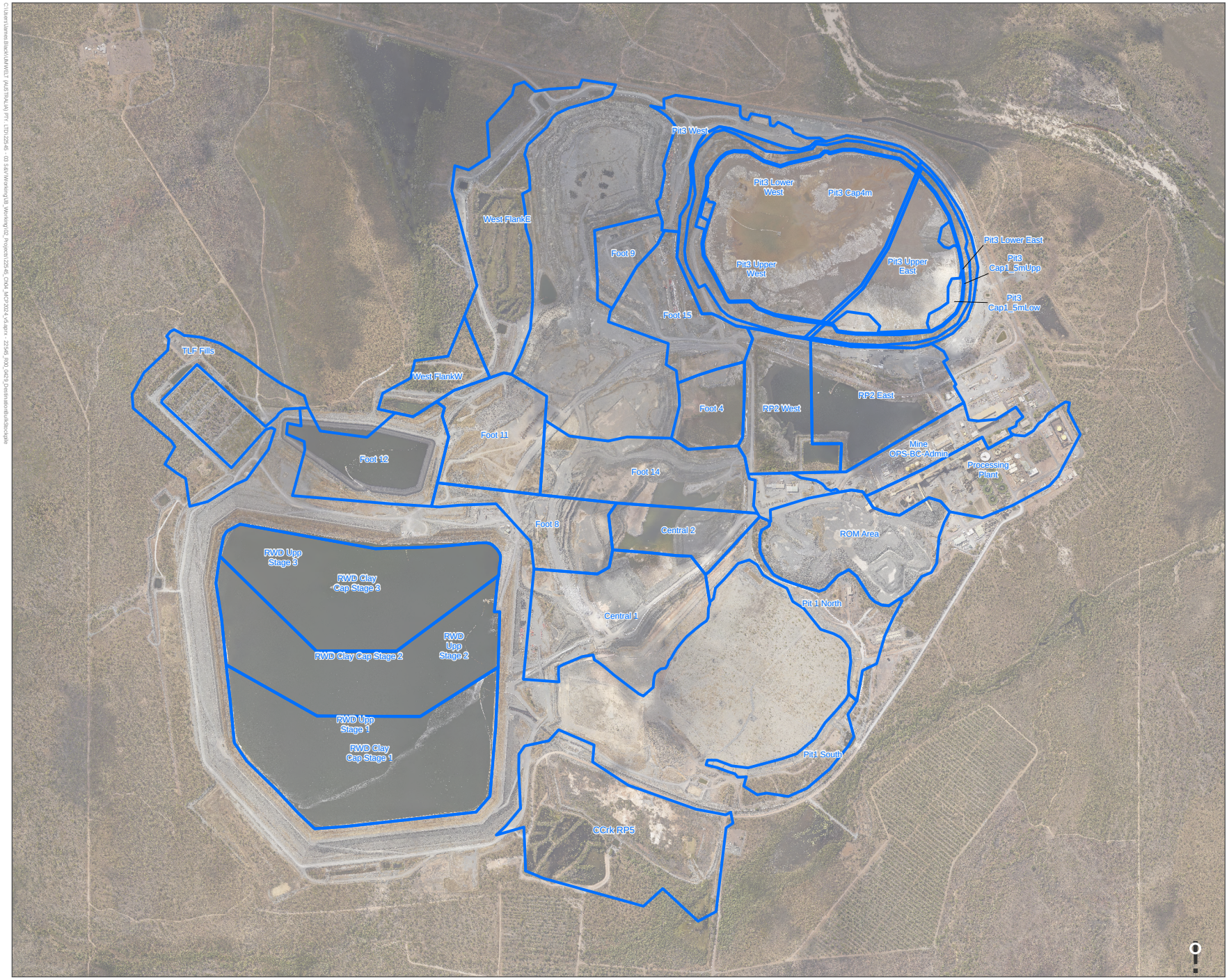

FIGURE 4-29

Destination locations of bulk material movements

LEGEND

BMM Destination Locations

0 250 500

Metres

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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. 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. This assumption is being reviewed as part of the development of the Bulk Material Movement Plan.

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 material composition and construction method of the final landform surface layer is important to minimise gamma exposure to the public, minimise contamination (e.g. flushing of CoPCs from the upper layers/vadose zone) and provide a suitable plant growth medium.

The Bulk Material Movement Plan will guide the placement of stockpiled waste rock to minimise potential contamination from the upper layers.

To facilitate plant root development for areas of the waste rock landform with a depth of waste rock exceeding 3 m (i.e. not overlying natural ground), a ‘vegetation growth layer’ will be constructed. Like the methodology used in the construction of the TLF (Daws and Poole, 2010) and Pit 1, the vegetation growth layer is likely to be constructed in two relatively thick layers (where waste rock depth exceeds 3 m), with a combined thickness of up to 6 m, using techniques known as tip-head and paddock dumping.

As illustrated in Figure 4-30, tip-head dumping (and compaction by heavy traffic) will be used for the lower of the two layers to achieve a consolidated boundary layer, which mitigates potential macropores, blocks preferential flow paths, slows water percolation and improves water-holding capacity in the upper profile. Paddock dumping will be used for the upper (surface) layer. For the TLF and Pit 1, this method was applied and has proven to be suitable for the provision of sufficient plant available water (PAW) to the developing rootzone for Savanna woodland vegetation.

Also, key to this is the availability of fine-grained sediments throughout the substrate profile. Studies (described in Appendix 9.1) have shown that for a waste-rock depth of at least 6 m, a minimum of 25% of fine-grained sediments (<2 mm diameter) is sufficient to sustain the proposed Savanna Woodland vegetation. Analysis of waste-rock stockpiles has indicated a general range of between 20%–45% fines.

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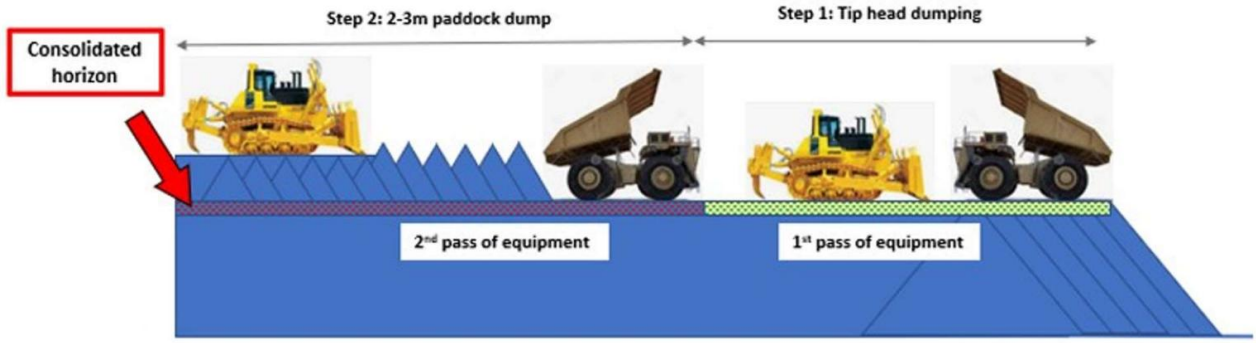

Figure 4-30: Construction method for final landform vegetation growth layer

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.

4.8.4 Surface Preparation

A variety of surface treatments have been identified by the Ranger Rehabilitation Project Team 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 dozer tynes, leaving deep linear gouges across the surface. The majority of the Stage 13.1 surface was subsequently graded to achieve a mostly flat surface.

Stakeholder consultation with the NLC and the GAC have indicated that deep 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. However, this very low level of scarification may not suitably manage sediment and erosion on steeper slopes (noting that Pit 1 is flat). A water, erosion and sediment control plan is being developed that will recommend an appropriate scarification program that balances sediment risk and benefits for revegetation success with the need for a traversable surface.

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 Final Landform application and future MCP iterations.

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4.8.4.1 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), similar to Stage 13.1. A comparison between dynamic cone penetrometer (DCP) testing at Stage 13.1 (Douglas Partners, 2019) and local natural soils (Construction Sciences, 2020) was conducted. Results however were confounded by the presence of rocks and generally inconclusive.

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.

4.8.5 Ecosystem Establishment on the Final Landform

The Ranger Rehabilitation Project Team continues to partner with Kakadu Native Plant Supplies Pty Ltd (KNPS), a local Indigenous business owned and managed by Dr 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 the Ranger Rehabilitation Project Team to undertake land management activities (e.g. weed and fire management) 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.

Informed by decades of research and ongoing monitoring, the current Ecosystem Establishment Strategy is presented in Chapter 9. This includes a description of methodology for:

- final landform growth substrate construction, including backfill methods and addressing of any relevant constraints to the establishment and long-term support of target vegetation communities;
- surface preparation, including considerations for scarification and ripping and construction of rocky habitat features;
- seed collection and storage, including the approved seed provenance zone;
- tubestock propagation, including nursery capacity, seasonal considerations and tubestock quality standards;
- provision of suitable irrigation and application of pre-emergent herbicide;
- mechanical preparation of planting holes;
- fertiliser application during planting and the following wet season;
- tubestock planting, direct seeding and secondary introductions; and
- species specific details, including species relevance, target stems, predicted development, proposed establishment method and planting/seeding rates.

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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 interim control 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 4-31, 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 water quality objectives 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 Final Landform application and future iterations of the MCP. If the second erosion and sediment trial area is constructed (see Section 4.1.8), it may also provide an opportunity to test the effectiveness of sediment basins as an interim control measure.

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;

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- 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.

The Ranger Rehabilitation Project Team will maintain access tracks throughout the monitoring and maintenance period. Before site relinquishment, the Ranger Rehabilitation Project Team will liaise with relevant stakeholders (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).

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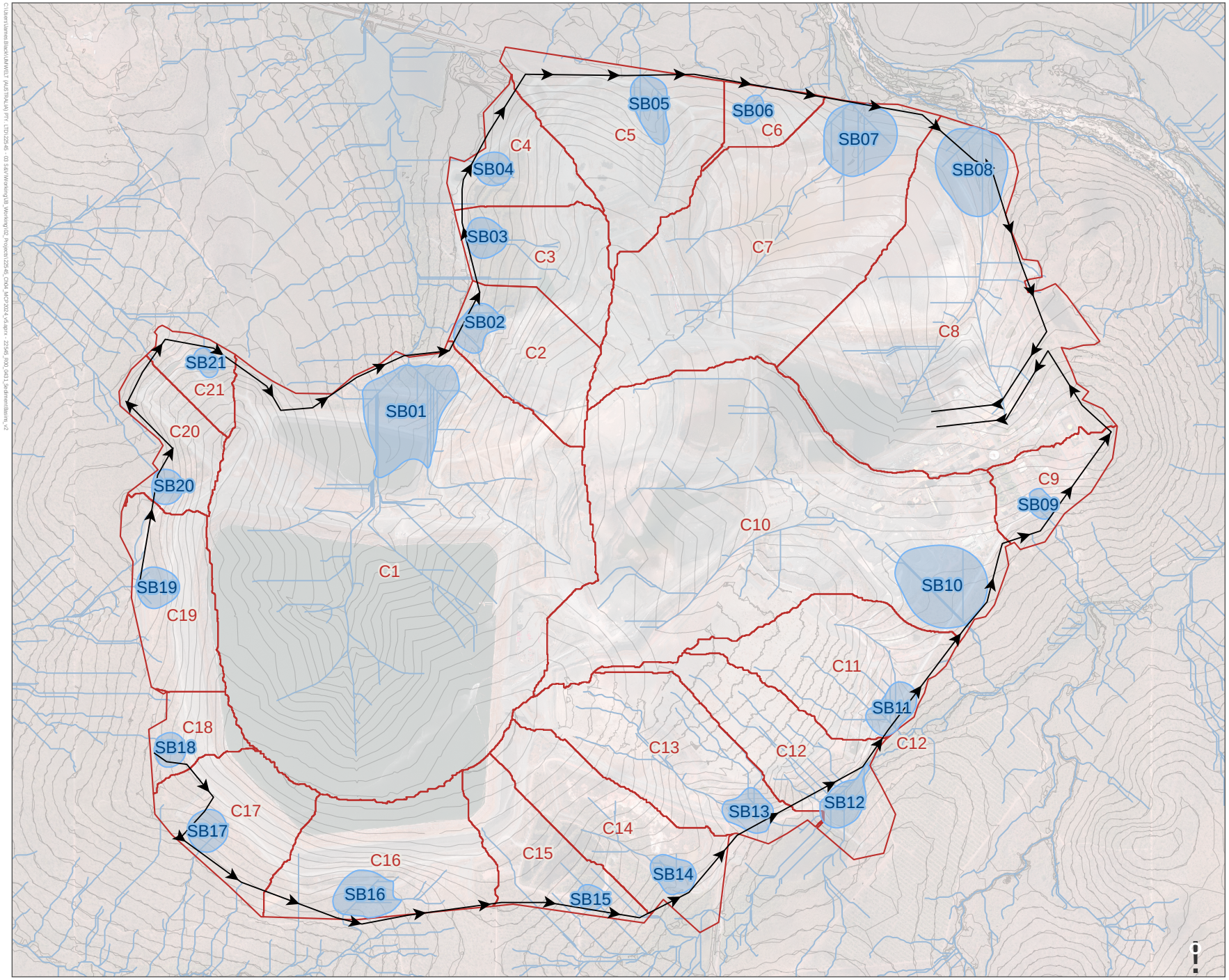
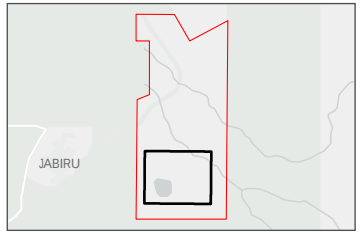


FIGURE 4-31

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 1:19,500 at A4
GDA 1994 MGA Zone 53

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5 STRUCTURE AND CONTENT OF CHAPTER 6 TO CHAPTER 11

Photo: Processing plant with RP2 and Pit 3 in the background (2025)

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 ERs, and the activities that are yet to be completed in order to achieve ERs. 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 Rehabilitation 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:

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- ***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 2024 (by the Commonwealth Minister). Those closure criteria that were approved in the 2023 MCP and the 2024 MCP, are identified within this section of each chapter. Closure criteria that have changed since the 2024 MCP and closure criteria yet to be approved are also described in this section of Chapter 6 to Chapter 11.
- ***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 the ERs. 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 the 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***: this section describes how well 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 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 2025 MCP are a work in progress and will continue to be refined and strengthened through future iterations of the MCP.

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- ***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 'Landform' theme as an example). This is the Ranger Rehabilitation Project Team'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.

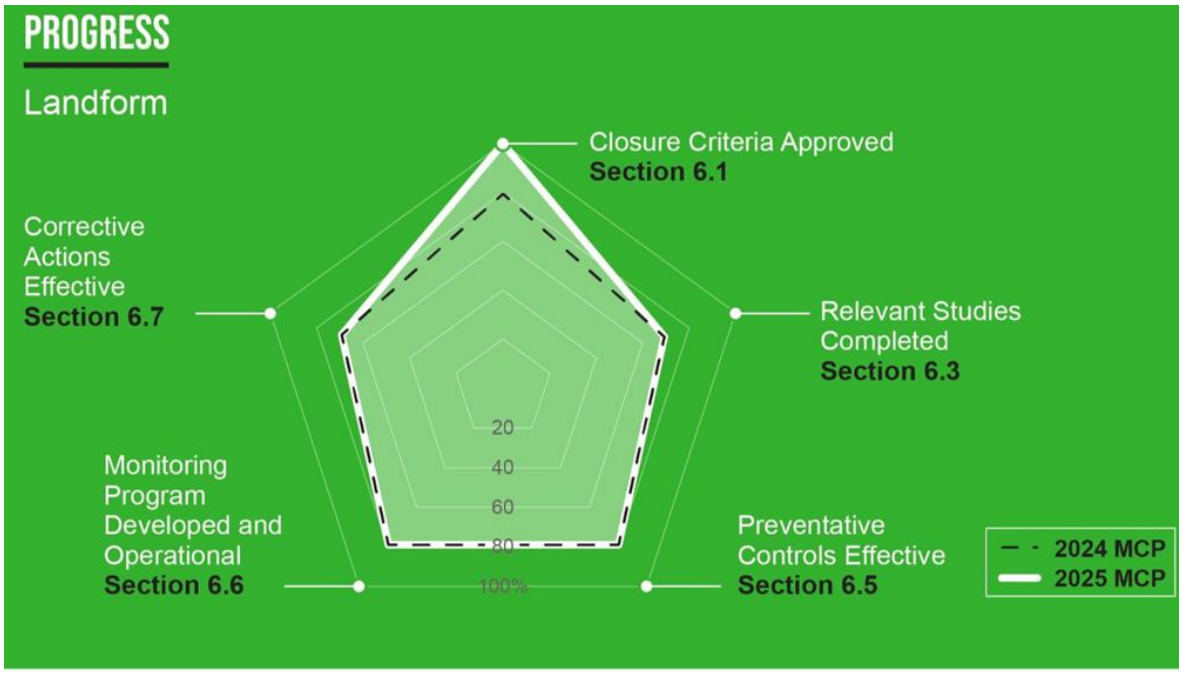

Figure 5-1: Spider web diagram from the Landform theme showing subjective percentage complete and any changes from 2024 to 2025

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 after the creation of the final landform.

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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 action 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 action is predicted to be effective, which provides an indication of the Ranger Rehabilitation Project Team's 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 may 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.

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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***: 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***: 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***: 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 resources, uncertainty as to whether control/corrective action would be successful at any point in the future.	Weak

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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 ERs 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 project's risks reported via the 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 relevant to rehabilitation 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 the 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 may 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.

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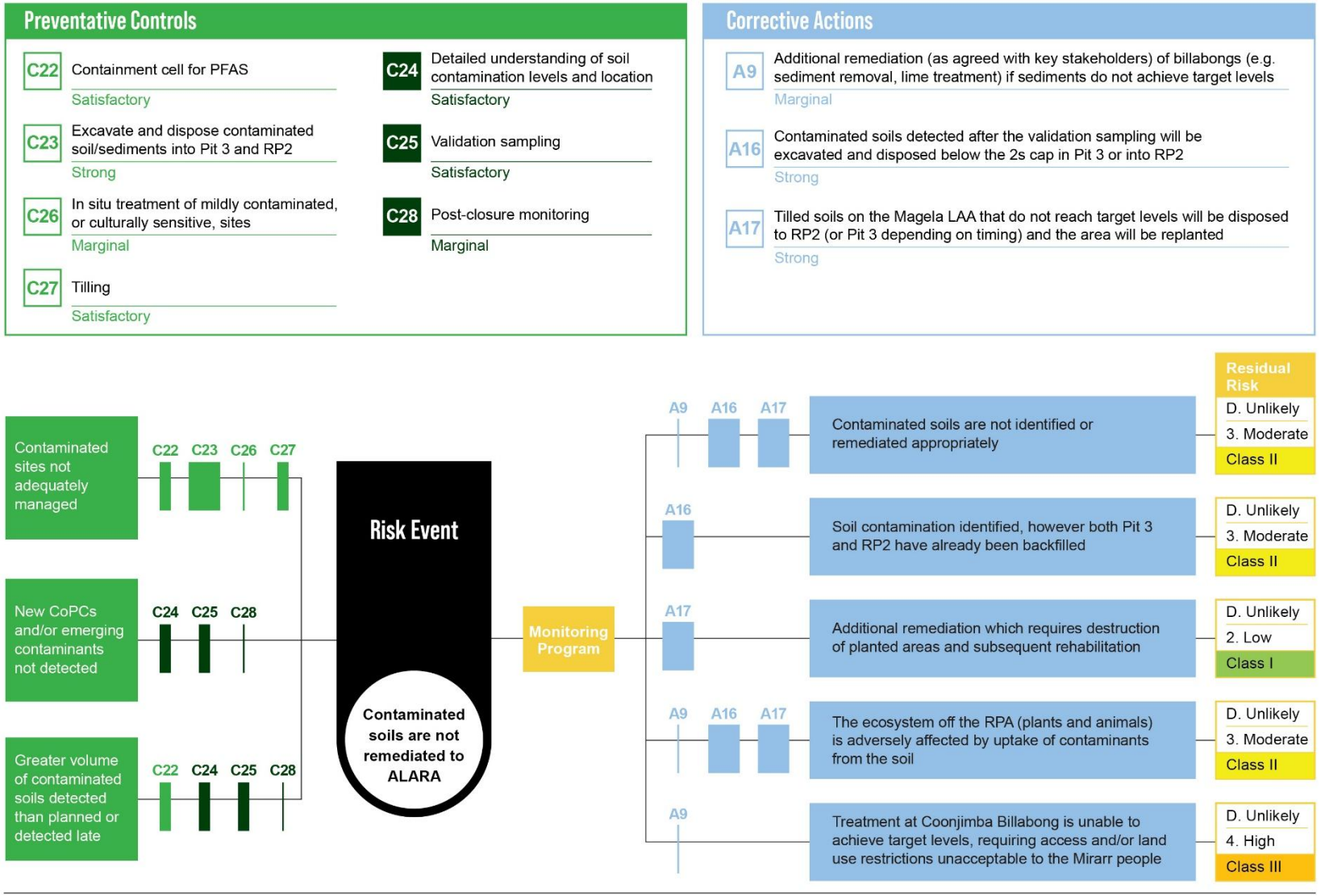

Figure 5-2: Example output from the bow-tie risk assessment process (Soils theme)

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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:

- Seven closure criteria have been developed for this theme, five were previously approved and two additional criteria have been added for approval via this 2025 MCP (70%, Section 6.1).
- Landform related studies to inform the final design are advancing and will continue to progress throughout the closure period. The Ranger Rehabilitation Project Team have commenced studies to inform a Water, Erosion and Sediment Control Plan. The erosion and sediment control structure designs included in that Plan will be incorporated into the final landform design and included in the Final Landform 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 the erosion and sediment controls that will be applied to the final landform (80%, Section 6.5).
- A comprehensive monitoring program has been established and implementation has commenced on Pit 1. The RRP are considering another erosion and sediment trial (additional to Stage 52) to help inform and refine the monitoring program for the final landform area (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).

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6.1 Closure Objectives and Criteria

Table 6-1 lists the ERs the RRP consider to be 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.* *2.3 Where all the major stakeholders agree, a facility connected with Ranger may remain in the Ranger Project Area following the termination of the Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation set out in subclauses 2.1, 2.2 and 3.1.*	2.2 (c) 2.3
11 Management of Tailings *11.2 By the end of operations all tailings must be placed in the mined out pits.* *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.*	11.2 11.3 (i)

The Ranger Rehabilitation Project Team, working with stakeholders, 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. Seven closure criteria have been developed for this theme, five of which were approved via the 2023 MCP and two are seeking approval via this 2025 MCP. The seven criteria relate to the following three matters:

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

6.1.1 Retention of facilities

As shown in Table 6-2, one closure outcome and criteria have been derived from the ER related to the retention of facilities.

Table 6-2: Retention of Facilities – Approval of this Closure Criteria is sought

Closure Objective	Closure Outcome	Parameter	Closure Criteria
In accordance with ER 2.3, where all the major stakeholders[1] agree, a facility connected with Ranger may remain in the Ranger Project Area following the termination of the Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation set out in ER 2.1, 2,2 and 3.1.	Remove all plant, equipment, buildings and other structures. Some infrastructure may remain on the RPA provided approval of the major stakeholders is given in accordance with ER 2.3.	Presence/absence of facilities as agreed under ER 2.3.	Supervising Authority and Commonwealth Minister confirms all facilities removed with the exception of those agreed under ER 2.3.

[1] - 'major stakeholders' has the same meaning as in the Environmental Requirements (i.e. the Ranger Authority).

6.1.2 Erosion Characteristics

As shown in Table 6-3, two closure outcomes and two corresponding closure criteria have been derived from the ER related to erosion characteristics.

Table 6-3: Erosion Characteristics – Approved Closure Criteria

Closure Objective	Closure Outcome	Parameter	Approved Closure 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.	Landform Evolution 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.
	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.

With regards to the criteria shown in 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 of 0.075 mm/a. 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.
- 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.

6.1.3 Isolation of Tailings

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

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Table 6-4: Tailings Isolation – Approval of this Closure Criteria is sought

Closure Objective	Closure Outcome	Parameter	Closure Criteria
By the end of operations all tailings must be placed in the mined out pits	Tailings have been placed in Pit 1 and Pit 3	Office of the Supervising Scientist (OSS) Verification report	All tailings have been placed in Pit 1 and Pit 3.
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 control 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 the extent of forecast gully erosion, beyond what would ordinarily occur in the region, could no longer expose tailings.

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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 Water, Erosion and Sediment Control Plan, in conjunction with lessons learnt from previous ripping and scarification completed at Ranger, will inform the ripping and/or scarification required to reduce erosion on the final landform surface;
- the surface will be planted 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 the 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, the Ranger Rehabilitation Project Team are investigating the installation of sediment basins at the terminal point of each sub-catchment that are likely to remain in place until agreed release water quality criteria can be demonstrated.
- approximately 67 Mt of tailings were produced over the life of mine, of that:
    - 27 Mt of tailings was directed to the then Tailings Dam;
    - 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 Tailings Dam was transferred to Pit 3 (therefore 42 Mt have been placed within Pit 3 and 25.6 Mt within Pit 1);
- in both Pit 1 (completed) and Pit 3 (currently underway), 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 estimated to be ~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.

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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).
    - Stage 52 Release Approval (Section 6.3.1.5).
    - Studies to be completed (Section 6.3.1.6).
- 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 the Ranger Rehabilitation Project Team 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 criterion is 0.075 mm/a.

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The results suggest that the FLv6.2 final landform is not yet approaching the denudation rate over a 10,000 year period. However, the current modelling is being undertaken using 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 unlike the 10,000 year requirement for tailings isolation, the closure criterion related to denudation rate does not have a defined timeframe in which it must be achieved.

It is also 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 (and is considered overly conservative) 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 basic grass cover present.

The findings of the OSS modelling assessment of FLv6.2 have been taken into consideration by the Ranger Rehabilitation Project Team in the development of FLv7.

The Ranger Rehabilitation Project Team continue to review and optimise final landform design FLv7 based on the geomorphic landform design principles. Recent design revisions include:

- reducing linearity of flow lines (both surface and channel flow);
- greater consistency in spacing between drainage lines;
- general smoothing of areas around the landform with steep or sharp landform components;
- improvement of flow direction to drainage lines; and
- additional rock-lined drainage channels/ridges where required (south/west slopes of the RWD).

Once the optimisations are showing little or no improvement in the Ranger Rehabilitation Project Team's 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.

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6.3.1.2 Landform Material Properties and Erosion Characteristics

A number of studies have been undertaken by both the Ranger Rehabilitation Project Team 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 including LAN3C and LAN3D. 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 (2019): 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.

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- 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 for simulated periods of up to 1,000 years (FLv6.2).
- Supervising Scientist (2024b): using CAESAR-Lisflood, extended the assessment on the impact of extreme rainfall events on the stability of the conceptual final landform for simulated periods of up to 10,000 years (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 truncating the catchment. The Pit 1 perimeter drain is lined with rock to reduce erosion of shedding water and 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. To date, the rock check dams have been effective at settling out heavier sediments (Photo 6-1). 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 the release of suitable quality water into the Corridor Creek catchment. An automated shut-off system allows the sluice gates to be automatically closed when fail-safe triggers for electrical conductivity (500 µS/cm) and turbidity (250 NTU) are triggered.

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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 over the last four wet seasons, commencing in 2021/22 as detailed in the Pit 1 Interim Water Management Plan. Fixed 'fauna' cameras have been 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 observing the turbidity of the water leaving the Pit 1 surface and entering the CRS.

Photo 6-1: Pit 1 perimeter drain with sediments visible behind rock check dams

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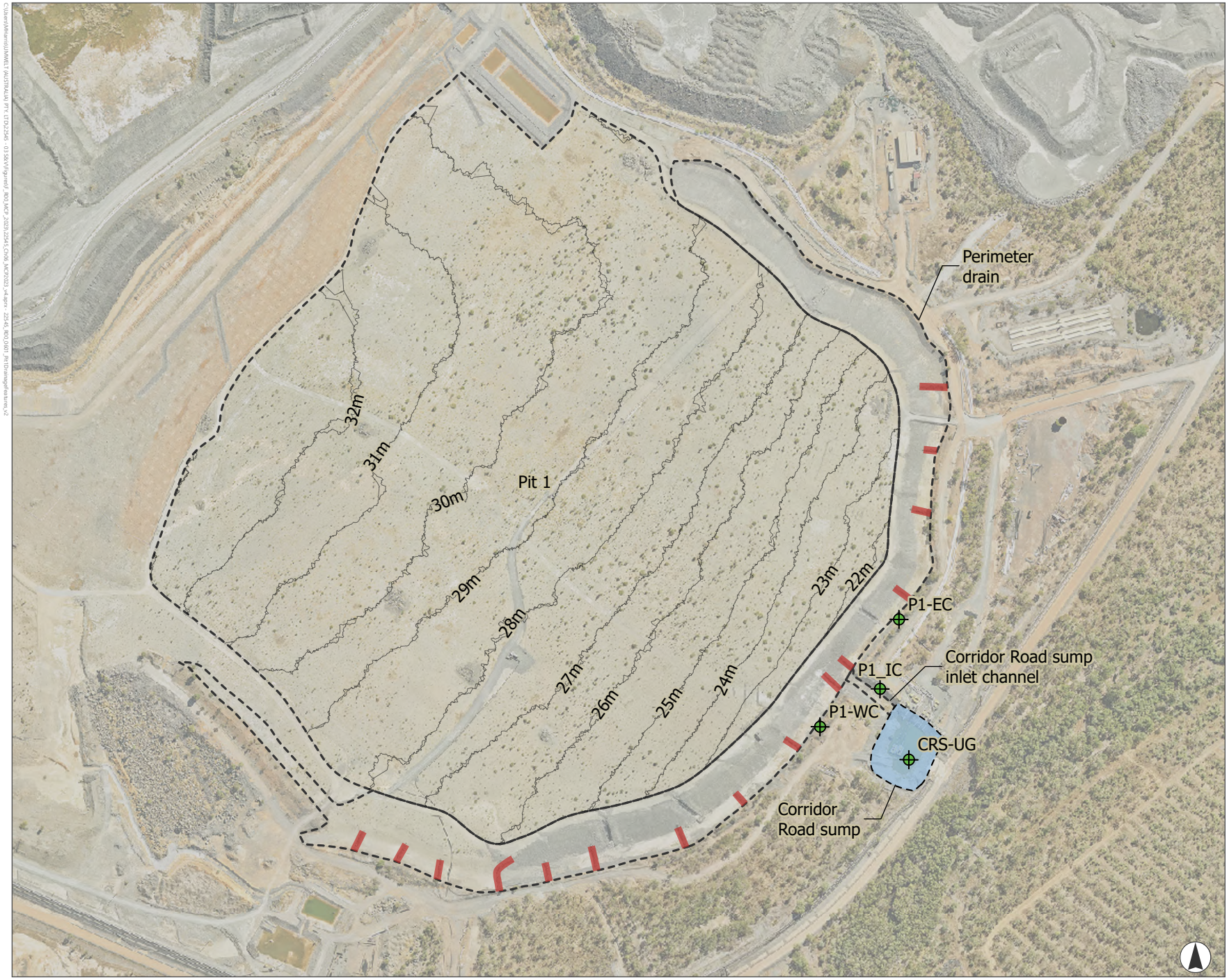

FIGURE 6-1

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

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

Continuous and laboratory turbidity measurements from the Pit 1 inlet channel are shown in Figure 6-2 and Figure 6-3. It is noted that any samples that exceeded 3,000 NTU have been classed as 3,000 NTU for plotting purposes. The water quality reporting from the Pit 1 landform indicates an improvement of turbidity and EC values since 2021/22, with higher reporting coinciding with larger rainfall events. Ongoing scour of the Pit 1 perimeter drain during these events will also have contributed to the sediment load. Given the Pit 1 perimeter drain is not a final landform component it should be noted that the general trend of a reduction in turbidity from the catchment is evident. These observations as well as those from Stage 13, Stage 52 and the TLF are being used in the development of a Water, Erosion and Sediment Control Plan.

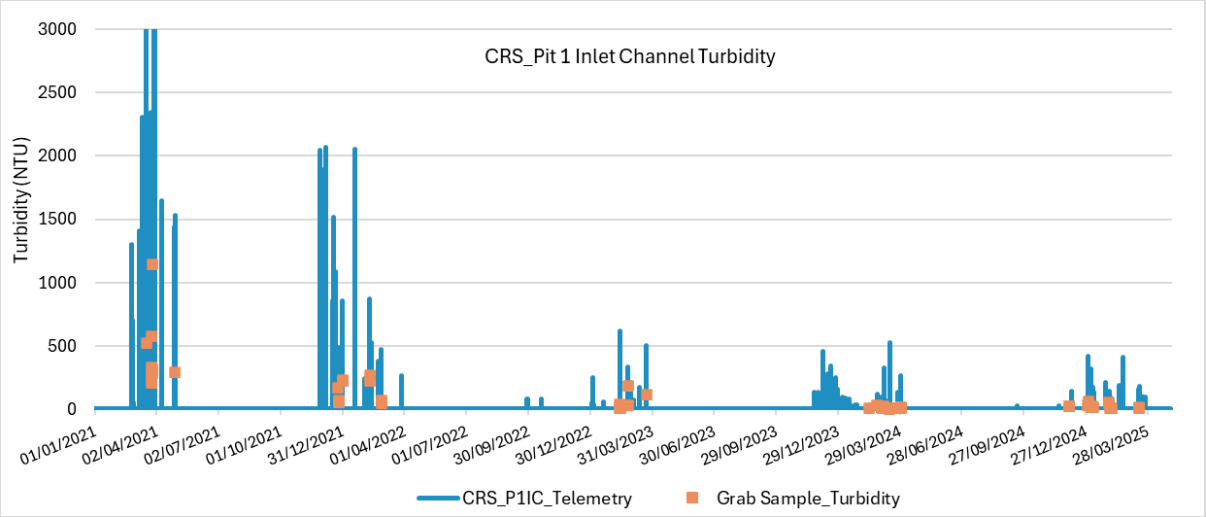

Figure 6-2: Pit 1 inlet channel telemetry and lab turbidity (2021-2025)

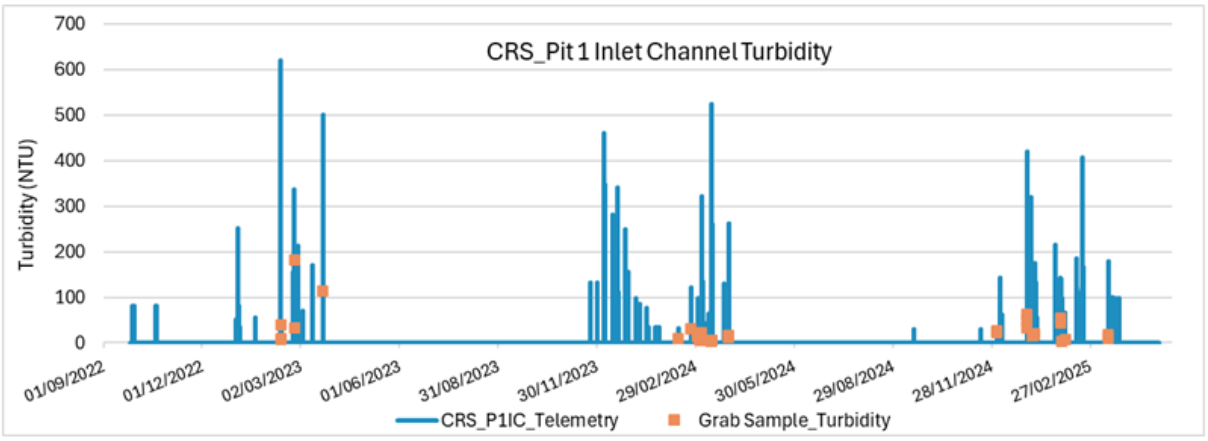

Figure 6-3: Pit 1 inlet channel telemetry and lab turbidity (2022-2025)

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 true for both the Pit 1 catchment and the TLF annual bedload yield, which is characterised by an exponential decline since construction (Figure 6-4).

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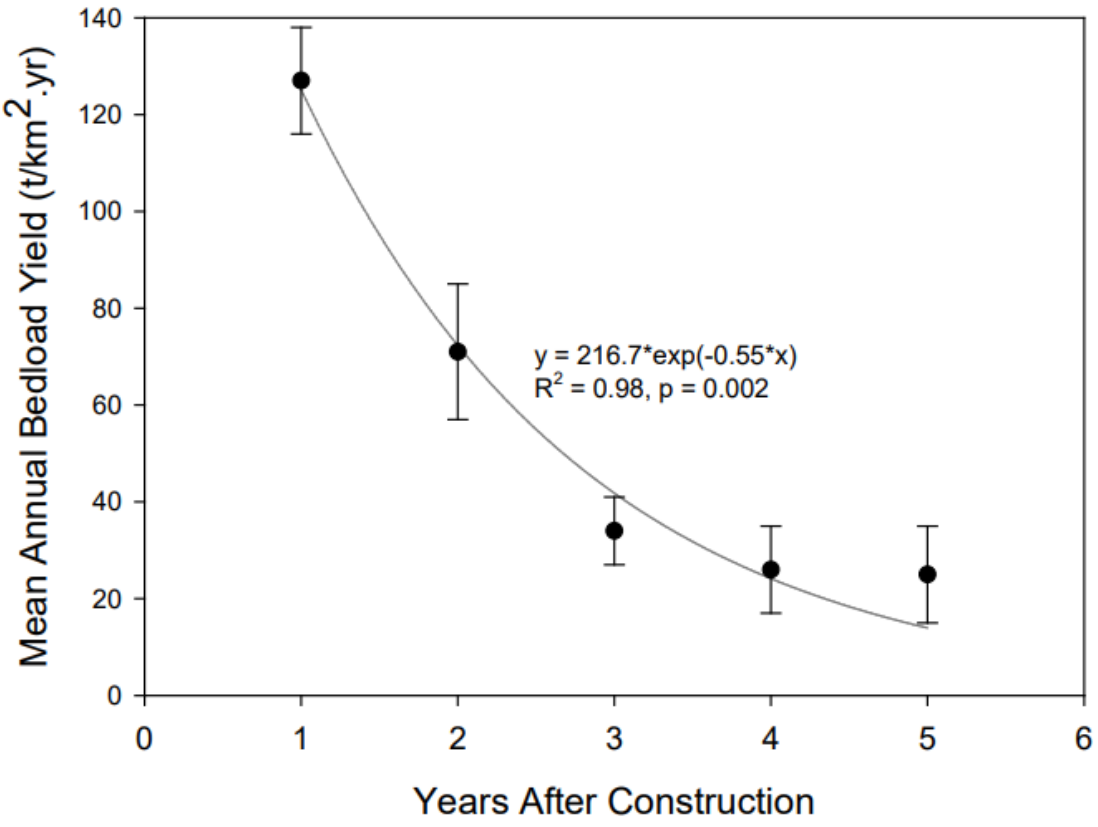

Figure 6-4: Decrease in mean annual bedload yield with time since construction on the TLF (Lowry and Saynor, 2015)

ERA applied to release suitable quality water from the CRS to Corridor Creek in the 2023/24 wet season in accordance with the 2023/2024 Ranger Water Management Plan and the Pit 1 Interim Water Management Plan. Following consultation with OSS, approximately 73 ML of water was released from CRS between March 2024 and April 2024 (Photo 6-2). Release from the CRS to Corridor Creek occurred in 2024/2025 wet season from January until last rain in April.

The Ranger Rehabilitation Project Team have an extensive dataset available to assess Pit 1 release behaviour including salts, metals, nutrients and herbicides. Herbicide analysis to date indicates that no herbicides were detected at the two downstream monitoring locations (GC2 and Georgetown Billabong) including immediately before and during the 2024 CRS release period. Further information on the herbicide analysis is available in Chapter 7.

The Ranger Rehabilitation Project Team will continue to collect and analyse water quality results from the Pit 1 landform to support the development of a whole final landform Water, Erosion and Sediment Control Plan. Water quality datasets from Pit 1, the Stage 52 catchment conversion trial (Section 6.3.1.4) and the Trial Landform area 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.

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Photo 6-2: Pit 1 inlet channel on 16 January 2024 – noting release from CRS was not occurring at this time

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 Water, Erosion and Sediment Control Plan, which will be included in the Final Landform application.

To help better inform that Plan, an area of approximately 7 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).

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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 5 ha of the 7 ha catchment area, delivering the water to a transfer sump. The collected water flows through a pipe to the HES forebay where it is treated via the addition of coagulant or flocculant to promote the settling of suspended sediment. The treated water then overtops via a level spreader weir to the HES main bay (Photo 6-3). Following additional retention times and treatment in the HES main bay, treated water flows via a spillway and 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.

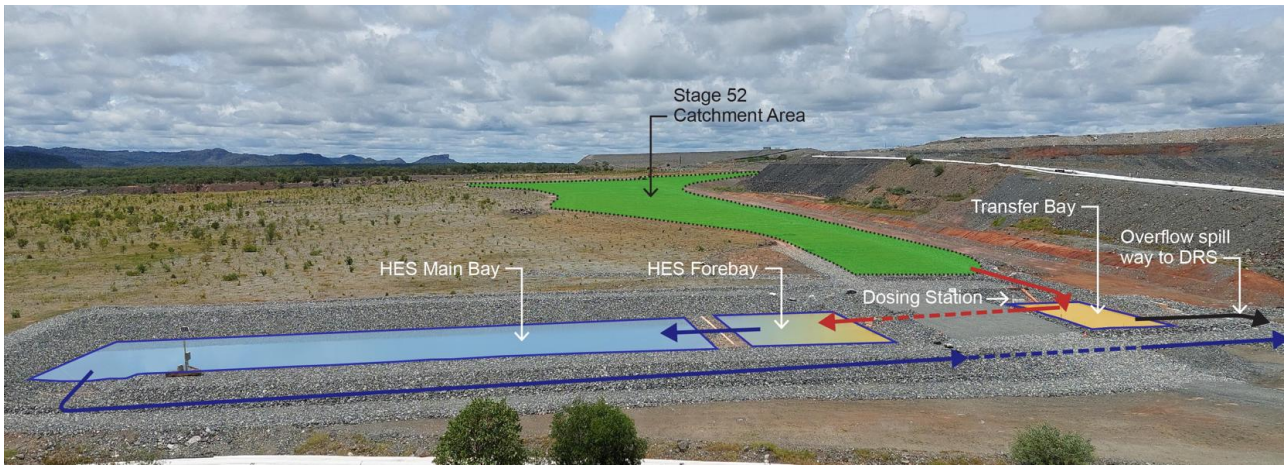

Photo 6-3: Stage 52 HES Basin (31 January 2023)

Water quality samples collected throughout the 2024/25 wet season, continue the trend of decreasing sediment loads and an improvement of turbidity values over the last three wet seasons. It is also noted that the material used to construct the Stage 52 landform area contains a higher proportion of lateritic clay material than what is proposed to be used on the final landform area.

The use of the two stage HES, including an automated dosing system, has been shown to be highly effective at reducing the turbidity and sediment load at the downstream spillway. Figure 6-5 demonstrates the turbidity of water from the Stage 52 area, showing the general trend of improved turbidity of the downstream (treated) water. Where the downstream turbidity is higher, this is considered to be erroneous data (likely due to a blocked sensor).

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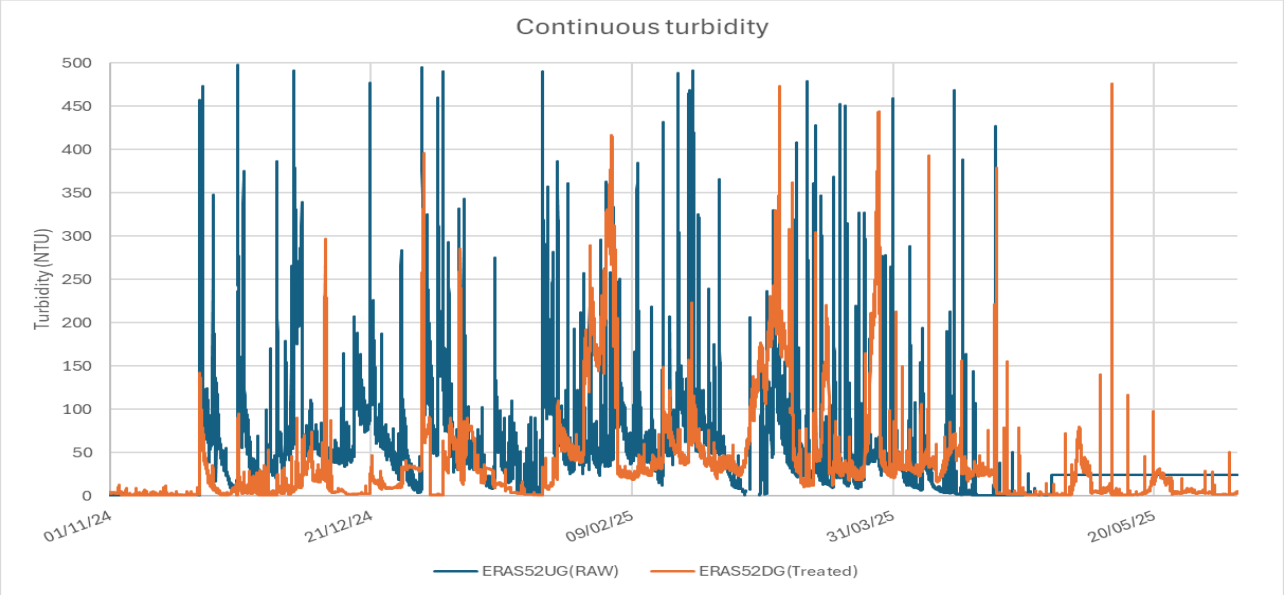

ERAS52UG (Raw) = upstream, ERAS52DG (Treated) = downstream.

Figure 6-5: Stage 52 Inflow vs Outflow Turbidity (March 2024)

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 water quality samples. The Ranger Rehabilitation Project Team have since updated the control logic to improve the sampling events. Grab sample collection was more frequent over the 2024/2025 wet season. However, telemetry data suffered similar issues with data noise particularly following rainfall where the sediment would become built up on the sensor. Other water quality parameters including salts, metals and nutrients have also been collected for the past three wet seasons for comparison of the inter-annual and seasonal trends.

Stage 52 also incorporated small cross-drains to reduce overland flow paths and main drains to collect and convey runoff. Rock check dams were also installed at 40 m intervals in the main drain leading to the transfer sump. No significant scouring has been noted on the landform after three wet seasons, however, some settlement of sediment has been observed in those drains.

The results obtained from monitoring through the 2022/23, 2023/24 and 2024/25 wet season and beyond will inform the development of a Water, Erosion and Sediment Control Plan.

The RRP are considering an additional erosion and sediment trial area to obtain additional monitoring data from the planned surface of the final landform. The exact location and extent of this trial area is yet to be determined but may be located in the wider surrounds of Pit 1. If this trial is implemented, runoff from the area would be collected and not released from site without meeting the applicable water quality release criteria.

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6.3.1.5 Stage 52 Release Approval

ERA provided notification to DLPE in October 2024 for the controlled release of treated water from the Stage 52 HES main bay to Corridor Creek, via the Pit 1 perimeter drain and CRS, over the 2024/2025 wet season.

The approved release criteria from CRS included an EC of <500 µS/cm and turbidity of <250 NTU. Based on the data from the 2023/2024 wet season, EC within the Stage 52 main bay was below 500 µS/cm at all times and turbidity was below 250 NTU most of the time, with turbidity levels reducing to less than 100 NTU after the first flush events early in the wet season. Monitoring of EC and turbidity recorded during the 2023/2024 wet season determined that the release of water from Stage 52 to the Pit 1 inlet channel/CRS could occur at any time, except for the first flush (the first four or five significant runoff events of the wet season). Runoff from the Pit 1 catchment and standing water in the CRS would also significantly increase dilution. There was no release from Stage 52 during the 2024/25 wet season as the required infrastructure to facilitate the release was not in place.

Ecotoxicity reporting for the flocculant and coagulants used in the Stage 52 HES have identified no effect or harm to aquatic organisms in their respective assessments, and no bioaccumulation potential (ERA, 2024a). ERA also completed ecotoxicity calculations that considered site-specific factors such as hydraulic controls and dilution. The results estimated downstream concentrations to be very low, and unlikely to have a discernible impact on the aquatic environment (ERA, 2024a).

The need to use flocculants and/or coagulants on a larger scale across the mine-site (outside trials) is yet to be determined.

6.3.1.6 Studies to be Completed

Water, Erosion and Sediment Control Plan

As indicated above, the Ranger Rehabilitation Project Team have commenced additional studies to support the development of a Water, Erosion and Sediment Control Plan, forming part of the Final Landform 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 our 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.

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- 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 as well as the Trial Landform.
- 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 a Water, Erosion and Sediment Control Plan will be provided in future iterations of the MCP.

Final Landform Design Optimisation

Concurrent to the above studies, the Ranger Rehabilitation Project Team are continuing to work with 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 includes:

- 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 (or future iterations);
- 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 a Water, Erosion and Sediment Control Plan.

Subsequent changes to the final landform design will be presented in future iterations of the MCP and discussed in the Final Landform application.

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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 6-6). 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).

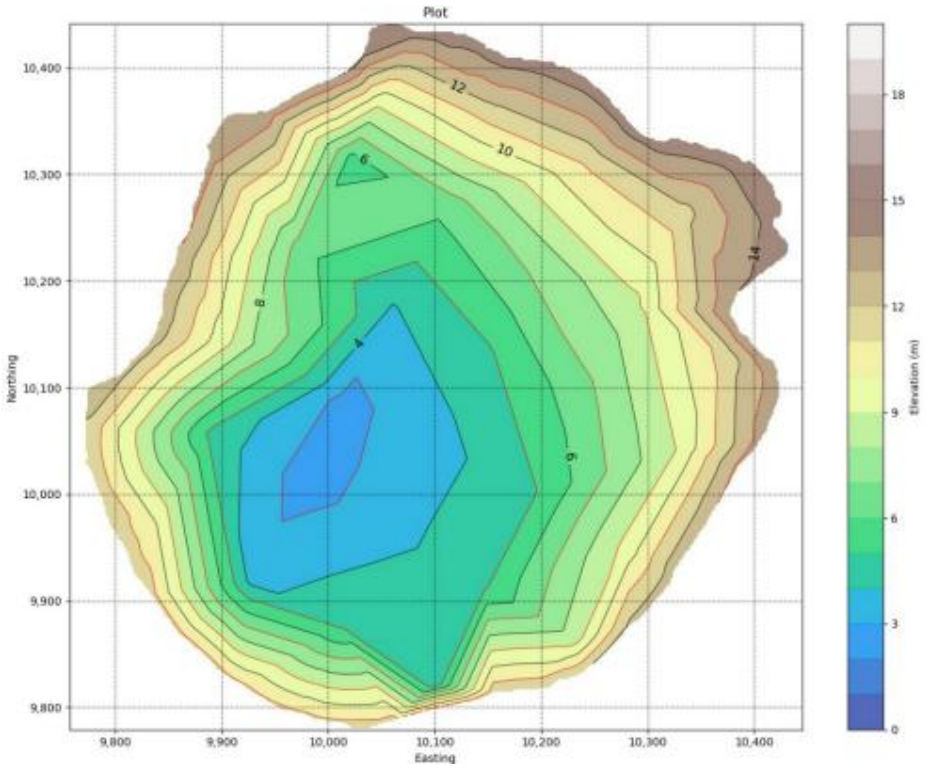

Figure 6-6: Calculated Pit 1 tailings surface as of May 2021 (S. Murphy, per. comms.1 June 2021)

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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 recent findings presented in the Pit 3 Capping, Waste Disposal and Bulk Material Movement Application submitted to the MTC members in September 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).

The Ranger Rehabilitation Project Team will continue to monitor the consolidation of Pit 3 tailings and Pit 1 tailings and waste rock in accordance with Section 6.6.1.

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). Ongoing work in landform design and LEM is refining these estimates.

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 rock armouring in drainage channels) 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 landform evolution 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 3. These include the introduction of first order drainage lines with sinuosity, moving a larger proportion of the flow of surface water away from the Pit 3 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.

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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 (closed out at ARRTC 54 held in May 2024) seeks to understand what major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, climate). Three investigations are of particular relevance and are discussed below.

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

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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 bow-tie 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 (INTERA, 2017). 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. The updated assessment reviewed the information derived for the NT from the latest (6th) 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 6.3.1.6, the Ranger Rehabilitation Project Team have engaged a geomorphic landform subject matter expert to undertake a review of the final landform design and landform evolution modelling to date. This work is ongoing at the time of writing and will include optimisation of the geomorphic design and inclusion of erosion control features including appropriately rock armoured major drainage channels and rock check dams in strategic locations.

Tailings consolidation modelling

The Ranger Rehabilitation Project Team will continue to monitor the consolidation of Pit 3 tailings and Pit 1 waste rock and tailings in accordance with Section 6.6. 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.

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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 6-7 and Figure 6-8.

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 the 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.

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Preventative Controls

C1 Final landform design, construction and verification
Satisfactory

C2 Erosion control measures including preparation of final landform surface
Marginal

C3 Sediment control measures including sediment basins
Marginal

C4 Drainage control structures including sinuous armoured drainage channels
Marginal

C5 Revegetation of the final landform surface
Satisfactory

C6 Understanding final tailings elevations
Satisfactory

Corrective Actions

A1 Maintenance of erosion and sediment control measures
Satisfactory

A2 Undertake earthworks to repair significant substrate limitations, gullying or eroded areas
Satisfactory

A3 Extension of landform monitoring and maintenance phase
Marginal

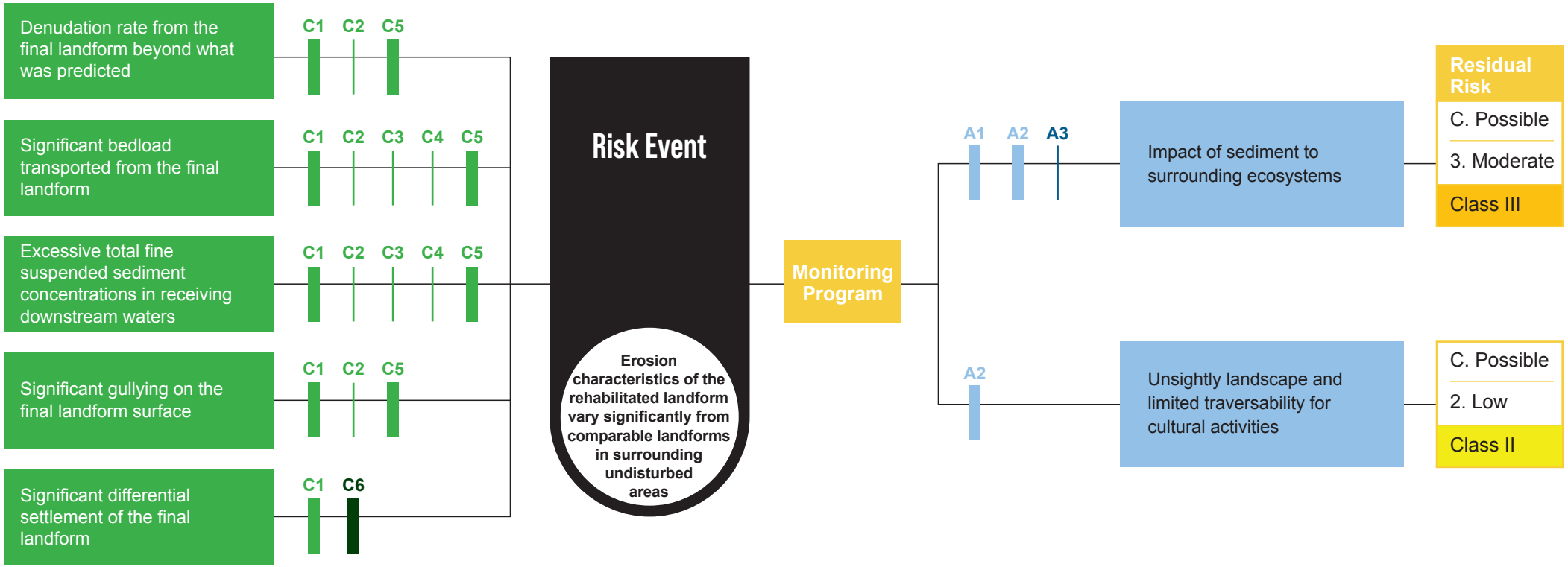

Figure 6-7: Bow-tie diagram for erosion characteristics (L1)

Preventative Controls

C1 Final landform design, construction and verification
Satisfactory

C2 Erosion control measures including preparation of final landform surface
Marginal

C5 Revegetation of the final landform surface
Satisfactory

C7 All tailings deposited into Pits 1 and 3
Strong

C8 Tailings buried below predicted depth of gully formation
Satisfactory

C6 Understanding final tailings elevations
Satisfactory

C9 Legal instruments
Weak

Corrective Actions

A2 Undertake earthworks to repair significant substrate limitations, gullying or eroded areas and rectification of constructed landform
Satisfactory

A4 Restricting access to any exposed tailings
Marginal

A5 Removing any contaminated or impacted material (water and sediment)
Weak

A6 Conducting health monitoring
Satisfactory

A7 Increasing the frequency of field inspections for erosion and gully formation
Satisfactory

Figure 6-8: 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 the Ranger Rehabilitation Project Team 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. The Ranger Rehabilitation Project Team 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, the Ranger Rehabilitation Project Team identified five threats that if realised, could lead to tailings becoming exposed:

- failure of the constructed landform to meet the approved landform design;
- 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, construction and verification	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

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Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
			based on the assessments proposed to develop a Water, Erosion and Sediment Control Plan.
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 a Water, Erosion and Sediment Control Plan.
C4	Drainage control structures including sinuous armoured drainage channels	Marginal	As above and another component that will be advanced as part of a Water, Erosion and Sediment Control Plan.
C5	Revegetation of the final landform surface	Satisfactory	The Ranger Rehabilitation Project Team has demonstrated successful rehabilitation on Pit 1 after ~3 years and on the TLF after ~14 years. Further work is planned regarding the Ecosystem Establishment Strategy and suitability for landform stabilisation in initial stages.
C7	All tailings deposited into Pit 1 and Pit 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 the Ranger Rehabilitation Project Team 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 four 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.

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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).

The Ranger Rehabilitation Project Team have engaged 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. Trials conducted historically in rehabilitation areas have contributed to concerns by Traditional Owners around traversability and they have indicated a preference to minimise ripping wherever possible across the final landform. There are also concerns regarding potential increased water infiltration that may impact solute transport.

Saynor and others (2017) noted that single, widely spaced deep ripped furrows can be effective at reducing sediment load from a rehabilitated landform, and rip lines do not exist in landscapes for perpetuity as the rip lines peaks erode overtime and the rip depressions are infilled with organic matter and eroded material (Saynor *et al.,* 2017).

A Water, Erosion and Sediment Control Plan is being developed that will recommend an appropriate scarification program that balances sediment risk and benefits for revegetation success with the need for a traversable surface.The location and methodology for scarification and/or ripping will aim to reduce surface runoff velocities that typically generate downstream scour.

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 and to balance competing constraints. The details regarding surface preparation activities and temporary and permanent erosion management treatments will be established through the development of a Water, Erosion and Sediment 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 post-construction, while vegetation establishes across the 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 4-31, 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.

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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 and operation (i.e. inspections, maintenance) of the sediment basins 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 a Water, Erosion and Sediment 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 drainage 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 a Water, Erosion and Sediment 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. Established vegetative groundcover is planned to occur as soon as possible, to reduce short- and long-term erosion and the resulting sedimentation. 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. The Ranger Rehabilitation Project Team acknowledges the integral role revegetation plays in reducing gully erosion and stablishing channels. Whilst much progress has been made, this rating reflects further work that is planned regarding the Ecosystem Establishment Strategy and its suitability for landform stabilisation in initial stages. These studies are described in Chapter 9 and the effectiveness of this control will be improved, as those studies progress.

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6.5.6 All Tailings Deposited into Pit 1 and Pit 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.

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 29 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. The Ranger Rehabilitation Project Team 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 and further information will be detailed in the Tailings Settlement Monitoring Plan (noting that this Plan is a condition of approval from the Pit 3 backfill application). Whilst the Ranger Rehabilitation Project Team have confidence in the consolidation modelling, uncertainty remains in some areas (e.g. the

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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 the Ranger Rehabilitation Project Team, 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 the Ranger Rehabilitation Project Team 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. The Ranger Rehabilitation Project Team acknowledges that the highest risk of erosion on a newly constructed landform is during the initial wet season, however erosion events can still occur as the landform settles. The Ranger Rehabilitation Project Team's response to landform monitoring will continue to be reviewed, ensuring the monitoring frequency and methods are proportionate to the risk of erosion.

For the purpose of this landform monitoring program, the closure phase refers to the period from the commencement of Pit 3 initial capping, through to the completion of the final landform. Post-closure monitoring will commence following the completion of the final landform through to the relinquishment of the RPA. The monitoring to occur in each phase is described in Section 6.6.1 and Section 6.6.2.

As indicated in Section 6.3.1.6, the Ranger Rehabilitation Project Team have commenced additional studies to support the development of a Water, Erosion and Sediment Control Plan, which will form part of the Final Landform application. This application will provide more details on the post-closure monitoring and associated TARPs.

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6.6.1 Closure Monitoring Program

6.6.1.1 Material Placement and Landform Construction Monitoring

Material placement monitoring will be used to ensure that bulk backfill is undertaken in accordance with the Bulk Material Movement Plan (noting that this Plan is a condition of approval from the Pit 3 backfill application). The Ranger Rehabilitation Project Team 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 during bulk material movement.

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.

6.6.1.2 Construction Landform Monitoring

Following the construction of each final landform surface, a high-resolution digital elevation model (DEM) will be generated via LiDAR survey methods (or similar). 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 the Ranger Rehabilitation Project Team 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, the Ranger Rehabilitation Project Team can rectify the landform as part of closure execution activities.

The high-resolution DEM will be accompanied by field inspections to ensure early detection and mitigation of gullying or erosion on the surface of the final landform area. These inspections will also inform subsequent maintenance, if required. The frequency in which these inspections occur will be determined by the risk of erosion events occurring (e.g. season, vegetation cover).

6.6.1.3 Pit 3 Tailings Consolidation Monitoring

Tailings settlement monitoring towers will be installed in Pit 3 to monitor tailings settlement. These towers are also used to monitor water quality, water level and EC through the inclusion of drain slots, enabling water migration into the tower. Some towers in Pit 3 may also be configured for water extraction via submersible pumps. 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. It is expected that this monitoring will occur until a plateau of measured tailings consolidation is observed. As noted above, a Tailings Settlement Monitoring Plan will be submitted for approval prior to the commencement of bulk backfill works.

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6.6.2 Post-closure Monitoring Program

6.6.2.1 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.

6.6.2.2 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 initially on a monthly basis in the wet season and following rainfall that causes significant runoff (nominally >50 mm in 24 hours). The inspection frequency will be reduced over the active period. A comprehensive pre-wet season inspection will be undertaken in Q4 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 development of the Water, Erosion and Sediment Control Plan will detail the management of these basins, however conceptually, the management and maintenance of the sediment basins will include:

- the removal of accumulated sediment, if required;
- minor repairs to sediment basin walls as necessary; and
- management of accumulated sediment at the cessation of active management.

Erosion inspections will be undertaken along access roads and tracks to identify erosion that may be a source of bedload moving offsite.

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6.6.2.3 Post-construction Landform Monitoring

Following the initial DEM survey described in Section 6.6.1, annual DEM surveys will be undertaken post-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 (tailings and waste rock consolidation). 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 for five years post-construction of the final landform. Following the initial settling of the landform (approximately five years), it is expected that no significant erosion will occur. The Ranger Rehabilitation Project Team will, however, continue to undertake landform erosion inspections every second year from five years through to ten years post landform construction, then again reducing the frequency to every five years from ten years to 25 years post landform construction. The Ranger Rehabilitation Project Team will re-commence DEM surveys if significant erosion (greater than what was predicted) is identified during field observations (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 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.

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Table 6-9: Landform monitoring

Aspect	Objective/s	Method	Variable	Frequency
Closure Monitoring				
Constructed landform inspections	Comparison of constructed surface elevation and landform to the approved landform design	Topographic Survey	Surface elevation	Annually for five years post-construction of the final landform Contingency for event based DEMs from 6 years (i.e. event based after five years) through to relinquishment
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
Post-closure Monitoring				
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	Wet Season average difference in turbidity	Continuous in the wet season until net annual turbidity between sites located upstream and downstream at the boundary of the RPA are comparable to background values over the course of five consecutive wet seasons
Temporary erosion and sediment control structure inspections	Confirm erosion control structures are functioning effectively	Field inspections of erosion and sediment control structures on the final landform surface	Condition and status of erosion and sediment control structures	Initially on a monthly basis in the wet season and following rainfall that causes significant runoff (nominally >50 mm in 24 hours). The inspection frequency will be reduced over the active period

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Aspect	Objective/s	Method	Variable	Frequency
Constructed landform inspections	Comparison of year-on-year DEM change to quantity final landform surface erosion and settlement (tailings and waste rock consolidation)	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	Annually post -wet season for the first five years, reducing to every second year from five years to ten years and then five yearly from ten years to 25 years

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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 Table 6-10 will be implemented. 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 (if required).
A2	Undertaking earthworks to repair significant substrate limitations, 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 impacted by exposed tailings)	Weak	If monitoring detects contaminated material has been transported from the mine disturbance area it will be remediated up until relinquishment.
'Knowledge-based / Administrative' corrective actions			
A3	Extension of landform monitoring and maintenance phase	Marginal	There is no plan for the Ranger Rehabilitation Project to extend the monitoring and maintenance phase beyond the estimated 25 years.
A6	Conducting health monitoring	Satisfactory	Accepted and common practice, and Ranger Rehabilitation Project Team resources would be available up until relinquishment. This would only occur in the event of an incident that triggered the need (e.g. tailings exposure).
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.

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6.8 Trigger, Action, Response Plan

Table 6-11 consolidates the monitoring and adaptive management programs described above into the form of a TARP. 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.

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

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.	Failure of the structure and/or significant accumulated sediment is identified within rock check dams or sediment basins that does not yet have an impact on the function of the structure.	Failure of the structure and/or significant accumulated sediment is identified within rock check dams or sediment basins that may have an impact on 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.
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.

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Inspections of temporary erosion and sediment control features			
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 validation of the tailings model (measured by tower height and extracted PTF).	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 from approved final landform design.	Quarterly review of material balance suggests variance 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.

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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:

- Relevant studies completed (70%):
    - Development of a Water, Erosion and Sediment Control Plan: The Ranger Rehabilitation Project Team have commenced studies to inform a Water, Erosion and Sediment 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 Final Landform application that is submitted to regulators for approval.
    - The outcomes of the Water, Erosion and Sediment 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 Final Landform application.
    - The Ranger Rehabilitation Project Team are working with 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. The Ranger Rehabilitation Project Team 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.
    - The Ranger Rehabilitation Project Team will continue to monitor the consolidation of Pit 1 tailings and waste rock and Pit 3 tailings in accordance with Section 6.6.1.3. If monitoring identifies a variance in the rate of tailings consolidation, the tailings consolidation model will be reviewed and updated.
    - Development of a Bulk Material Movement Plan.
- Preventative controls effective (80%):
    - The development of the Water, Erosion and Sediment 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 the Ranger Rehabilitation Project Team, 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.

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- Monitoring program developed and operational (80%):
    - Future work will be undertaken to better inform the monitoring that will occur to manage the risks associated with the landform construction period. An additional erosion and sediment trial area (additional to Stage 52) may be constructed.
    - Development of a Tailings Settlement Monitoring Plan.
- 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.

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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).
- Water and sediment related studies are advancing and will continue to progress throughout the closure period. Further work continues to be undertaken to improve the understanding of spatial and temporal aspects of CoPC movement, to reduce uncertainty in both groundwater and surface water modelling, and to minimise the potential post-closure impacts to ecosystem and human health. Studies to improve the acid sulfate soils (ASS) conceptual models and the role Ranger may play in ASS processes on site are also progressing (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 (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).

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7.1 Closure Objectives and Criteria

Table 7-1 lists the ERs the RRP consider to be 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:* *(b) maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park);* *(c) protect the health of Aboriginals and other members of the regional community;* *(d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.*	1.1(b) 1.1(c) 1.1(d)
1.2 *The company must ensure that operations at Ranger Mine do not result in:* *(a) damage to the attributes for which Kakadu National Park was inscribed on the World Heritage List;* *(b) damage to the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stage I and II of Kakadu National Park);* *(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(a) 1.2(b) 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
3.4 Process water must be totally contained within a closed system except for: *(b) seepage of a quality and quantity that will not cause detrimental environmental impact outside the Ranger Project Area.*	3.4(b)
7 Management of Excavated Material *7.1 All excavated material must be managed such that there is no detrimental environmental impact outside of the Ranger Project Area, and that environmental impacts within the Ranger Project Area are as low as reasonably achievable.*	7.1
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

The Ranger Rehabilitation Project Team 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).

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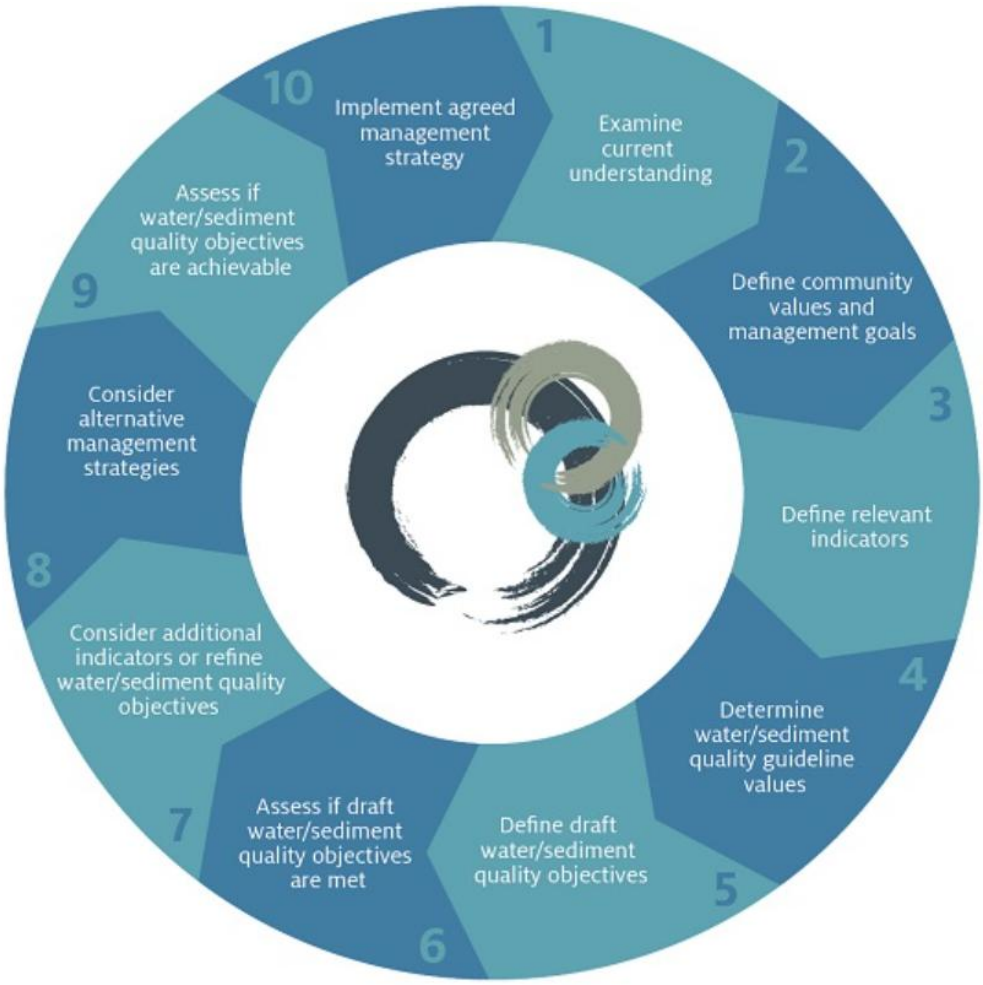

Figure 7-1: The Water Quality Management Framework (ANZG, 2018)

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).

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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, 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 Rehabilitation 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.

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Table 7-2: Approved guideline values for each management goal – most stringent and therefore adopted Guideline Values (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, 3.4(b), 1.1(b), 1.1(c), 1.1(d) and 1.2(a), 1.2(b) and 1.2 (c), 7.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Rehabilitation 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, 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_4 500 mg/L, Mn 500 µg/L, NO_3 50 mg/L, *<u>NO_2 3 mg/L</u>*, U 17 µg/L (NHMRC, & NRMMC, 2011; v4.0 updated 2025).	$NO_2 \leq 3$ 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, 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: NHRMC, 2008). • SO_4 400 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.	-

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ER	Objective	Management Goal	Indicator	Guideline Values for each management theme[1]	Draft Water/Sediment Quality Objectives[2] (Closure Criteria)
3.1, 3.4(b), 1.1(b), 1.1(d) and 1.2(a), 1.2(b) and 1.2(d), 7.1, 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the R Ranger Rehabilitation 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 Rehabilitation 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, 4].	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.

[4] A site-specific guideline value is being developed by OSS for aluminium.

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

ER	Objective	Management Goal	Indicator	Water/Sediment Quality Objectives under review
3.1, 3.4(b), 1.1(b), 1.1(c), 1.1(d) and 1.2(a), 1.2(b) and 1.2 (c), 7.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Rehabilitation 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, 3.4(b), 1.1(b), 1.1(d), 1.2(a), 1.2(b) and 1.2(e) and 2.1, 7.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Rehabilitation 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 Rehabilitation 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 Rehabilitation 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.

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ER	Objective	Management Goal	Indicator	Water/Sediment Quality Objectives under review
3.1, 1.1(b), 1.1(d) and 1.2(a), 1.2(b) and 1.2(d), 7.1 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Rehabilitation 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 Rehabilitation 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.

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7.1.3 Justification for Outcome, Parameter and Criteria

As described above, the Ranger Rehabilitation Project Team are 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, 2025) and between hydrological processes and ecosystem dynamics (BMT, 2017).

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- 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; Thomas *et al.*, 2024).
- 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 (Supervising Scientist, 2025a).

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).

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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; v4.0 updated 2025) 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; v4.0 updated 2025).

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.

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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 value 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.

Potential aesthetic impacts associated with any eutrophication effects, metal oxide precipitates (flcos) or sediment deposition will also be considered in terms of impacts on recreational values of waterways.

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, the Ranger Rehabilitation Project Team has adopted the OSS site-specific guideline values for uranium in both water and sediment as closure criteria.

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Guideline values based on ecotoxicity studies by the OSS are available for species protection levels of 99%, 95%, 90% and 80%. Guideline values for 99% species protection are currently used as the default 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).

The Ranger Rehabilitation Project Team 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 are compared to guideline values for each theme in the *Aquatic pathways risk assessment project* (see Section 7.3.7).

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Predicted concentrations of several CoPCs (Water Solutions, 2021a, ERA 2023a) 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 potential mitigation actions (see step 8) to reduce the concentration of contaminants reporting to the water bodies on and off the RPA. Works to reduce model uncertainty include:

- review of source terms of different materials on site that may present a long-term source of CoPC to the groundwater and surface water systems;
- improved understanding and modelling of surface water and groundwater interactions;
- increased spatial and temporal resolution; and
- improved integration between surface and groundwater solute transport models.

The water quality objectives can also be reviewed as per step 7.

If concentrations exceed the proposed or adopted 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 the Ranger Rehabilitation Project Team 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 7.3.8 provides a description of the project).

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

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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).

Notwithstanding pH and dissolved oxygen are not currently being considered appropriate for establishing a site-specific guideline value for these parameters, ongoing monitoring of these physiochemical properties remains appropriate in selected locations given the roles that both pH and dissolved oxygen play in bioavailability and reactive transport processes.

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 *Aquatic pathways risk assessment* project identified risks to the aquatic ecosystem related to contaminant levels from the current mine closure strategy (see Section 7.3.7). 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 the Ranger Rehabilitation Project.

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.

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.

The Ranger Rehabilitation Project Team 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.

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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.

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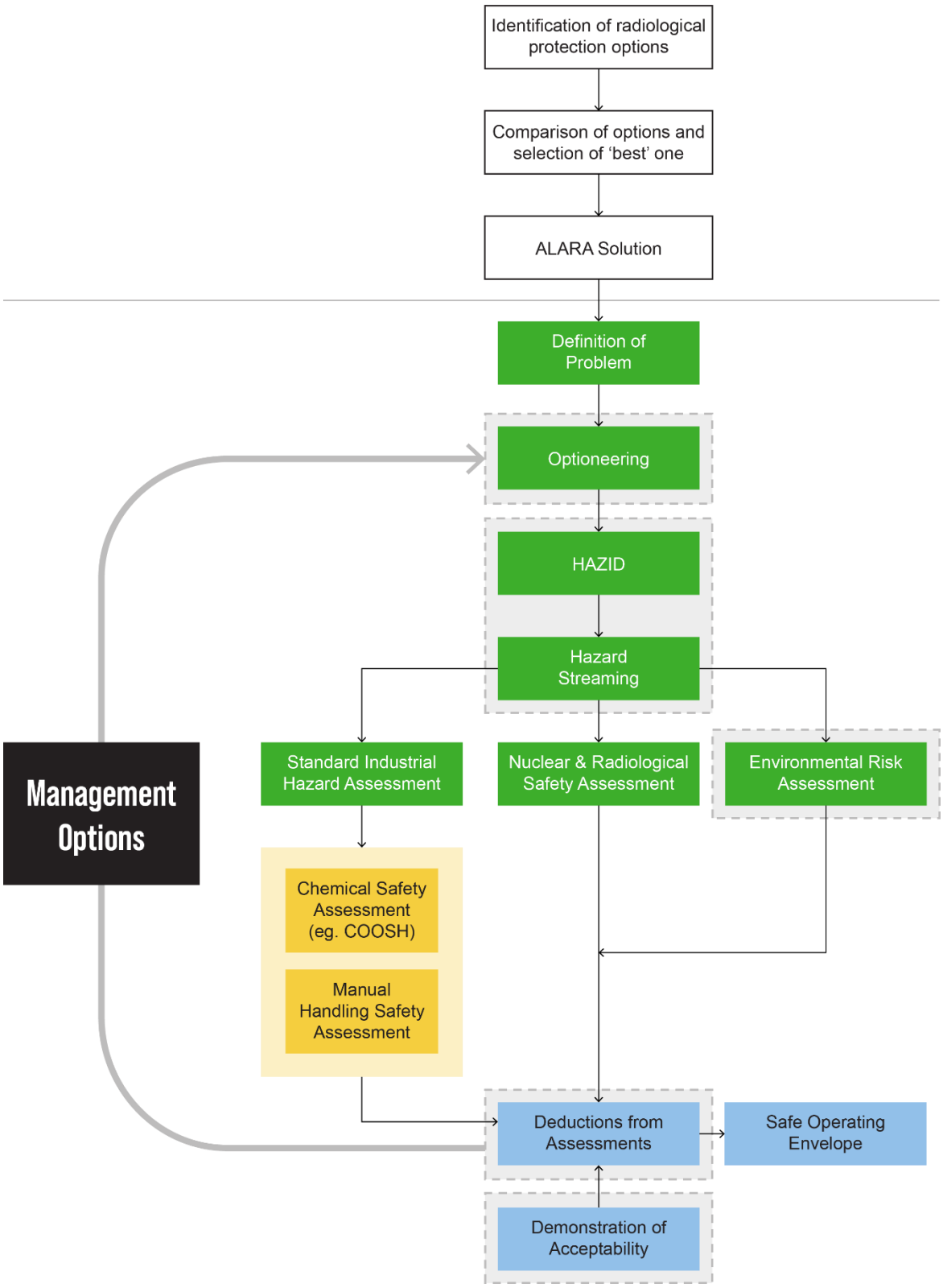

Figure 7-2: (Top) The main features of the ALARA procedure (Oudiz *et al.*, 1986) and (Bottom) Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (from Bryant *et al.*, 2017)

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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 an appropriate time post-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).
- Mineralised material 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).
- Demolished and contaminated material will be disposed into Pit 3 and RP2 and buried below the conservative 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 4.5.4.4).
- The final surface landform of the RWD will be constructed to form a drainage flow path running south to north along the alignment of 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. A number of studies have progressed but are not yet completed, so the percentage complete has not changed.

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 7.3.11). A number of these studies are ongoing and a summary of the works yet to be completed are also described (Section 7.3.12).

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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). An updated conceptualisation of the Pit 3-Djalkmarra groundwater shed was also developed for the Pit 3 application (ERA, 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.

Each of the conceptual models describes the features, processes and events governing the groundwater system at that scale. The conceptual models are spatially related but are not nested. The regional conceptual model encompasses the sitewide scale conceptual model, which in turn encompasses the areas of interest that contain mining related solute sources and other features, processes, and events.

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);

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- 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. Data analysis of new and existing Gulungul Creek bores has been completed (INTERA, 2025). The data review concluded:

- overall conditions at the upstream location are consistent with the conceptual model for Magela Creek;
- conditions at the downstream gauge are not consistent with the conceptual model for Magela Creek;
- vertical hydraulic gradients at the downstream location are downward during the first part of flow period, then they switch to upward during the latter part of the flow period while the creek is under gaining conditions;
- EC data for the downstream location show very small changes in creek EC even though groundwater EC is about ten times larger, and groundwater continues to discharge into the creek during the recession period; and
- the groundwater discharge rate into Gulungul Creek at the downstream location is much smaller than the creeks recessional flow rate.

Work has commenced to review and update the groundwater-surface water interaction conceptualisation. This includes additional groundwater and surface water modelling to provide further understanding of solute flow paths from the points of groundwater exfiltration into the surface water system and into Magela Creek. Conceptual models will also continue to be updated to reflect improved understanding of ASS and eutrophication processes as well as location specific groundwater and surface water interactions.

The conceptual models continue to be reviewed as improved knowledge of groundwater and surface water systems is obtained. For the Pit 3 application, the sitewide numerical groundwater flow and transport model was used to estimate groundwater solute loading from Ranger sources to the creek receptors for subsequent prediction of surface water concentrations. While the numerical model encompasses the sitewide scale, its spatial resolution is much smaller to capture the features and processes at the different scales needed to make loading predictions to individual creeks. The separate numerical surface water model took the results from the numerical groundwater model to make predictions of surface water concentrations along Magela Creek and its key tributaries.

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In 2024, further work has been undertaken to improve the modelling of the complex interaction between groundwater and surface water systems, including:

- Starting to develop catchment based ‘inset’ groundwater models to explore higher spatial and temporal resolutions.
- The development of updated surface water models that have improved capacity to model complex hydrodynamic and biogeochemical processes in surface waters relevant to the Ranger receiving water environment.
- Collaboration between groundwater and surface water developers to improve integration between the models.

The increased complexity of these models is expected to reduce modelling uncertainty, but has also necessitated the collection and analysis of additional monitoring data to inform model calibration.

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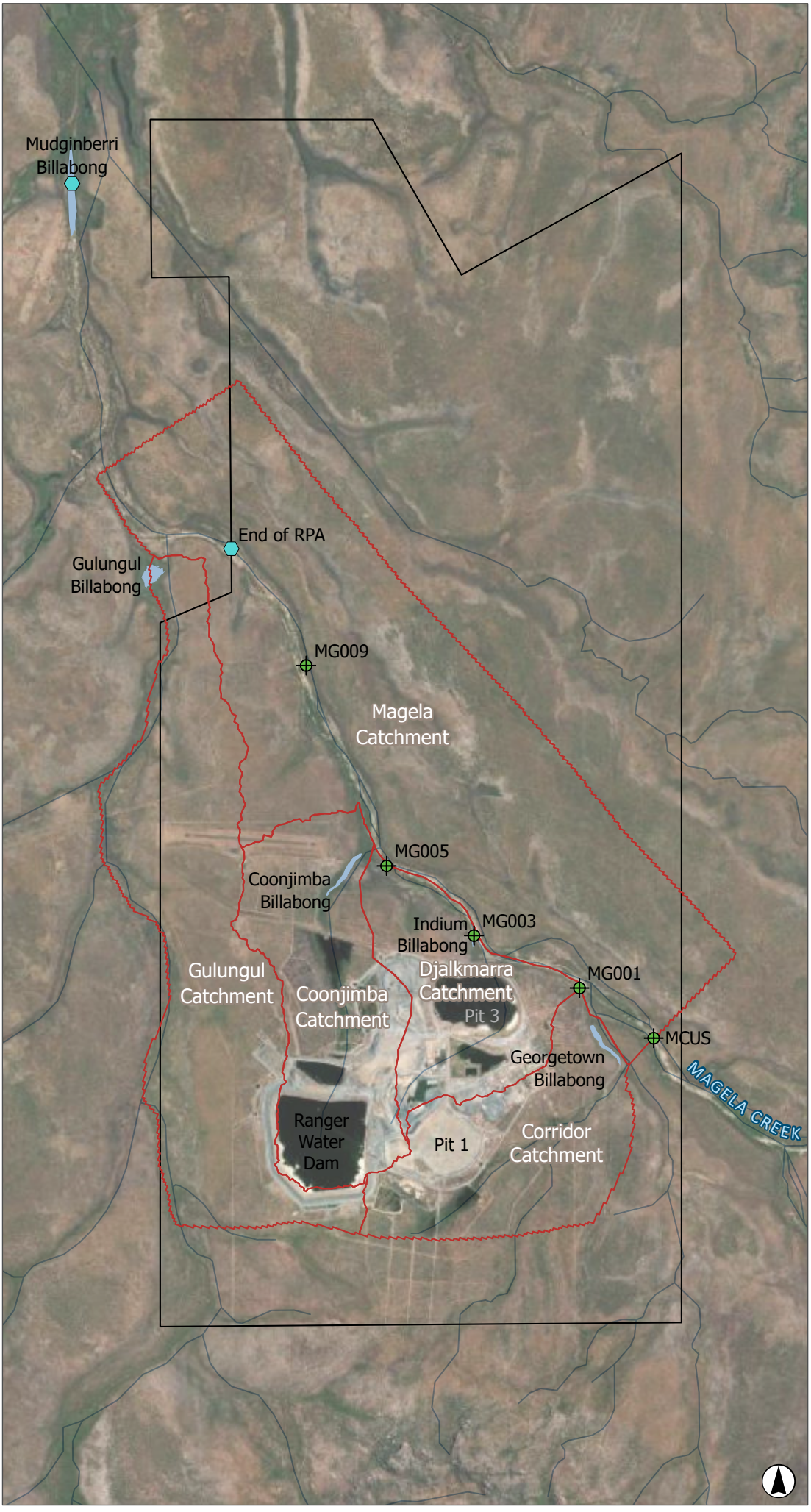
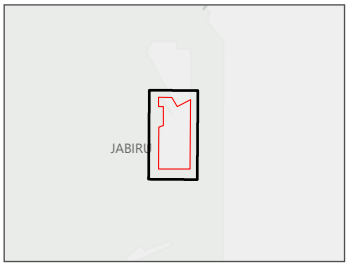


FIGURE 7-3

Ranger Mine Sitewide Groundwater Sheds

LEGEND

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



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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 tailings dam
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.

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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.

During the previous assessment, development of BTVs was not able to be completed for selected CoPCs in some HLUs due to insufficient data. Since then, additional monitoring bores have been installed in key HLUs, and additional analytical suites have been added to the monitoring programs. This has allowed for an additional ~80,000 data points to be collected over a 5-year period.

A program of works is underway develop the background CoPC dataset and develop BTVs for HLU analytes combinations which were data constrained and unable to be developed previously. The works will also assess whether Ca, Fe and Po210 are CoPCs for groundwater based on statistical assessment, and if so develop BTVs where possible. Phase 1 of the works (ERM 2025) includes a data sufficiency assessment to review additional data available (since the ERM 2020a work) and identify which HLUs can have BTVs developed. Phase 2 of the works will involve updates to background datasets and the BTVs for the CoPCs and/or HLUs identified in Phase 1.

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

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Solute	Abbreviation	Unit	HLU Specific BTV Concentration		
			S-WC	D-WC	S-BC
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

During November and December 2024, 20 groundwater monitoring bores were established across the site (Stantec 2025a):

- four within the Pit 1 area;
- five within the Trial Landform area;
- six north of the RWD;
- two along the RWD walls; and
- three surrounding Pit 3.

Data collected from these bores will be used in the source term updates for plumes associated with the RWD, stockpiles and RP2, as well as source terms associated with waste rock emplacement in the saturated zone (SZWR) and the vadose zone (VZWR).

An additional nine groundwater monitoring wells were installed in December 2024 in the processing plant area as part of the contaminated soils drilling program. Data from these bores will be used in the source term updates for the processing plant area.

Monitoring of the hydraulic and water quality conditions near Pit 1 has been ongoing for many years, including assessment of the potential interactions between Pit 1 (process water, tailings and waste rock backfill) with adjacent aquifers and surface water (including in Corridor Creek/Corridor Creek Tributary and Georgetown Billabong). This historical assessment has included multiple numerical groundwater modelling scopes and some geochemical modelling by EWL Sciences (2003), CSIRO (2014) and INTERA (2014b, 2018, 2019 and 2021c). The modelling has been revised and updated as the understanding of the geology/hydrogeology surrounding Pit 1 has developed, and as the approach to backfill and closure of Pit 1 has been refined. In 2025 ERM completed a detailed review of Pit 1 data to understand the groundwater quality, movement, and effectiveness of the monitoring program (ERM, 2025b). The work undertaken has improved the conceptual model of the as-built Pit 1 and further work is ongoing to reduce uncertainty in Pit 1 related source terms, and utilise data from Pit 1 to further reduce modelling uncertainty within the broader site for the Final Landform application.

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7.3.3 Groundwater Modelling and Uncertainty Analysis

For the Pit 3 application, 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. This uncertainty analysis included consideration of all known potential sources associated with the proposed final landform. 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 based on site understanding and planned closure activities at the time (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.

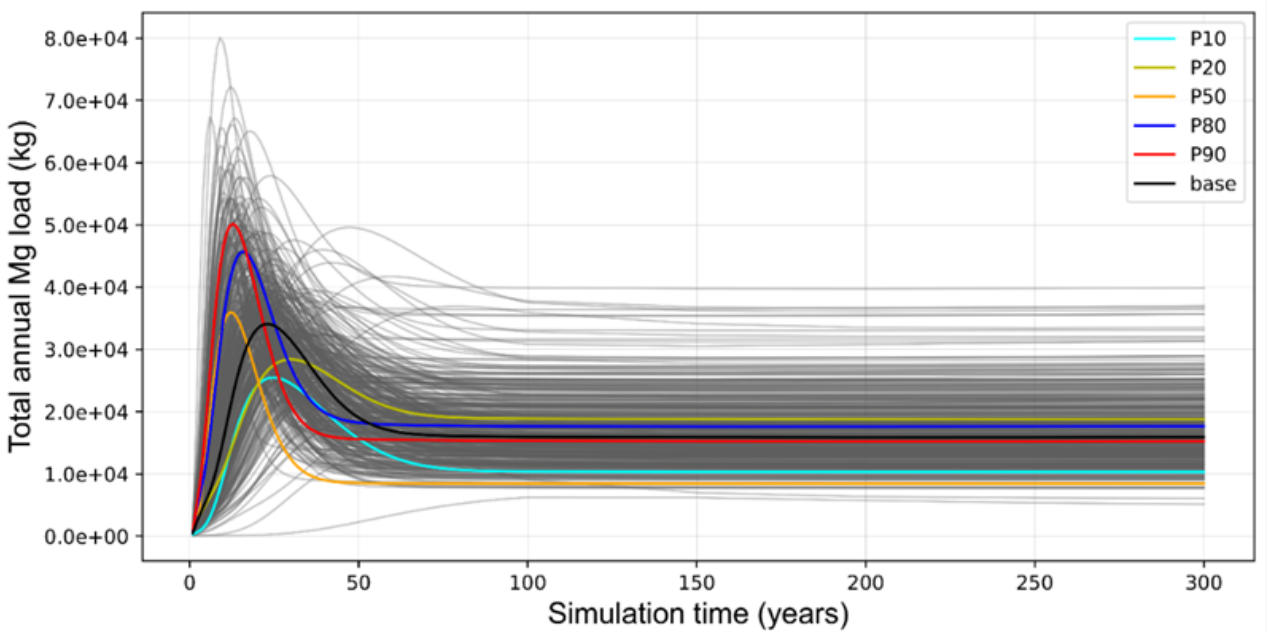

Figure 7-4: Horsetail plot of Pit 3 uncertainty analysis modelled magnesium loads from Pit 3 sources (Px realisation classification is based on peak loads only)

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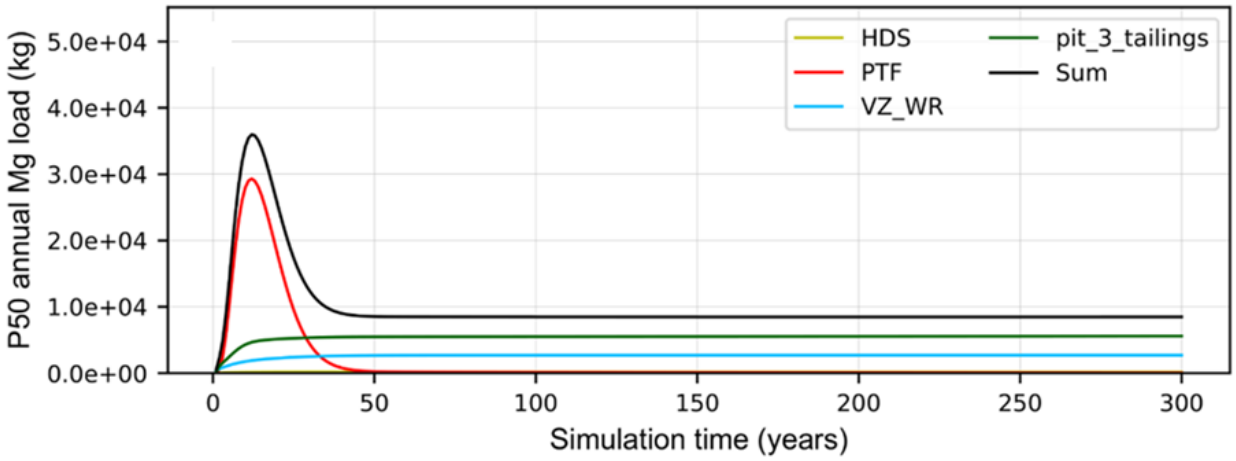

Figure 7-5: P50 (peak) realisation load contributions from Pit 3 sources

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).

Work is progressing to review and update the groundwater source terms, as well as a review of the baseline CoPCs in groundwater to develop BTVs for HLU analyte combinations that were previously identified as being data constrained (see Section 7.3.2). These updates will feed into an updated whole-of-site groundwater model and updated uncertainty analysis of predicted CoPC loads entering surface water systems as part of the final landform application.

The Ranger Rehabilitation Project Team is also investigating additional remediation and plume management options to reduce loads from final landform and RWD plume sources. As identified in Section 7.3.1, significant updates to groundwater and surface water modelling is being undertaken to improve modelling of groundwater-surface water interactions, and the integration of the two models to further reduce uncertainty in model predictions for key CoPCs.

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

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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 of these groundwater-surface water interactions 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 Operation Simulation Modelling (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.

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. Development of an updated surface water solute transport model (SWSTM) is progressing that includes hydrodynamic and water quality/reactive transport modelling, including the implementation of components of the Aquatic Eco-Dynamics (AED) model (Hipsey, 2022). The initial focus of the work is on the Coonjimba catchment, and the updated model will eventually progress to the other sub-catchments and Magela Creek (see Section 7.3.12.1). The SWSTM includes sub-daily rainfall runoff and flow dynamics as well as the capacity to model backflow and flushing in onsite billabongs. Additional work on the groundwater-surface water interaction and pathways is a key component of this update and the ongoing groundwater conceptualisation and modelling.

Noting that the SWSTM is in development, the current functional tool for estimating downstream water quality remains the RSWM. 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. Distribution of annual groundwater loads to daily surface water loads is based on conceptual models of groundwater flow to Magela Creek documented in INTERA (2021b).

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In the modelling undertaken for Pit 3 solute movement, conservation of mass was assumed for all CoPC movement within the Magela Creek system and no allowance was 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 RSWM. Modelling of solute movement through billabongs will be refined as part of the SWSTM updates and broader groundwater modelling and conceptual model updates used for assessment of impacts associated with RWD deconstruction and final landform development. The assessment of these components will include consideration of additional measures (mitigations/controls) to reduce solute loads from RWD and VZWR sources. As noted above, the SWSTM will also include hydrodynamic features including mixing, flushes, peak inflows and flood events.

The outcomes from the full suite of model runs from the Pit 3 assessment 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, and will include improved understanding and modelling of groundwater-surface water interactions.

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 and Table 7-7 are discussed in Section 7.3.7 to Section 7.3.11.

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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

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	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	0.099 9	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.
Note: A site-specific guideline value is being developed by OSS for aluminium.

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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

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	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.
Note: A site-specific guideline value is being developed by OSS for aluminium.

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7.3.6 Solute Movement in Surface Water

As described in Chapter 6, the controlled release of surface water from the rehabilitated Pit 1 landform occurred during the 2023/2024 and has continued during the 2024/2025 wet season. Water quality data collected over the last five wet seasons (commencing in 2020/21) indicates an improvement and stabilisation in electrical conductivity (EC) values and uranium concentrations, similar to the trend observed for turbidity, which provides confidence in the ability to selectively discharge during the wet season and meet relevant water quality criteria in receiving waters downstream (see Section 6.3.1.3). Figure 7-6 and Figure 7-7 show the EC and filtered uranium concentrations recorded in the Corridor Road Sump (CRS) since the 2021 wet season. Figure 7-8 shows the filtered uranium concentrations in the CRS focussed on the past three wet seasons, indicating that the concentrations have continued to improve. This is consistent with the observations by Saynor and others (2014) in relation to runoff on Plot 1 of the trial landform.

It is noted that there is some shallow groundwater connectivity directly between Pit 1 and the CRS, and when water levels in Pit 1 are high (as observed in 2021 and 2022) the perimeter drain (and thus CRS) also collects near surface seepage and this likely contributed to the elevated EC and uranium levels during these years (see Figure 7-6 and Figure 7-7)(ERM, 2025b). Re-commencement of pumping from the North Decant during the 2022/23 wet season resulted in inward hydraulic gradients being re-established, which also contributed to lower concentrations within the CRS from 2023.

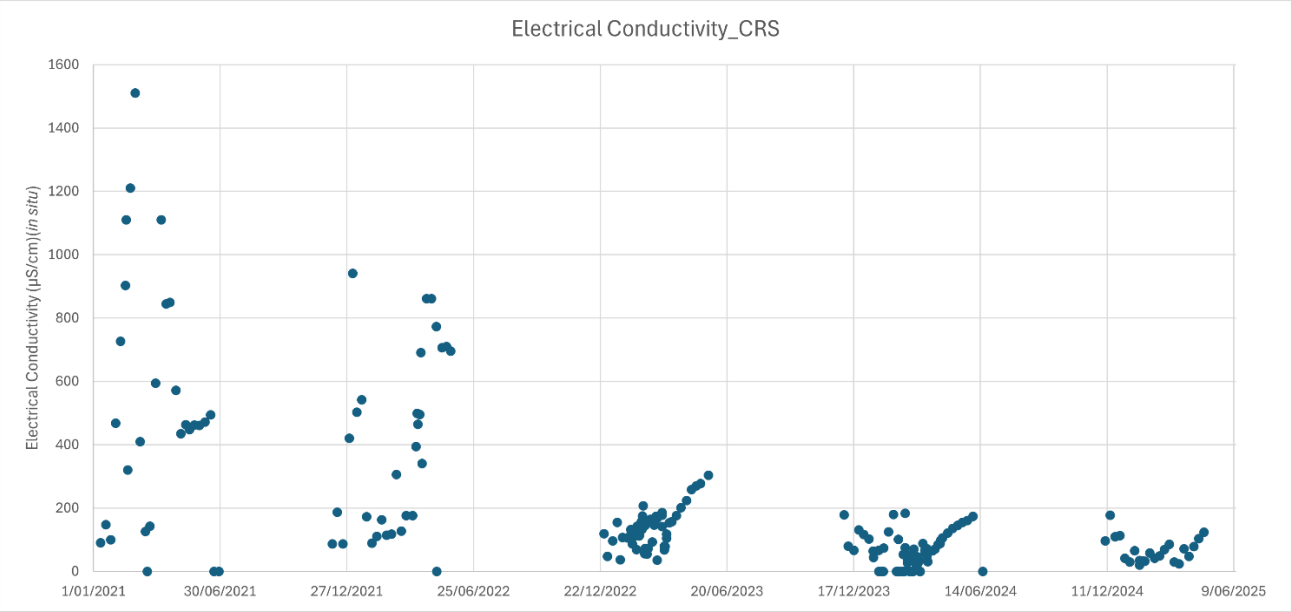

Figure 7-6: Pit 1 - CRS water quality data – Electrical Conductivity – 2020/21 to 2024/25 wet season

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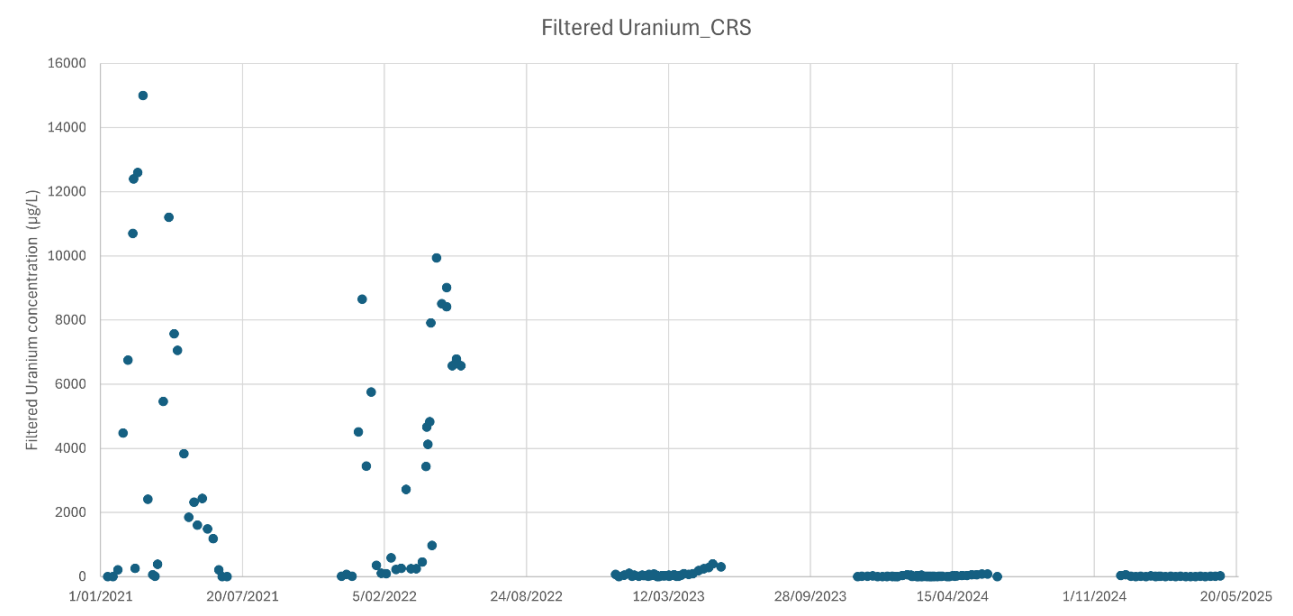

Figure 7-7: Pit 1 - CRS water quality data – Filtered uranium – 2020/21 to 2024/25 wet season

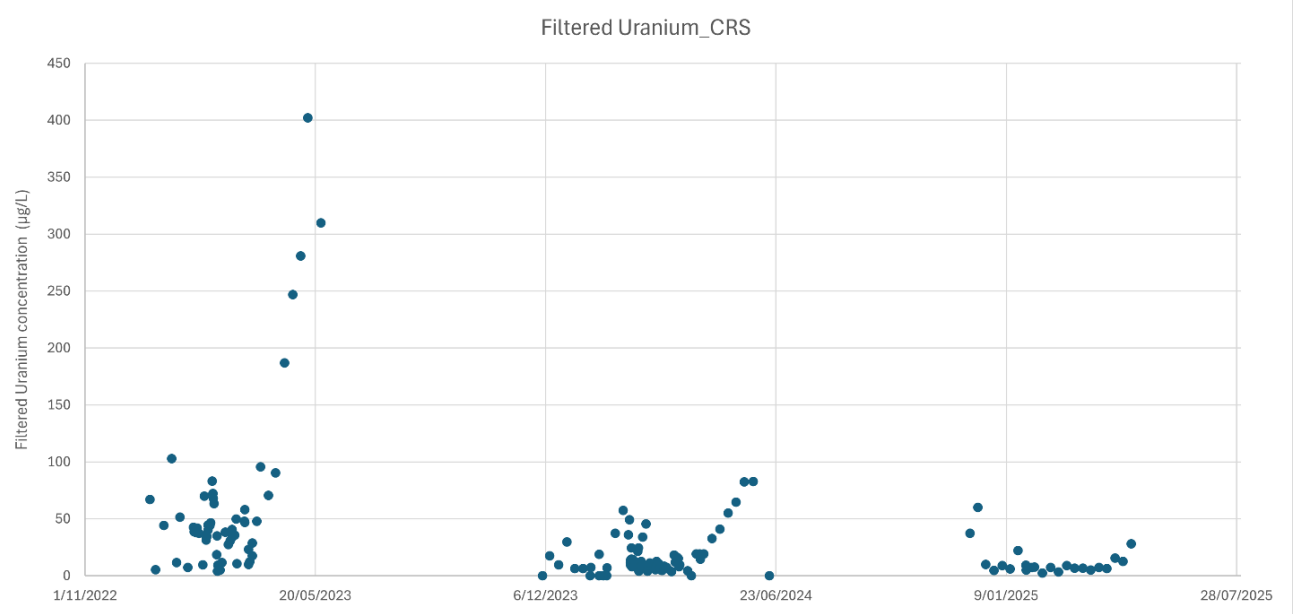

Figure 7-8: Pit 1 - CRS water quality data – Filtered uranium – 2022/23 to 2024/25 wet season

As reported in the 2024 RMCP, water quality samples were collected from the Pit 1 inlet channel, the CRS, and two downstream sites (Corridor Creek Tributary (GC2) and Georgetown Billabong (GTB)) during or just after surface water release from the CRS during the 2023/24 wet season. The samples were analysed for herbicide active ingredients glyphosate, oxyfluorfen and sulfometuron methyl, as well as aminomethylphosphonic acid (APMA), the principal degradation product of glyphosate. Clopyralid was not analysed as only a small volume was applied to the Pit 1 catchment on one occasion during the water release events.

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Detections of glyphosate, well below the ANZG freshwater quality 99% species protection value, in both CRSP1IC and CRSUG were likely associated with localised spraying on the batters of the CRS or the perimeter drain. There were no detections of glyphosate from Stage 52 during 2023. No glyphosate, APMA, oxyfluorfen or sulfometuron methyl concentrations were detected at the downstream monitoring locations (GC2 and GTB), indicating that the dilution of the CRS release water from GCMBL and local catchment flows are significant. The potential impact of these pesticides on the ecosystems of downstream receiving waters is considered to be negligible.

Controlled releases from the CRS will continue during future wet seasons. Ongoing monitoring of turbidity and EC within the CRS will be undertaken during the release period, as well as downstream monitoring described in the RWMP and RWMS.

As discussed in Chapter 6, approval has been granted for the controlled release of treated water from Stage 52 HES main bay to Corridor Creek, via the Pit 1 perimeter drain and CRS. The Stage 52 release is subject to the same approval conditions as the release from CRS. There was no release from Stage 52 during the 2024/25 wet season.

7.3.7 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. It is noted that the APRA risk tool is being used to determine whether CoPCs are subject to the VAF. Residual risk ratings shown in the bow-ties have applied the Rio Tinto risk lookup tables as described in Chapter 12.

Figure 7-9 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

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- 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.

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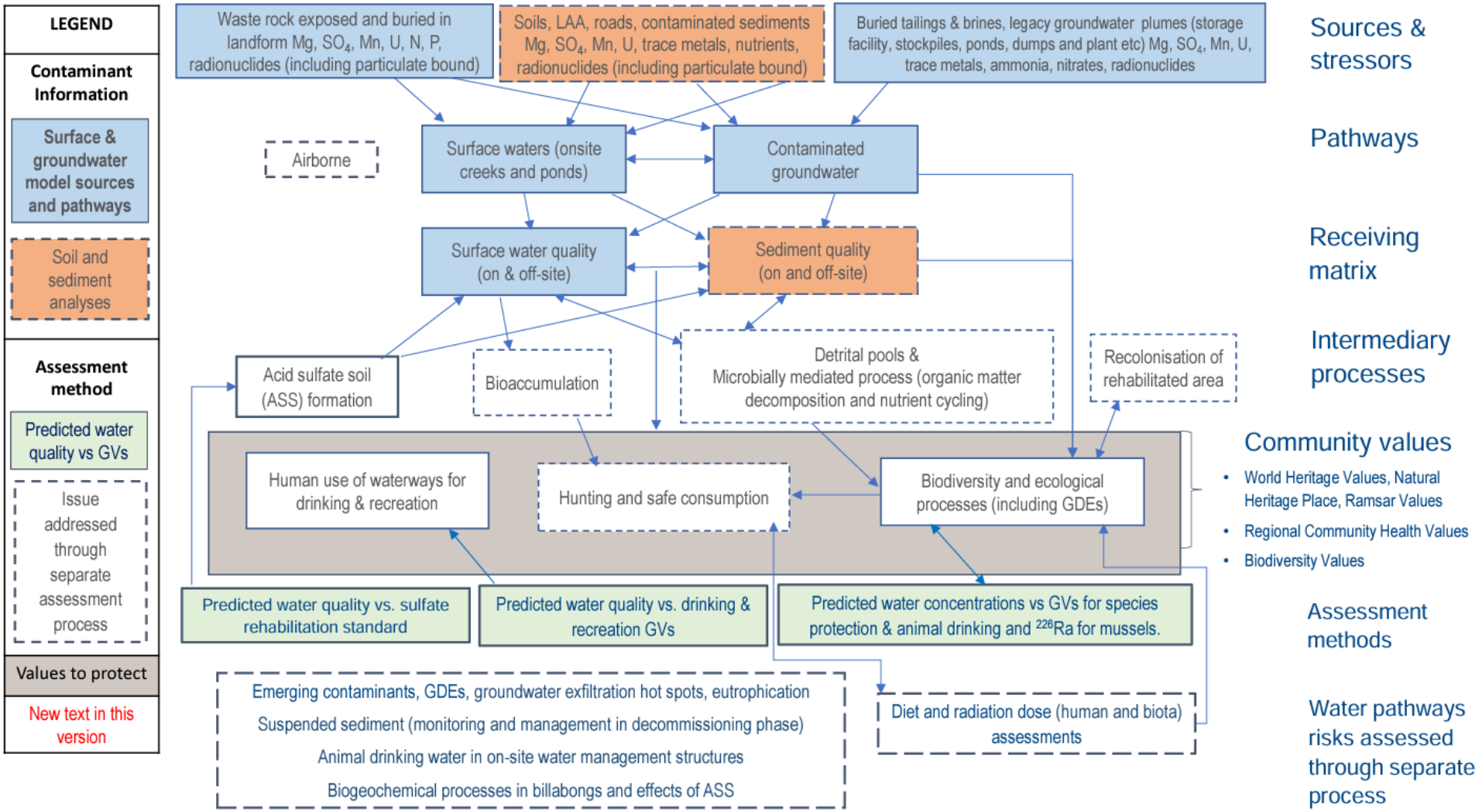

Figure 7-9: Conceptual model underpinning the APRA (BMT, 2023a)

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Table 7-8: Risk rating matrix

Likelihood	Consequence Severity				
	Very Low	Low	Moderate	High	Very High
Almost Certain	Class II	Class III	Class III	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)

Predicted manganese in water Vs GV: 73, 153, 240, 443 µg/L for 99, 95, 90 and 80% SPL[1]							
	Exposure Likelihood		Consequence to species				
Exceedance probability predicted by RSWM	Off-site	On-site	Very Low	Low	Medium	High	Very High
	≤1%	≤1%	No GV exceedance	1% exceedance any GV	NA	NA	NA
	-	>1–10%		74–153	154–240	241–443	>443
	>1–10%	>10–25%	Mn conc 0–73	NA	74–153	154–240	>240
	>10–25%	>25–50%			NA	74–153	>153
	>25%	>50%				NA	>73

[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.

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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. 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. OSS has undertaken ecotoxicity studies to derive a site-specific guideline value for aluminium and work is progressing to determine an agreed guideline value.

Table 7-11 shows the colour coded comparison of manganese concentrations to the guideline values at each of the surface water sites. The table shows exceedance probabilities modelled by the RSWM 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. Appendix 7.1 includes a full list of predicted concentrations of CoPC in Magela Creek at MG009, which is used as a proxy for impacts at the RPA boundary. As discussed in Section 7.3.3, Section 7.3.4 and Section 7.3.5, further work is being undertaken to improve modelling processes for predicting impacts on surface water systems through improved understanding of groundwater-surface water interactions. Updated predictions of CoPCs at key locations within the RPA and at the RPA boundary will be provided as part of the Final Landform application, and these will include consideration of all proposed management and mitigation measures incorporated as part of the final landform design.

A review of the role and application of the APRA moving forward will be investigated due to the different modelling outputs that will be generated by the SWSTM.

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Table 7-11: Comparison of manganese concentrations against consequence categories provided 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

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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.
Composite = 2023 Pit 3 UA combined with 2020 UA for other spatial areas (sub-catchments).

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7.3.8 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 (see Figure 7-10) 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 manganese concentrations for the Pit 3 application for the P50 composite source scenarios described above were input into the manganese VAF. The predicted peak manganese 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 80% SPL was met 99% of the time (1% exceedance). Manganese concentrations were predicted to exceed the 99% site-specific GV of 73 µg/L manganese 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.

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In June 2024, sampling was conducted during the late wet season across billabongs and artificial waterbodies on the RPA, along with reference billabongs in Kakadu National Park (KNP). A range of indicators were assessed, including water and sediment quality, various aquatic organisms and physio-chemical parameters. The study focused on mine exposed waterbodies (i.e. Retention Pond 1 (RP1), Coonjimba (CJB), and Georgetown (GTB)), which were compared to KNP reference sites following WRM (2010) methodology.

These mine-exposed sites exhibited varying levels of mine water influence, which was evident in both environmental and biological measures. RP1 and CJB showed the greatest divergence from reference conditions, while Gulungul Billabong aligned closely with reference sites and GTB showed moderate impact. Despite these variations, all mine-exposed sites supported diverse and abundant aquatic communities, comparable to or exceeding those in reference areas. Differences in community composition were largely due to shifts in the relative abundance of certain taxa, rather than changes in species presence; a pattern also observed during earlier WRM (2010) studies. Key aquatic species were found at all mine-exposed locations (BMT, 2025).

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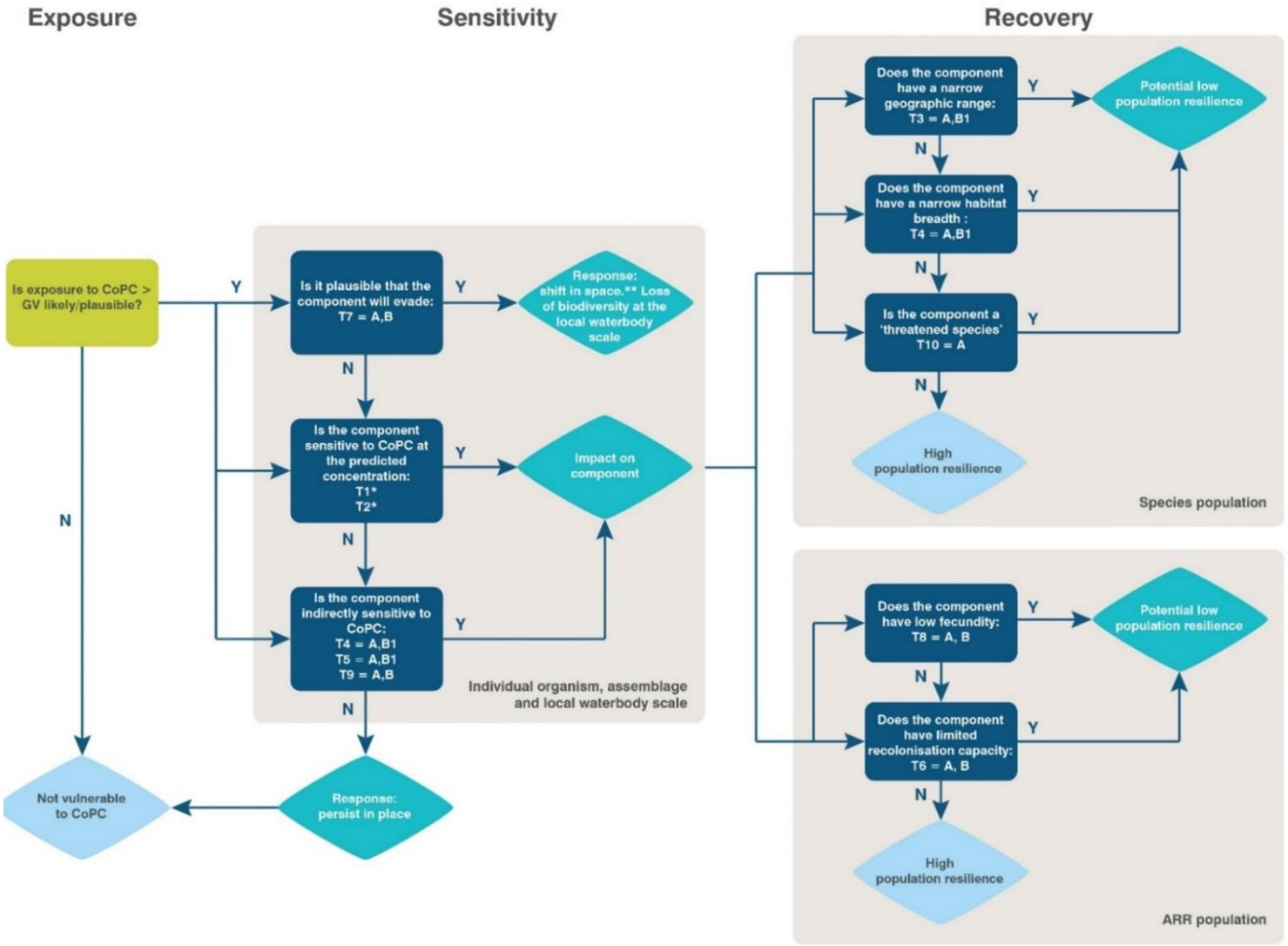

Figure 7-10: Decision tree for vulnerability assessment framework

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7.3.9 Eutrophication

Potential eutrophication risks associated with mine related sources of nutrients 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 blast residue from open cut mining operations was also a historical source of nitrates, however the majority of this source is considered to have already depleted and elevated levels of nitrate are no longer observed in waste rock sources and nitrate from this source 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, 2022/23 and 2023/24 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 Pit 1 and Pit 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.

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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)				All sources P50 load as % of max BG
	Pit 3 (P50)	All Sources (P50)	2021/22	2022/23	Variability		
Total P	7	14	1,627	3,482	1,855		1%
TAN (NH3-N)	3,190	3,390	1,108	2,024	916		167%
NOx-N	2	2	5,798	1,260	4,583		0%
Total N	3,192	3,392	14,981	40,900	25,919		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 (Photo 7-1). Further work is proposed by OSS to understand the potential effects of higher concentrations of N associated with mine influenced groundwater inflows during the recession period.

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Photo 7-1: Filamentous algae in Magela Creek – Western channel upstream from MG003 (9 May 2023)

7.3.10 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). Seepage and runoff from the enclosed landform 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. There is an early wet season acidification signature in Coonjimba Billabong monitoring data with the magnitude and duration of events varying from year to year. The ASS signature is seen in lower pH and dissolved oxygen levels and increased temporary concentrations of some metals including manganese and uranium.

Monitoring undertaken by the OSS during the start to the 1977/78 wet season (Hart and McGregor, 1982) observed a similar potential acidification event in billabongs prior to mining commencing at Ranger. As the wet season progresses, this signature disappears, and water quality and other biological indicators return to acceptable levels. 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 more severe acidification events 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 earlier and faster and severe effects of acidification are not observed.

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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 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.
- Thomas B, Fitzpatrick R, and Mosley LM (2024): site investigation including collection and analysis of water and sediment samples of targeted sites within the Magela Creek area.

The 2020 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 7-11). 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 7-11) and monitoring of sediments in the 2020/21 sampling program indicate Indium Billabong may have ASS present.

An investigation of targeted sites in the Magela Creek area was undertaken in October 2023 (late in the dry, prior to the wet season) to verify findings of previous acid sulfate soil investigations, gain an understanding of site conditions, and support planning of further works (Thomas *et al.,* 2024). This work indicated the potential presence of ASS material at a MCUS sampling point upstream of Ranger where the mine's potential for influencing ASS generation is absent. Additional sampling was conducted during the 2024 dry season to collect additional data, and to inform the development of conceptual models and hazard maps.

Updated conceptualisation will include areas not covered by the 2020 site wide model, including Georgetown Billabong, Magela Creek sediments, and the Coonjimba-Magela confluence. Results from investigations would then be used to inform the development of acid sulfate soil management plans.

FIGURE 7-11

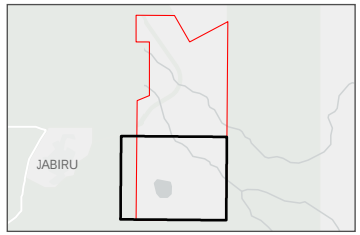
Summary of Preliminary Site Wide ASS Conceptual Model – Potential Source Areas (ERM, 2020a)

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



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7.3.11 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). Manganese is the only 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 7.3.12.7 describes the further work being undertaken to investigate the conservatism in the model and the manganese concentrations.

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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

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7.3.12 Studies to be Completed

There are multiple studies occurring in the water and sediment theme, including groundwater modelling and plume management planning in the RWD/Coonjimba Catchment and Pit 3/Djalkmarra Catchment; waste rock characterisation and source term updates; refinement of the updated surface water solute transport model (SWSTM) for billabongs; additional surface water and groundwater field data collection, and ongoing work to improve understanding of the role of geochemical and biogeochemical reactive processes in the solute movement pathway. The studies discussed below are a subset of the studies that are progressing in the water and sediment theme.

7.3.12.1 Groundwater-Surface Water Interaction and Solute Transport Modelling

The Ranger Surface Water Model (RSWM) was 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. Additional work is planned 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.

The SWSTM is being developed to incorporate hydrodynamic processes and bio-geochemical phenomena to more accurately predict solute concentrations over time. Given the complexity of processes and uncertainties in the rehabilitation strategies and outcomes, a staged modelling approach is to be implemented. The focus of the modelling during the first stage will be on the hydrodynamics and mixing interaction between Coonjimba Billabong and Magela Creek. Subsequent stages will expand the spatial context (i.e. Gulungul, Corridor and Georgetown catchments).

Data from Gulungul Creek will be used to improve conceptualisation of the groundwater-surface water interaction in this catchment. The overall groundwater-surface water conceptualisation will be reviewed and/or updated having regard to improved understanding of groundwater exfiltration, including model flux from the toe of the landform.

7.3.12.2 Field testing and data collection program

A number of field testing and data collection programs are planned to contribute to groundwater modelling maturity.

Additional groundwater bores are planned to be installed, including ten bores north of the RWD and three bores at the Western Stockpile. The purpose of these bores is to collect data to better define the source terms for plumes associated with the Western Stockpile, RWD and improve characterisation of the plume present north of the RWD. These bores are expected to reduce uncertainty in predicted CoPC concentrations in model outputs.

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Pending completion of design, up to six groundwater bores will also be installed within waste rock locations across the site, and will be used to measure temperature, carbon dioxide and oxygen levels at various depths within the vadose zone.

Hydraulic testing of bores in Pit 1 will be undertaken to improve understanding of hydrogeological properties of backfilled material in Pit 1 and waste rock generally. This data is expected to further reduce uncertainty in groundwater modelling.

A trench/seepage interception system is also planned to be installed on the edge of the Trial Landform to provide additional data informing vadose zone waste rock source terms. Civil construction of the trench has been completed and the installation of instrumentation and the pump system is in progress.

7.3.12.3 Best Practicable Technology

The Ranger Rehabilitation Project Team 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.

Initial stages of the BPT for the RWD deconstruction and Coonjimba catchment rehabilitation have been undertaken with a range of options being analysed for further consideration in subsequent BPT assessment processes. The findings of these BPTs, and preferred remediation options to reduce CoPCs to derive/define ALARA, will be incorporated into the final design for the Ranger closure project.

7.3.12.4 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.

The results of the 2024 aquatic ecosystem sampling program (BMT 2025), along with historical data (BMT 2023b), support the development of water quality sensitivity grades for future aquatic ecosystem assessments under the VAF framework.

The Ranger Rehabilitation Project Team are also investigating the need and practicality of assessing microbial activity in relevant creeks/detrital pools as part of the APRA and VAF.

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7.3.12.5 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.

The Ranger Rehabilitation Project Team will continue monitoring nitrate, ammonia and Total N and Total P concentrations at MCUS and MG009 over the coming wet season (2025/26) with this monitoring likely to continue to subsequent wet seasons. This ongoing 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 and will be used to calibrate the SWSTM.

As noted above, further work on the SWSTM will occur and this refined understanding will continue to inform understanding of the spatial and temporal nature of predicted changes in concentrations 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.

Results from continued monitoring and site-specific studies undertaken by OSS will be used to improve conceptual models regarding nitrogen cycling processes and understanding of bioavailable nitrogen loads likely to enter Magela Creek during recession periods.

7.3.12.6 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 significant 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. The analysis of samples collected in 2024 continues to be undertaken.

Opportunities to further reduce sulfate loads will be investigated as part of the Final Landform application. Potential mitigation options being considered for reducing manganese loads in the above-mentioned BPTs will also be beneficial for reducing sulfate loads.

Further assessment of ASS risks 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. Where possible, these future investigations will draw upon the existing longitudinal groundwater, surface water and sediment monitoring and studies undertaken by the Ranger Rehabilitation Project Team and OSS.

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7.3.12.7 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 groundwater-surface water interaction and development of the SWSTM.
- Investigation, optioneering and BPT evaluation to define required remediation and identify preferred option/s for plume management from Pit 3.
- Finalised BPT evaluation to define required remediation and identify preferred option/s from plume management from the RWD and 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.
- 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 7-12, Figure 7-13 and Figure 7-14. The bow-ties have been developed based on consideration of groundwater and surface water catchments, and the final landform.

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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 the 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.

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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 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

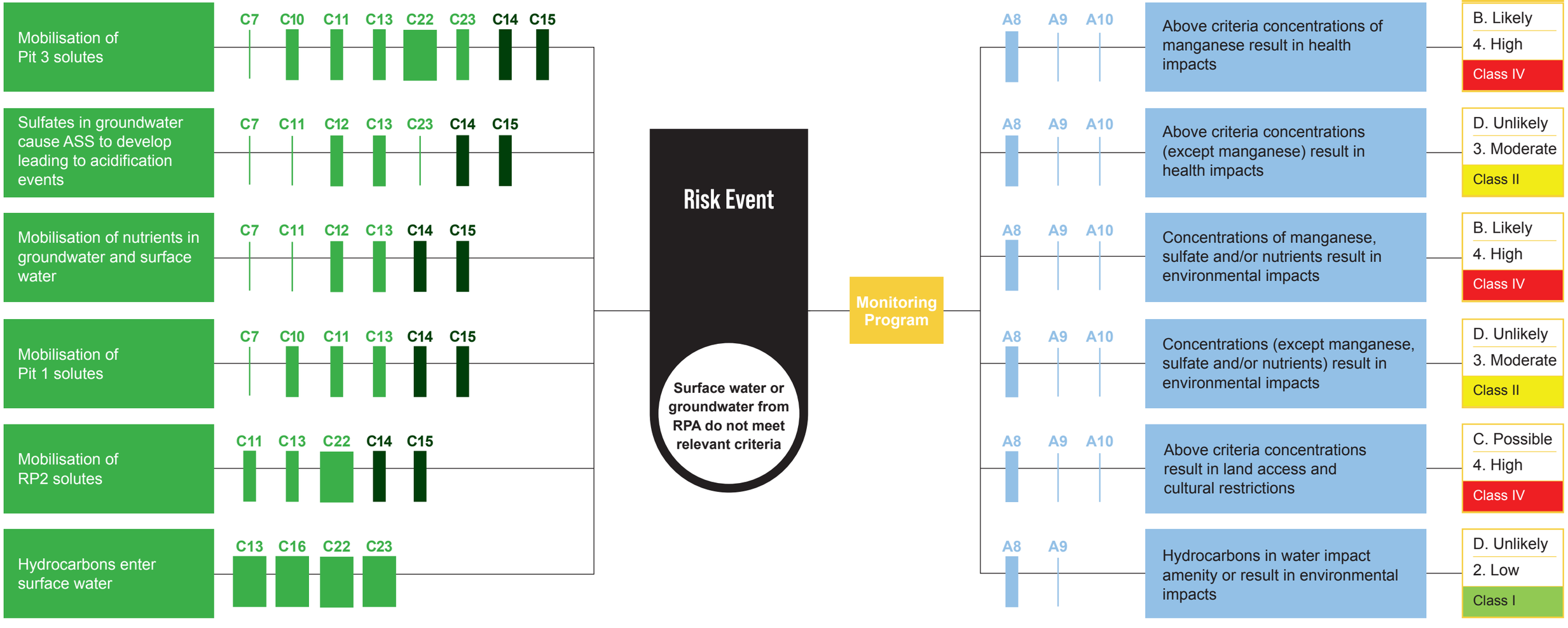

Figure 7-12 Bow-tie diagram for Djalkmarra and Corridor Creek catchments (WS1)

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 Undertake earthworks to repair significant substrate limitations, 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

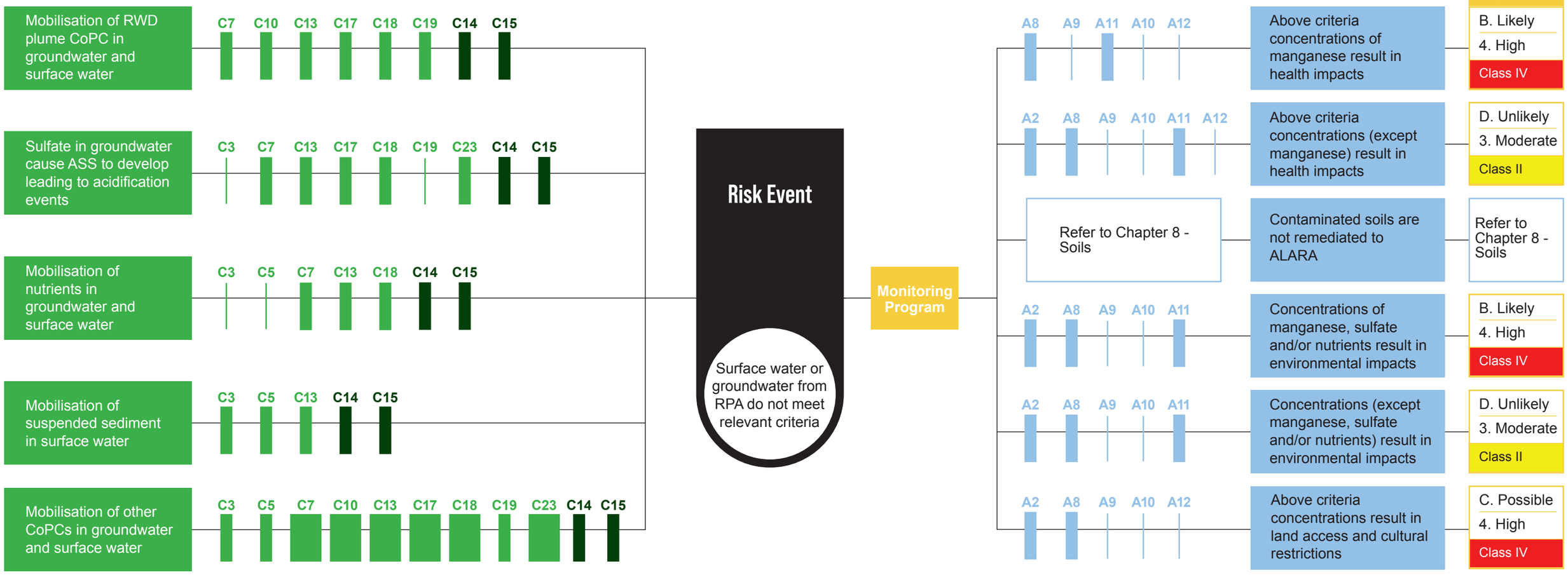

Figure 7-13: Bow-tie diagram for Coonjimba and Gulungul catchments (WS2)

Preventative Controls

C1 Final landform design, construction and verification
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 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 Undertake earthworks to repair significant substrate limitations, 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

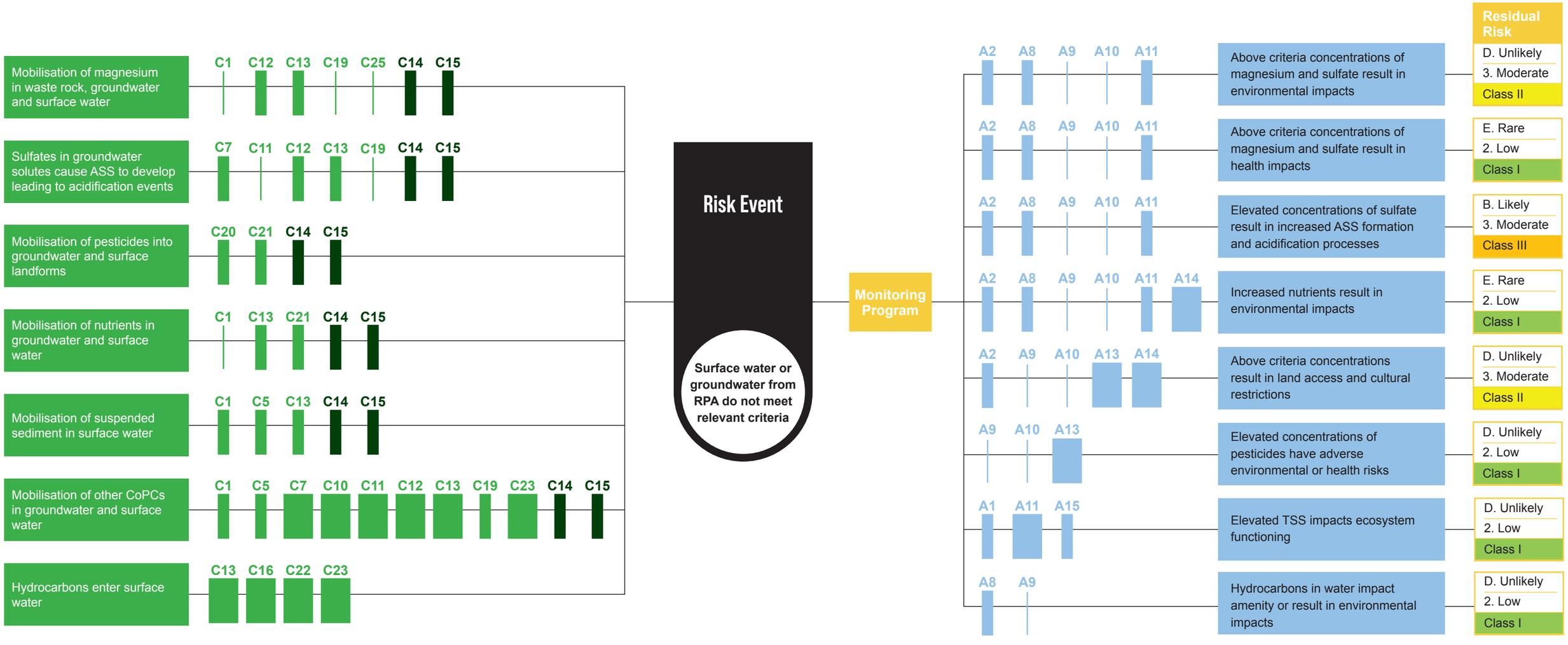

Figure 7-14: Bow-tie diagram for Final Landform and Land Application Areas (WS3)

7.5 Preventative Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well the Ranger Rehabilitation Project Team 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.

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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 Pit 1 and Pit 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 Pit 1 and Pit 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.

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All Tailings Deposited into Pit 1 and Pit 3

The effectiveness of emplacement of tailings within Pit 1 and Pit 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 given the relatively high annual loads predicted. Given the large natural variability in total N levels within Magela Creek relative to predicted incremental loads on ammonia from mine sources, this rating is considered to be conservative and increased understanding of this hazard is likely to result in the control effectiveness rating being improved and the risk profile being reduced.

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 Pit 1 and Pit 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 Pit 1 and Pit 3

Low grade ore material that was not processed will be (and has been) disposed of in Pit 1 and Pit 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 Pit 1 and Pit 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 Pit 1 and Pit 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.

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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 Pit 1 and Pit 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 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 available spaces of 29 Mm^3 and 2.5 Mm^3, respectively (refer Chapter 4).

Where concentrations and/or loads of CoPC within this material are predicted to present an increased environmental 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.

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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. The Ranger Rehabilitation Project Team 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. Ongoing work to improve the confidence in source terms is being undertaken including the collection of new data from a drilling program and inclusion of additional water quality data.

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 Pit 1 and Pit 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 areas appropriately bunded	Strong	'Strong' due to it being an engineered control and accepted industry practice.

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Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
C22	Containment cell 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 Pit 1 and Pit 3

Decant wells and monitoring bores installed in Pit 1 and Pit 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 Pit 1 and Pit 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 Pit 1 and Pit 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.

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Containment cell 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, construction and verification	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 detrimentally affect 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 Water, Erosion and Sediment Control Plan (see Section 6.5.3). This preventative control has been rated as 'marginal' to 'satisfactory'.

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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.

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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, construction and verification	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 Pit 1 and Pit 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'.

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Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
C21	Fertiliser use 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 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.

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Groundwater and surface water

The Ranger Rehabilitation Project Team 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 report but rather provide a summary of additional monitoring that will be undertaken during the closure phase. Table 7-20 describes this monitoring.

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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 of Pit 3)	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 of Pit 3 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.

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7.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subjective 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 substrate limitations, gullying or eroded areas	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.

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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 basins 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 Pit 1 and Pit 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.

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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.

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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 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.

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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.

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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.

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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 7.3.12 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.
- The Ranger Rehabilitation Project Team commits to progressing the 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 Final Landform 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.

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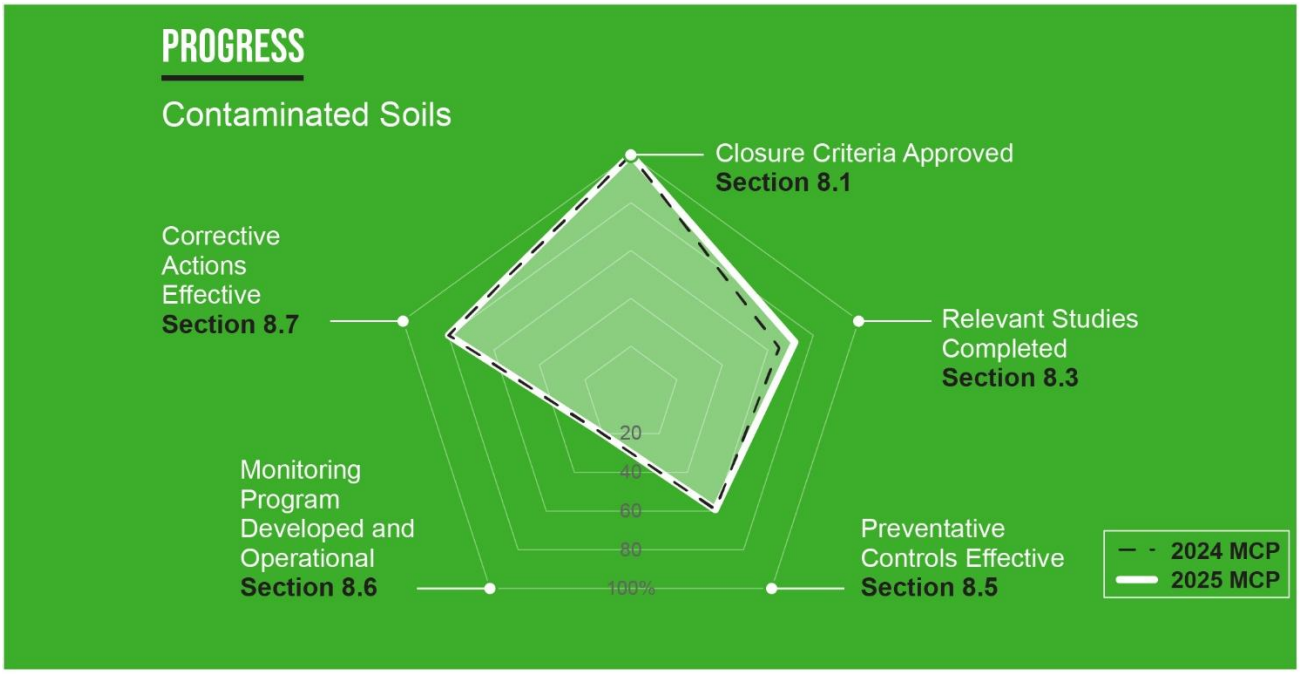
8 SOILS

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-six 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. ERA commenced further sampling of contaminated sites in 2024 as part of Phase 2 of the planned studies. The development of Remediation Action Plans and the execution of remediation activities (Phase 3) are planned future work (70%, Section 8.3).
- Preventative controls to manage soil contamination have been described and will be further developed during Phase 2 and Phase 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).
- The corrective actions to treat contaminated soils, should they be detected during the validation sampling, are well understood and common practice (80%, Section 8.7).



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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 6).

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 two corresponding closure criteria have been derived from the ER related to the soils theme. The closure criteria received Ministerial approval on 30 September 2021 and no changes are proposed in this MCP.

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 Rehabilitation 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 contaminated material is to maximise use of Pit 3 as the primary disposal location, where:
    - Approximately 455,000 m^3 of demolished and/or contaminated material is proposed to be disposed to Pit 3. The total space available within the Pit 3 footprint, to the final landform surface is approximately 29 M m^3.

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- Approximately 117,400 m^3 of demolished and/or contaminated material is proposed to be disposed to RP2. The total space available within the RP2 footprint, to the final landform surface is approximately 2.5 M m^3.

- The bulk of this material is contaminated soils, representing a conservative estimate of approximately 405,000 m^3 (or 89%) and 35,000 m^3 (or 30%) of the demolished and/or contaminated material to be disposed to Pit 3 and RP2 respectively. The bulk of contaminated soils is expected to come from beneath the processing plant, with smaller volumes to come from constructed water bodies including wetland filters and retention ponds (volumes to be determined).

8.3 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'. 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.

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- 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.
- Stantec (2024): to characterise the current contamination status and assess if AoPCs can likely be closed-out at the Djalkmarra Release Point and Indium Billabong, 35 soil samples were collected and analysed for CoPCs.

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- A detailed site investigation undertaken in late 2024 of 42 AoPC within the processing plant area, including soil and groundwater sampling, to identify areas of potential contamination.

The following sections of this chapter draw from the studies listed above, which summarise the current status of contaminated soils on the RPA.

8.3.1.1 Phase 1 – Preliminary Site Investigation

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 (B), 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.
Pit 1 and Pit 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, B, 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 • Counter Current Decantation 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, B, 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.

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Source	Potential Contaminant
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, B, 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, B, 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).
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, B, 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, B, 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 – unlikely to require ex-situ remediation;
- Orange – sampling required in these areas to inform risk;
- Red – remediation to be considered; and
- Blue – active closure areas not subject to the contaminated soils assessment.

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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 Phase 1 screening exercise are listed in Table 8-4 and Table 8-5. Phase 2 investigations have commenced and are discussed in Section 8.3.1.2.

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 are described in Chapter 7 because this material is a potential source term to be considered in the groundwater and ultimately surface water modelling.

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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:Gagadju 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:Jabiru Airport Aviation Emergency Response Area
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)

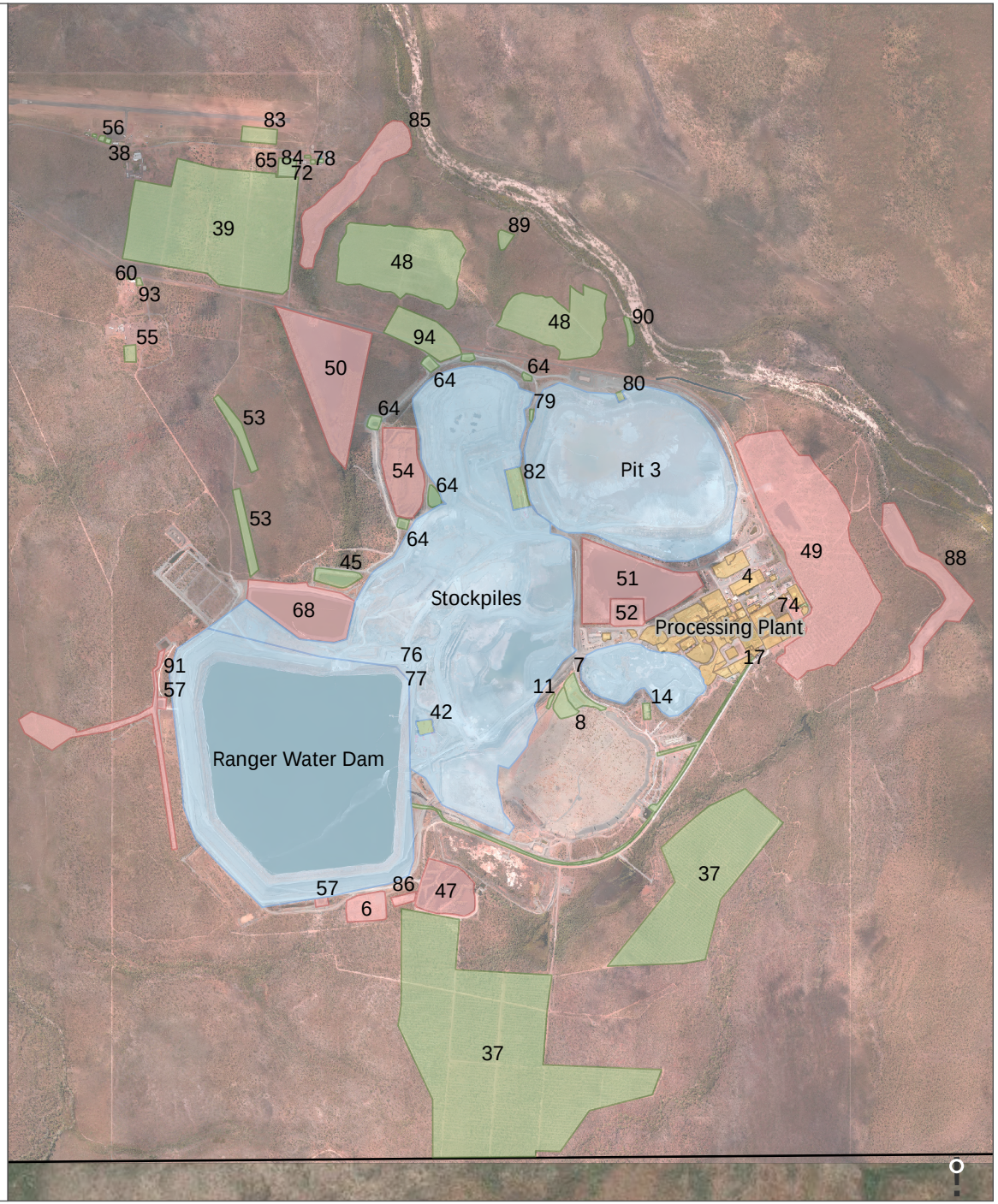

FIGURE 8-1

Areas of Potential Concern for Contaminated Soils on the RPA

LEGEND

- Ranger Project Area
- Unlikely to required ex-situ remediation
- Sampling required in these areas to inform risk
- Remediation to be considered
- Active closure areas not subject to contaminated soils assessment

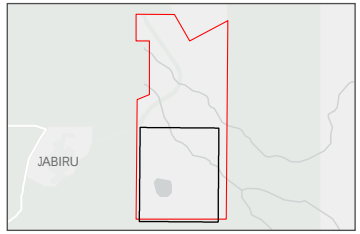

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Table 8-4: Soil assessment screening criteria (focus values) – heavy metals

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

* Ecological soil assessment screening criteria are based on conservative added contaminant limits.

^ Concentrations are shown as total elemental concentrations

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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	-	-	-	-	-

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8.3.1.2 Phase 2 – Detailed Site Investigation

The Phase 2 Detailed Site Investigation (DSI) was initiated in 2024, with further sampling undertaken to identify the nature and extent of contamination within and around the processing plant area (the areas shown as orange on Figure 8-1).

In June 2024, Stantec prepared a Sampling Analysis and Quality Plan (SAQP) to support works in the processing plant area. The sampling focused on high-risk or high-opportunity areas around existing infrastructure that is yet to be demolished. The scope of the 2024 soil sampling program was to:

- sample the AoPC accessible within the processing plant area (Figure 8-2 shows the AoPC targeted in the sampling plan and Figure 8-3 shows the soil bore locations);
- sample to a maximum depth of 5 metres below ground level (m BGL);
- analyse samples for CoPCs defined in the SAQP; and
- interpret results against the relevant soil assessment criteria.

The collection of soil data will be used to:

- assess the vertical and lateral extent of potential contamination;
- investigate the nature of contamination at or near potential sources or migration pathways;
- assist in the development of the groundwater Conceptual Site Model (CSM) with regards to source terms.

Preliminary results of the 2024 program are subject to independent audit and may be updated as further validation is undertaken.

Groundwater sampling was also undertaken to collect seasonal groundwater data and assess the nature and extent of groundwater contamination beneath the processing plant. This included sampling to evaluate potential leaching from soil to the shallow aquifer. The program included sampling 42 existing groundwater wells in and around the process plant area. These existing wells are subject to regular monitoring to inform understanding of the nature and extent of potential leaching. To enhance groundwater coverage, an additional nine groundwater monitoring wells were installed and sampled in December 2024. The results will be used to update the broader conceptual site model to finalised remediation action planning.

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AOPC AREAS

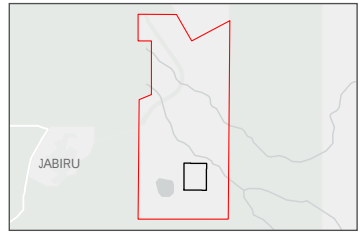
3. Bulk Fuel Area - Diesel Storage & Pump Facility
4. Supply Waste Oil Tanks
7. Current Domestic Landfill
8. Current Industrial Landfill at Pit 1
9. Maintenance Workshop
10. Vehicle Refueling Station
11. Bioremediation Pad
12. Mine Maintenance Workshop
13. Mine Washdown Bay
16. Ammonia Handling
18. Emergency Dump Tank
19. Emergency Response Training Facility / Gatehouse
20. Fine Crushing
21. Grinding & Pyrolusite
22. Hydrogen Peroxide Tanks
23. Laterite Plant
24. Leaching CCD's Clarification
25. Lime Mill
26. Neutralisation
27. Pond Water Holding Tanks
28. Precip Drying & Packing
29. Primary Crushing
30. Product Warehouse
31. Sand Blasting Yard
33. Solvent Extraction
35. Powerstation
36. Old Sewage Trenches
40. Demineralisation Plant
41. Radiometric Sorter
43. Water Treatment Plants
61. 61-Old Core Yard
63. Plant Services
66. Brine Concentrator
67. New Sewage Trenches
69. 69-R3D Exploration Facilities
73. Leach Tank Failure
74. Shellsol Underground and above ground tanks
75. Turbo Burning Yard
81. Brine Squeezer
87. Neutral Thickener
92. Fire Training Area

FIGURE 8-2

Study area for sampling of Areas of Potential Concern (AoPC) within the processing area

LEGEND

- Sampling required in these areas to inform remediation
- Processing Plant Study Area



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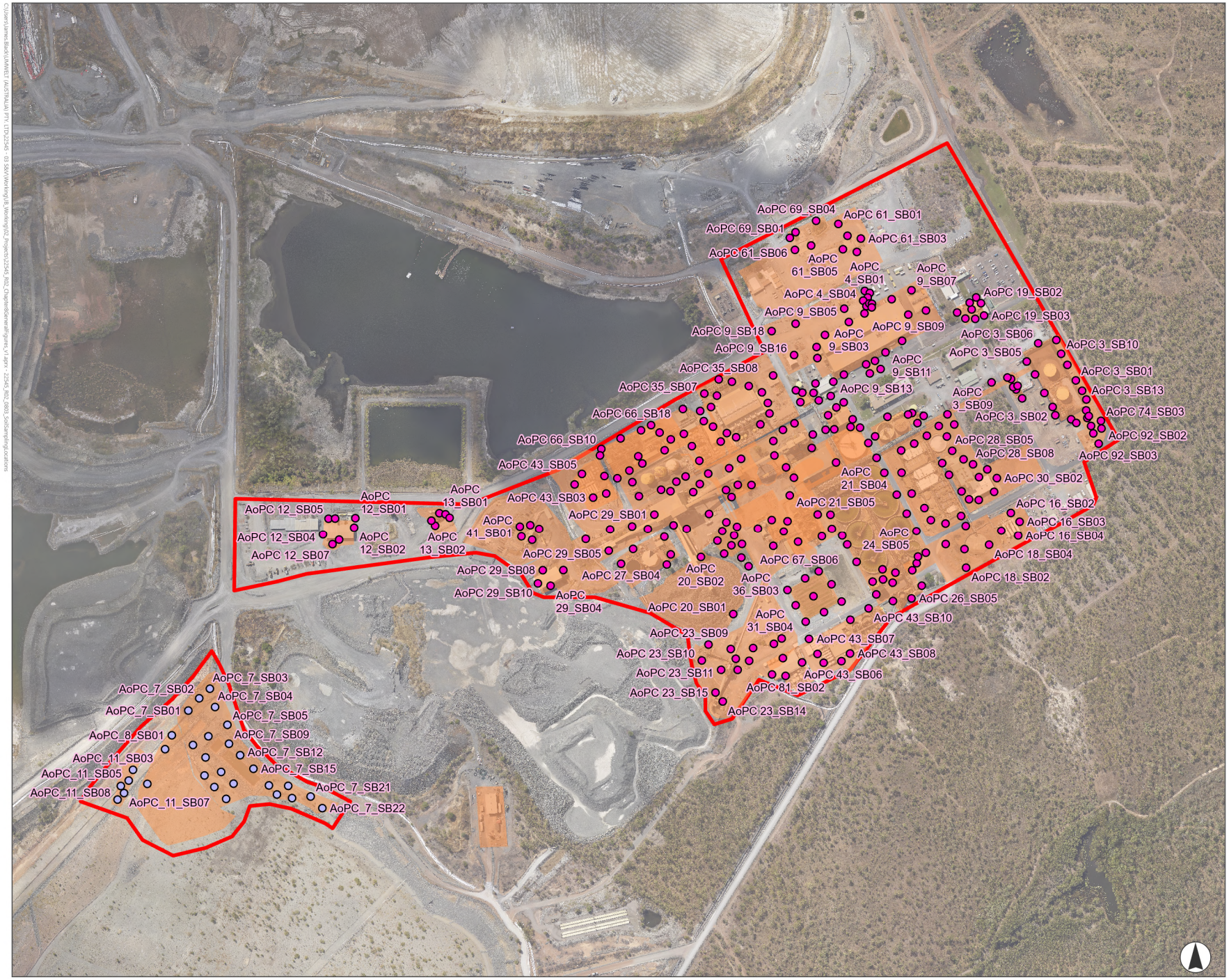
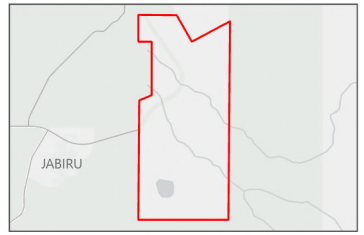


FIGURE 8.3

Soil and groundwater bore sampling locations

LEGEND

- Bore Locations
- Soil Sampling Locations
- Areas of Potential Concern
- Processing Plant Study Area



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The results of this initial stage of the DSI have been included in the Phase 1 Demolition approval application and indicate that the majority of the soils beneath the processing plant area do not require excavation to the full 1.5 m depth initially forecast. However, some areas may require deeper excavation, with possible depths extending up to 3.5 m. With the current level of information, the total volume of contaminated soils that may be disposed into Pit 3 (i.e. 405,000 m^3) remains unchanged from the *Pit 3 Capping, Waste Disposal and Bulk Material Movement* application (ERA, 2023a), taking a conservative approach to estimation of volumes for disposal pending finalisation of remediation action planning.

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 has commenced, with sampling being undertaken in AoPC in the process plant area (see Section 8.3.1.2). Future Phase 2 works will:

- conduct further soil/sediment sampling as required to address any residual data gaps (e.g. within on-lease waterbodies, airport);
- build upon the spatial and temporal dataset to inform the source terms for the Conceptual Site Model (CSM);
- engage stakeholders to develop and agree on the risk assessment and response approach for relevant CoPCs; and
- inform remediation and execution planning.

Phase 3 will then include the development of targeted Remediation Action Plans (specific to contaminated soils) where required across areas of the RPA, and on-ground execution of the remediation works set out in the Remediation Action Plans. Planning for appropriate validation sampling will be included as required in Phase 3.

A Contaminated Material Disposal Plan will be prepared as required by Condition 4 of the Pit 3 Capping, Waste Disposal and Bulk Material Movement Backfill approval. As per the condition of approval, the Plan will be submitted and approved before the commencement of bulk backfill works or the disposal of contaminated material into Retention Pond 2.

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 8-4. 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.

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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 affecting downstream receiving environments (see Chapter 7 for details);
- soil contaminants are transported into groundwater and/or surface water affecting 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).

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Preventative Controls

C22 Containment cell 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

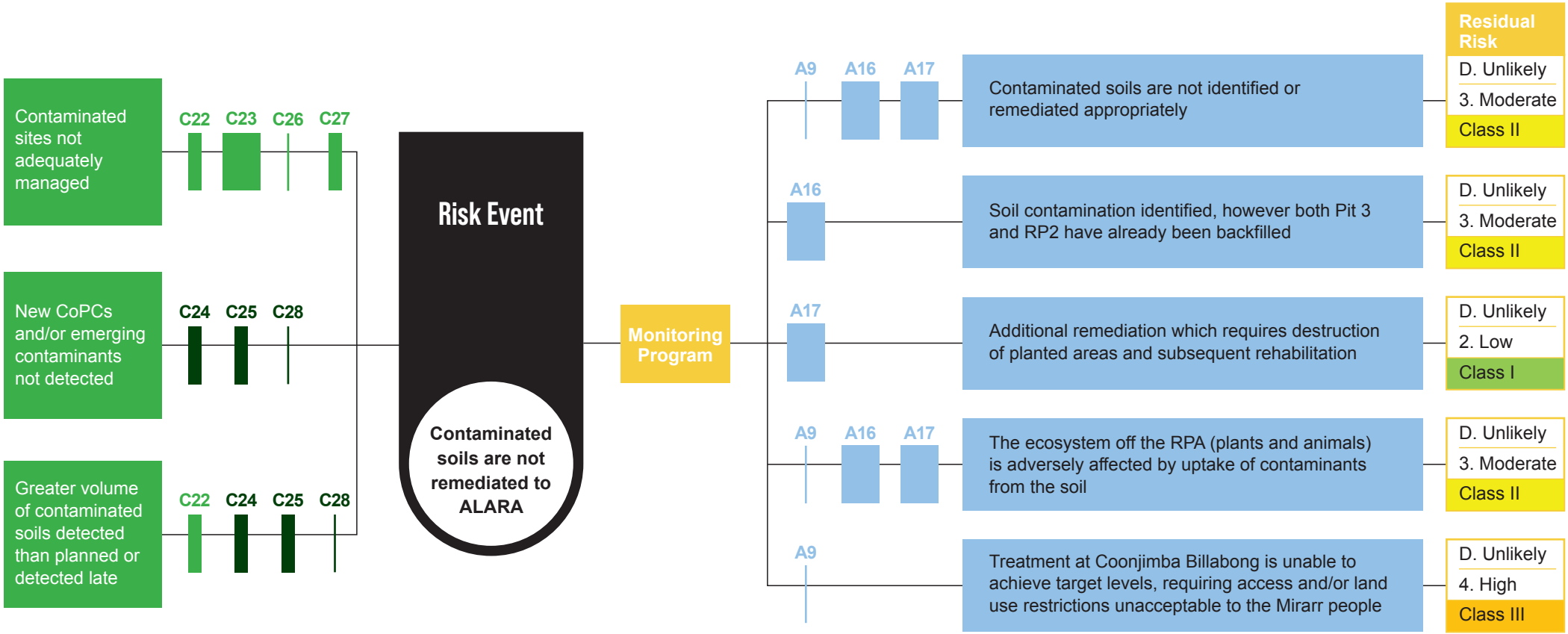

Figure 8-4: Bow-tie diagram for contaminated soils (S1)

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 8-4 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. For the remainder of the AoPC (orange and red areas on Figure 8-1) remediation may be required. Remediation Action 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 for PFAS	Satisfactory	Currently 'Satisfactory' because considerable data is available, well established and proven method, but uncertainty remains until Phase 2 and Phase 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.

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8.5.1 Containment Cell for PFAS

PFAS (polyfluoralkyl substances) are used in a large range of products. Most relevant to Ranger, they are used in firefighting foams and are therefore present throughout the operational site and airport. 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 materials with identified exceedances of PFAS would be excavated and placed within a containment cell (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 likely to be the preferred approach in view of the available storage area and 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 is expected to require containment. Containment cells are a standard and proven practice in waste management. The PFAS containment cell would generally consist of:

- a compacted floor;
- 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.

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If the cell was to be located within RP2, the total space available within the RP2 footprint to the final landform level is approximately 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

A conservative estimate of approximately 405,000 m^3 and 35,000 m^3 of contaminated soils are expected to 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 the screening values. The Phase 2 sampling program will confirm the areas and volumes for disposal (see Section 8.3.1.2). The disposal into Pit 3 would occur concurrent to the bulk backfill activities and burial of the demolition waste.

As mentioned above, the total space available within the Pit 3 footprint, to the final landform surface is approximately 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 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 the Ranger Rehabilitation Project Team 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 will be considered and this would be informed by engagement with 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 may 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 or otherwise 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).

This preventative control has been rated as 'satisfactory' in Table 8-6. It is a common and proven practice. It is noted that the remediation for the Magela LAA is yet to be finalised and therefore tilling of this area is yet to be confirmed.

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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 the risk assessment and response approach for emerging contaminants will be considered and discussed with key stakeholders.

The monitoring program for contaminated soils will be determined to evaluate the effectiveness of the remediation activities. The Remediation Action Plans will document the risk assessment and any validation requirements 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 targets; and
- records, documentation and reporting.

Once remediation activities have been completed, it is anticipated that validation sampling will be required to confirm effectiveness in some areas. The Remediation Action Plans will identify where validation sampling may be required. 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.

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The following corrective actions would be undertaken if and when required:

- 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 that require disposal 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 assessment processes establish that remediation goals and objectives have not been achieved, and that other remediation actions are not likely to achieve remediation goals and objectives, the material will be excavated and disposed into Pit 3 or RP2 (depending on the timing of the assessment).
- Further engagement with key stakeholders (GAC, NLC, OSS, DLPE) will occur to determine an appropriate path forward for Coonjimba Billabong. This would consider expectations for use of the billabong against risks and likelihood of success of various remediation approaches that may include 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 8-8 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 Phase 3 works are undertaken.

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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.

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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 has commenced: this phase will build upon and address data gaps identified in the Phase 1 study. Specific to contaminated soils, it will:
    - conduct further soil / sediment sampling (e.g. within on-lease waterbodies, the airport);
    - build upon the spatial and temporal dataset to inform the sources terms for the Conceptual Site Model;
    - engage stakeholders to develop and agree on the risk assessment approach for relevant AoPC and remediation plans; and
    - inform remediation and execution planning.
- Phase 3 of the soil contamination studies: this phase includes the development of targeted Remediation Action Plans (specific to contaminated soils) where required across areas of the RPA, and the on-ground execution of the remediation works set out in the Remediation Action Plans. Planning for appropriate validation sampling will be included as required in Phase 3.
- Preparation of a Contaminated Material Disposal Plan prior to commencement of bulk backfill works.
- 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.

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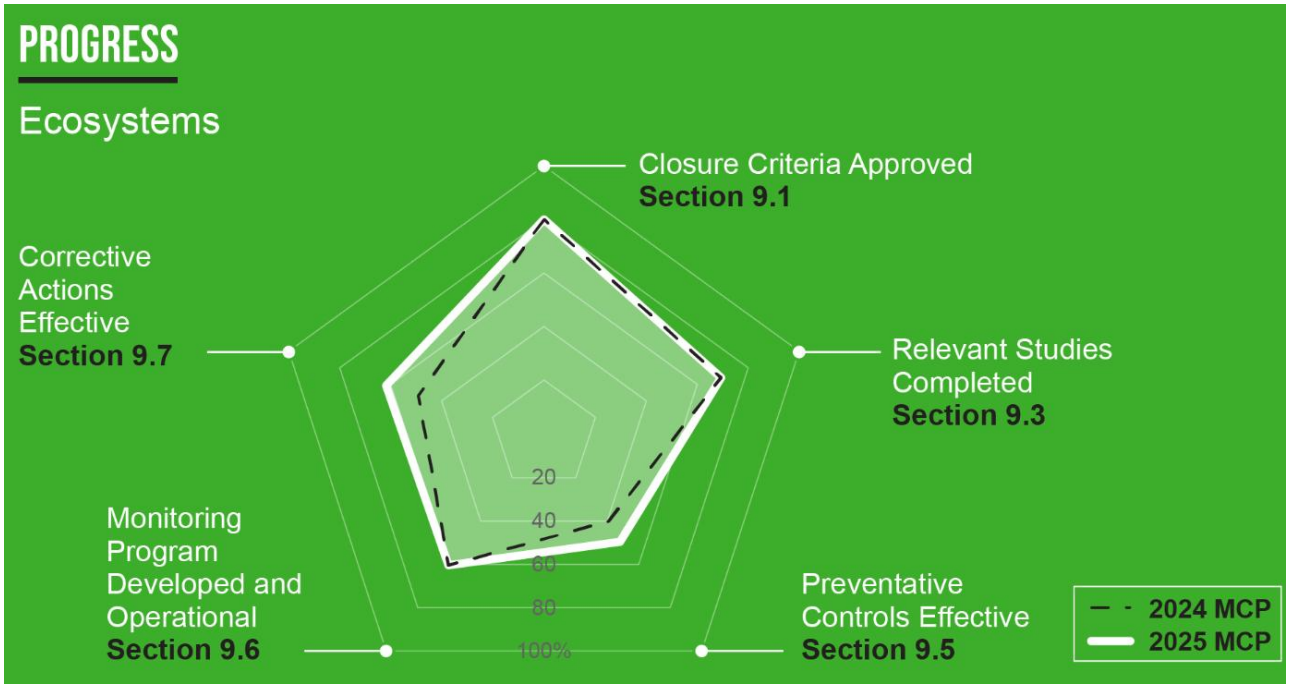
9 ECOSYSTEMS

The theme of 'ecosystems' in this MCP refers to the establishment and maintenance of vegetation, habitat and faunal communities on both 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 have been agreed, however further work is occurring to refine quantitative indicators. For similarity criteria and the 'reference ecosystem(s)', quantitative trigger values are likely to be captured for a range of time periods in state and transition (S&T) models and associated Trigger, Action, Response Plans (TARPs). Currently, criteria are being reviewed in consultation with stakeholders. As an outcome, it is expected that minor revisions will require further Ministerial approval through future iterations of the MCP (80%, Section 9.1).
- Decades of relevant studies and ongoing ecosystem rehabilitation trials have provided a substantial knowledge base for Ranger. Areas planned for further work include consolidation and analysis of monitoring data consideration of requirements for further development of reference ecosystems and associated ecosystem establishment strategies, and best practice adaptive management for emerging risks to ecosystem development (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. Controls for landform construction, frameworks for weed management on rehabilitation areas and construction of habitat have been further developed since the 2024 MCP. However, uncertainties remain around some key areas and further studies are underway (50%, 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 requires formalisation, and will be further refined and expanded (60%, Section 9.6).
- Corrective actions for ecosystems are relatively well understood and small-scale trials to correct a weed-dominated state, and invertebrate pest impacts at the Trial Landform (TLF) have demonstrated effectiveness. Outcomes will be documented and used to inform future implementation at scale for a constructed waste rock landform. Further work is planned (60%, Section 9.7).



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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 *2.1 Subject to subclauses 2.2 and 2.3, the company must rehabilitate the Ranger Rehabilitation 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.*	2.1
2.2 The major objectives of rehabilitation are: *(a) revegetation of the disturbed sites of the Ranger Rehabilitation 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)
10 Protection of Soil, Vegetation and Fauna *10.2 The company must ensure that the operations at Ranger will not result in any adverse impact on Kakadu National Park through the introduction of exotic fauna or flora.*	10.2

ERs 2.1 and 2.2(a) are 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. ER 10.2 is also relevant to the Ecosystem theme as it relates to potential impacts that may result from the introduction of exotic fauna or flora.

The development of similarity and sustainability closure criteria are the focus of KKNs ESR1B and ESR5A. Qualitative closure criteria relating to ecosystem similarity and sustainability were presented in the 2023 MCP and received Ministerial approval. These criteria were developed 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).

Currently, criteria are again being reviewed in consultation with stakeholders to clarify wording and shift focus from reference values (which are likely to change over the coming decades) to direct rehabilitation impact and management of risk.

As an outcome, it is expected that minor revisions will require further Ministerial approval through future iterations of the MCP.

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A series of workshops were held with stakeholders and subject matter experts through 2024 to develop quantitative metrics for many of these criteria. Further work will be undertaken to refine these metrics and the statistical method used to demonstrate achievement of closure criteria. With regard to ‘reference ecosystem(s)’, quantitative trigger values are likely to be captured for a range of time periods in state and transition (S&T) models, monitoring and associated TARPs (refer Section 9.8).

Appropriate S&T models and TARPs recognise 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 a Conceptual Reference Ecosystem (CRE) is appropriate for the dominant and broadscale savanna woodland community. It is also noted that the most appropriate reference ecosystems are likely to change over time, with consideration of reference sites, variations in substrate and topography, cultural values and species suitability. The current status of vegetation reference ecosystems is described in Section 9.3.1.

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Table 9-2: Ecosystems – Approved Closure Criteria

Attribute	Sub-attribute	Goal	Criteria
Ecosystem Similarity			
Species composition and relative abundance	Species composition of vegetation	The assemblage of overstorey species and understorey functional species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	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).
			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).
	Species richness of vegetation	Species richness of overstorey and understorey are similar to, or on a trajectory towards, that of the reference ecosystem(s).	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).
	Species abundance of vegetation	Abundance of overstorey and understorey species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	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).
Community structure	Structure	Vegetation structure similar to, or on a trajectory towards that of the reference ecosystem(s).	Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Vegetation strata	Overstorey and midstorey cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The distribution of percentage canopy cover is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
		Understorey vegetation cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).	Percentage cover of understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

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Attribute	Sub-attribute	Goal	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.

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Attribute	Sub-attribute	Goal	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 Rehabilitation 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 Rehabilitation 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 Rehabilitation Project Area are no greater than adjacent areas of Kakadu National Park.

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9.2 Design Elements

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 waste rock within the upper layer of the final landform, to a depth of at least 6 m (where not overlaying natural ground).
- Section 4.4.2 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.
- Section 4.1, Section 4.4.4.7 and Section 4.7.2 describe the construction of Pit 1, the Ranger Mine Village and TLF respectively, which have facilitated ecosystem rehabilitation research trials.
- Section 4.5 describes options for the RWD deconstruction, which could potentially have implications for the suitability of planned ecosystem rehabilitation.
- Section 4.4.3.6 describes the current plant nursery within which the management of local provenance seed, and propagation to tubestock occurs.

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 reference ecosystems (Section 9.3.1);
    - Fauna reference ecosystems (Section 9.3.2); and
    - Ecosystem establishment strategy (Section 9.3.3 and Appendix 9.1).
- 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:

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- Fauna reference ecosystems (Section 9.3.2, where related to key vegetation dispersing fauna);
- Ecosystem establishment strategy (Section 9.3.3);
- Weeds and other introduced flora and fauna (Section 9.3.4);
- Sustainability processes (including resilience to disturbance) and recruitment (Section 9.3.5);
- Fire resilience (Section 9.3.6);

Figure 9-1 shows the locations of current ecosystem development trials, many of which are discussed directly in the following sections.

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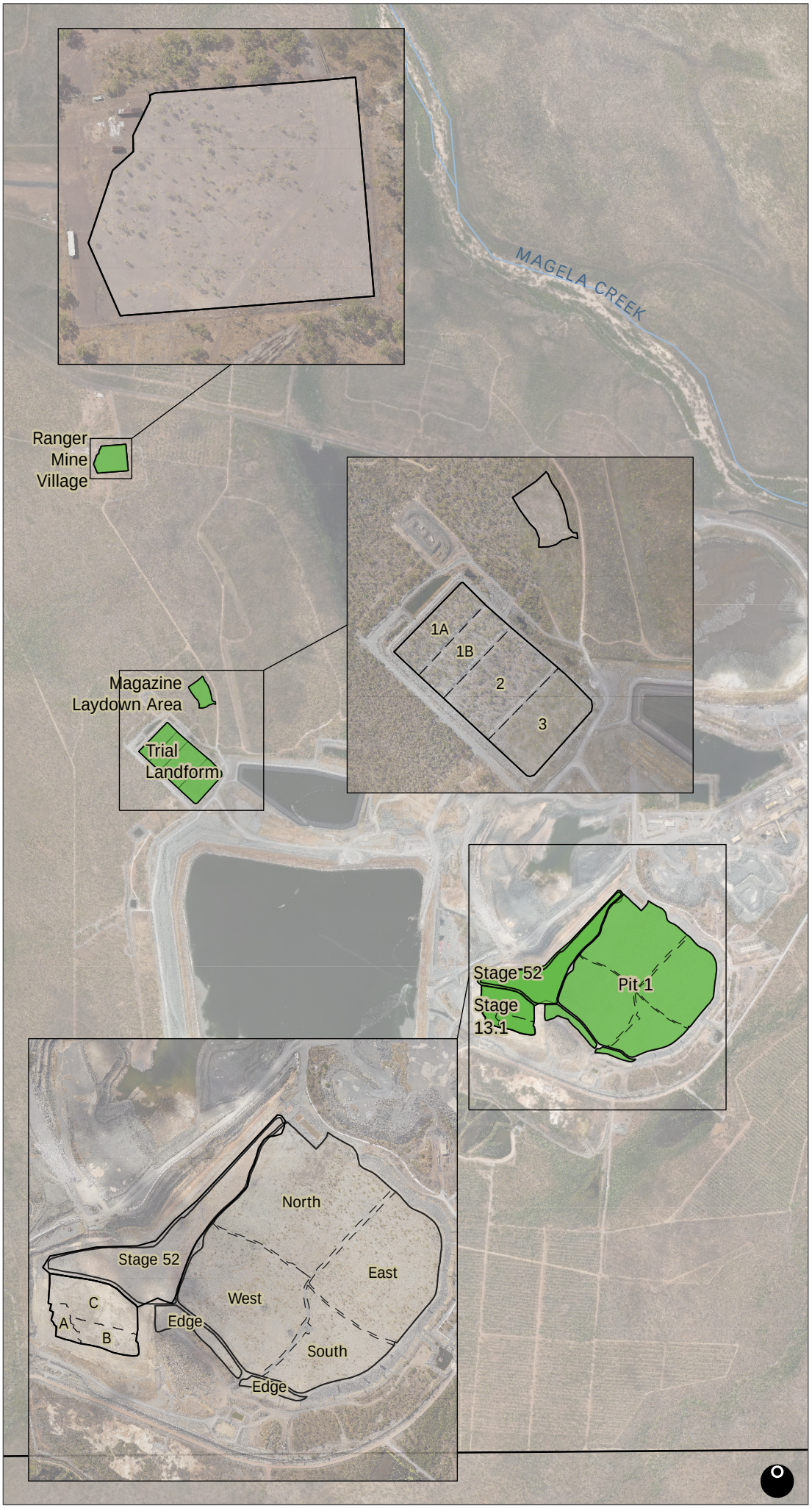

FIGURE 9-1

Revegetation Monitoring Areas

LEGEND

- Ranger Project Area
- Management 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 13.1- planted 2020/2021

Stage 52 - planted 2023

0 0.5 1
Kilometres

Scale 1:25,000 at A4
GDA 1994 MGA Zone 53

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9.3.1 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. Ecologically, 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 *Eucalytpus miniata* and *Eucalytpus 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.

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The waste rock substrate is composed of metamorphic, Cahill-formation schists with pockets of finer lateritic material, 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, monitoring outcomes have indicated there may be some constraints with regards to the suitability of substrate for some species. Considering the relative ecological and cultural importance of some of these species, further investigations may be undertaken to confirm viability of practical mitigations or establishment strategies. It is important that the proposed vegetation reference ecosystems can be adapted to reflect these constraints as they are realised.

The current understanding of proposed vegetation reference ecosystems that may be applied for different parts of the rehabilitated landform are outlined below, including related studies. These are representative of the vegetation types described by Schodde and others (1987) and are aligned with the general topographic features expected across the rehabilitated landform. Further detail regarding proposed species composition is provided in Appendix 9.1.

9.3.1.1 Savanna Woodland CRE

This proposed reference ecosystem is intended to be representative of the *Eucalyptus tetrodonta* and *Eucalyptus miniata*, or *Corymbia foelscheana*, dominated open forest and woodland communities, and will be established across the majority of the rehabilitated final landform. Although a functional understorey end-state is largely agreed, initial planting/seeding rates and timing of introduction for groundcover is subject to further consideration, where this relates to erosion risk and sediment movement. In consultation with Traditional Owners, the Savanna Woodland CRE may also include small pockets of dry monsoon forest species (as identified by Garde (2015) but not captured in the reference communities described above), particularly around established rockpiles. The following studies have helped guide the development of the Savanna Woodland 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 mine site.
- Humphrey (2013): Use of vegetation analogues to guide planning for rehabilitation of the Ranger mine site.
- Garde (2015): Closure Criteria Development – Cultural. ERA Ranger Integrated Tailings, Water & Closure.

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- 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.
- Paramjyothi and others (2023): Flowering and fruiting phenology of woody plant species used in the rehabilitation of the Ranger mine site.
- Paramjyothi and others (2024). Data collection to inform development of the appropriate fire regime for the rehabilitated Ranger mine (in review).
- Supervising Scientist (2025b): Technical Advice #080: Indicators and metrics for community structure attribute for conceptual reference ecosystems.

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 broadscale 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.

9.3.1.2 Seasonally Inundated Savanna and Drainage Lines

In 2019 and 2020, OSS surveyed four sites (F1-F4) described as intermittent flooding savanna sites (Supervising Scientist, 2020d). In 2024, an additional seven sites (SDL01-SDL07) adjacent to the mine disturbance footprint were surveyed, encompassing drainage lines (SDL01-04) and seasonal swamps (SDL05-07) (Supervising Scientist, 2025c) (see Figure 9-2). Data from these sites is being considered in the development of a suitable approach for the establishment of vegetation in areas of the rehabilitated final landform that may be subject to seasonal inundation or constructed as drainage lines. No permanent waterbodies are currently planned or expected to develop across the constructed final landform.

Based on the current design and preliminary estimates, the extent of seasonal inundation expected across the rehabilitated final landform is forecast to be less than 10% (it is noted that this estimate is preliminary and further work to improve the estimate of the likely extent is being undertaken).

The location and extent of drainage lines will be an engineered feature of the final landform and are therefore more amenable to estimates of extent. The planned drainage lines are predominately lower order tributaries (i.e., dry except for during periods of heavy rainfall). Based on the current FLFv7 design (which is being further refined), the total area potentially subject to constructed drainage lines (assuming a conservative maximum average width of 6 m) represents less than 1% of the constructed final landform. The need for a specific riparian vegetation community across drainage lines is yet to be confirmed.

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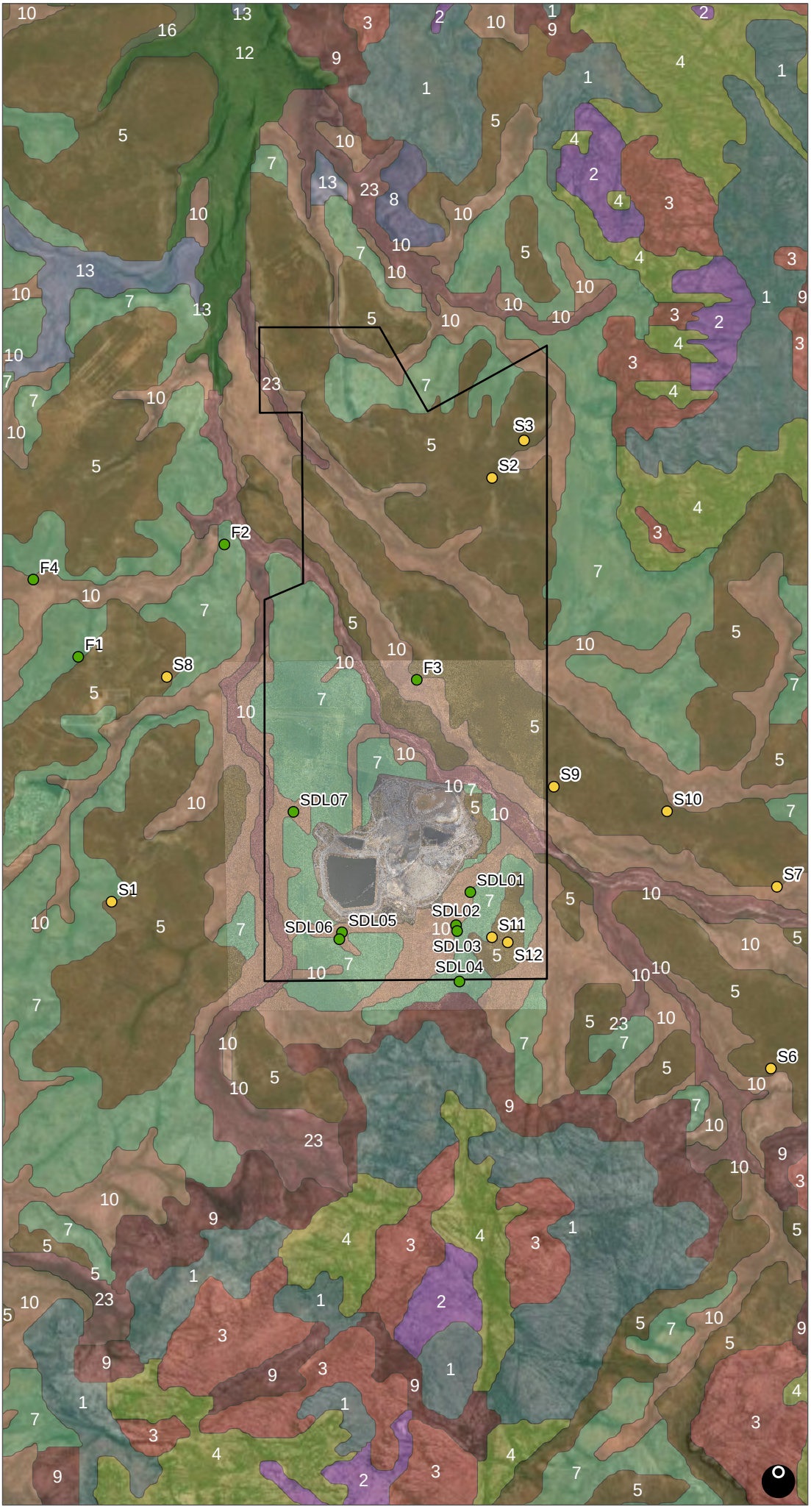

FIGURE 9-2

OSS 2018-2024 Surveyed Reference Sites, with Vegetation Types Mapped by Schodde and others (1987)

LEGEND

- Ranger Project Area

Reference sites

- Seasonally Inundated and/or Drainage Lines
- Savanna Woodland

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 1:120,000 at A4
GDA 1994 MGA Zone 53

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Image Source: ESRI Basemap (2024); Aerometrex (2024) **Data source:** NT Government Data (2023)

9.3.2 Fauna Reference Ecosystems

As described above, the final vegetation communities established at Ranger will reflect 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 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). Additionally, it is important to consider variations in trajectory for different fauna groups, which will be influenced by a range of factors (i.e. food and habitat resources) as established ecosystems continue to develop. Fauna trajectory is inherently difficult to predict for such a novel site, however ongoing monitoring of more advanced rehabilitation (e.g. TLF) is planned and will help to inform this.

9.3.2.1 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.

Native vertebrate species from 35 savanna woodland survey sites (SLR, 2021), and additional species highlighted by Dr John Woinarski (*pers. comm.* Woinarski, CDU, May 2024) are listed in Appendix 9.2.

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 indicated in Appendix 9.2.

It is also noted that the listed species in Appendix 9.2 are not exhaustive. The outcomes of recent surveys by OSS (currently unpublished), further planned surveys and more advanced monitoring techniques may be used to further inform an appropriate fauna reference ecosystem and indicative trajectory towards this.

9.3.2.2 Invertebrates

Although other invertebrate groups may be considered ecologically and culturally important, ants are the only group included in closure criteria.

The study by Oberprieler and others (2020) included a preliminary characterisation of reference populations for ants in 2018, comparing four sites on the TLF with seven natural reference sites surrounding the RPA.

A follow-up ant survey was conducted in May and September 2024 for the TLF as well as Pit 1, Stage 13.1, Stage 52 and three reference sites (including other mine rehabilitation sites) to improve understanding of trajectory and variations in reference populations. These studies have included opportunistic sampling and analysis of other invertebrate groups.

Results suggest that total ant abundance increases rapidly after revegetation, reaching reference levels within a number of years. Mean ant species richness has consistently increased over time at the sampled mine sites. However, species composition is still dissimilar to reference sites.

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Work is underway, as part of a larger fauna habitat features and enhancements review (under KIKN ESR2B) and fire regimes literature review (under KKN ESR8A), to better understand the habitat requirements of local native ant communities in the surrounding environment, which will inform future revegetation and land management activities.

9.3.3 Ecosystem Establishment 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 understorey 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 9.5.2), and considering the ecological and stability benefits, recent trials at Stage 52, 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 a range of functional understorey species, including suitable pioneers for early stabilisation, relatively non-aggressive, low biomass grasses, herbaceous species and shrubs 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. Management sections of the TLF are shown on Figure 9-1. Photo 9-1 illustrates the progress of vegetation establishment on the TLF over time.

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Photo 9-1: Trial landform (permanent monitoring plot 2) in 2009 (top left), 2016 (top right) and 2025

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).

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- Parry and others (2022): Improved native understorey establishment in mine waste rock in Australia's wet-dry tropics.

Between 2018 and 2023, revegetation trials were also established on waste rock at Ranger Mine Village (RMV), the Magazine Laydown Area, Stage 13.1, Pit 1 and Stage 52 (Figure 9-1), including several small-scale direct seeding trials for identified suitable species. The current ecosystem establishment strategy considers early published studies of the TLF, as well as data from a series of (unreported) studies, included in Table 9-4.

Table 9-4: Unreported studies and monitoring that have informed the current ecosystem establishment strategy

Month/Year	Area	Description
Ongoing since September 2018	TLF	Adaptive management monitoring, noting vegetation health and general abundance, evidence of flowering, fruiting, recruitment and weed spread.
Ongoing since February 2023	Pit 1, Stage 13.1 and Stage 52	
2019	TLF	Survey of every woody stem (including established permanent plots).
January 2019	TLF	Ongoing monitoring of understorey tubestock from a previous trial (Parry *et al*., 2022) that were planted into 'islands' on Section 1A and Section 1B and mulched with leaf litter collected from surrounds.
February 2020	TLF	Ongoing monitoring of several understorey and woody species, established via tubestock and/or direct seeding in selected plots with and without litter cover.
2020–2022	Stage 13.1	Ecosystem establishment research trials.
2021–2023	Pit 1	Ecosystem establishment research trials: exploring year-round revegetation and specific methods and materials to optimise initial seedling survival.
2021–2023	Pit 1	Small scale direct seeding trial consisting of five understorey and two midstorey species.
2022	TLF	Survey of understorey cover, using a quantitative point intercept method.
2022	TLF	Survey of every woody stem (including established permanent plots).
2023	Pit 1, Stage 13.1 and Stage 52	Condition assessment and mapping to inform further investigations into poor performance and facilitate adaptive management trials.
2024	TLF Sections 2 and 3	Pre and post burn monitoring of established permanent plots.
June and July, 2024	Pit 1	Intensive survey, including root sampling, of affected trees from sudden mortality event.
October and November, 2024	Pit 1, Stage 13.1 and Stage 52	Late dry season diagnostic substrate and leaf sampling.
March 2025	TLF, Stage 13.1, Stage 52, Pit1, RMV and the Magazine Laydown Area	Understorey species targeted meander survey.
March 2025	RMV and Magazine Laydown Area	Overstorey and midstorey survey of all stems.
April and May, 2025	TLF	Overstorey and midstorey survey of all stems (including established permanent plots).

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Month/Year	Area	Description
May and June, 2025	Pit 1, Stage 13.1, Stage 52 and Georgetown analogue area reference site	Late wet season diagnostic substrate and leaf sampling.
May and June, 2025	Pit 1	Follow-up survey of the affected trees from 2024 sudden mortality event.
June and July, 2025	TLF Section 1A	Trial burn and post-burn survey.

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). These areas may require 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 broadscale investigations conducted by EcOz (2022) and Dendra Systems in 2022, specific revegetation requirements for each unique non-waste rock area will be developed.

The outcomes of ongoing ecosystem rehabilitation monitoring (refer Section 9.6) will continue to be used to update the Ecosystem Establishment Strategy, inform further adaptive management trials, the State and Transition (S&T) Model and associated TARPs (refer Section 9.8). The current Ecosystem Establishment Strategy is provided as Appendix 9.1, and includes a description of methodology for:

- final landform growth substrate construction, including backfill methods and addressing of any relevant constraints to the establishment and long-term support of target vegetation communities;
- surface preparation, including considerations for scarification and ripping and construction of rocky habitat features;
- seed collection and storage, including the approved seed provenance zone;
- tubestock propagation, including nursery capacity, seasonal considerations and tubestock quality standards;
- provision of suitable irrigation and application of pre-emergent herbicide;
- mechanical preparation of planting holes;
- fertiliser application during planting and the following wet season;
- tubestock planting, direct seeding and secondary introductions; and
- species specific details, including species relevance, target stems, proposed establishment method and planting/seeding rates.

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This Ecosystem Establishment Strategy will provide the framework for ecosystem establishment planning for consultation with stakeholders and inclusion in future iterations of the MCP and the Final Landform application. It will be targeted to project implementation teams, and include:

- scheduling and spatial representation of distinct areas for ecosystem establishment;
- species specific seed collection and tubestock propagation requirements for each area and planting composition;
- details of planned irrigation infrastructure construction, operation and decommissioning;
- resourcing requirements and logistics for large scale planting; and
- quality assurance and control procedures to ensure:
    - growth substrate and landform surface is constructed with appropriate material and built to design;
    - sufficient viable seed is available for propagation and planting;
    - tubestock quality is in accordance with the established ‘tubestock standard’;
    - initial planting, seeding, irrigation and weed management is suitable to achieve target establishment success at two years; and
    - ongoing monitoring and maintenance procedures are in place and adequately resourced.

9.3.4 Weeds and Introduced Flora and Fauna

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.

Weeds are a material risk at Ranger. Without effective management, they have the potential to limit or reduce biodiversity by competing with or displacing endemic species and can also increase fire intensity.

Similarly, introduced fauna commonly thrive when their natural ecosystem drivers may not be present (e.g. predators), and have the potential to impact ecosystem rehabilitation.

Decades of disturbance at the RPA and surrounds have contributed to the presence and abundance of a range of weeds and introduced flora and fauna species, which require ongoing management.

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For weeds and other introduced flora, the Ranger Rehabilitation Project Team 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 management methods. Further collaboration with these organisations, as well as Kakadu National Park (regarding their own weed and introduced fauna management programs) may generate further opportunities for:

- improved weed and introduced fauna management programs;
- reduction of threats both from and to the immediate surrounds; and
- understanding of the residual risk and potential impacts to rehabilitation.

9.3.4.1 Management Methodology - Weeds and Introduced Flora

Current closure criteria are based on three categories of weeds (namely Class A, Class B and other introduced flora). Within each of these categories, previously detected species, currently managed species and/or species with the potential to occur in the future are listed in Table 9-5. It is noted that the species listed are not exhaustive and may be updated with the introduction of new species into active management programs.

Table 9-5: Weed categories and currently managed species

Relevant legislation / category	Growth form	Common name	Scientific name
Class A (NT *Weeds Act 2001*)	Grass	Gamba Grass	*Andropogon gayanus*[1]
	Grass	Thatch Grass	*Hyparrhenia rufa*
Class B (NT *Weeds Act 2001*)	Grass	Grader Grass	*Themeda quadrivalvis*
		Perennial Mission Grass	*Cenchrus polystachios*[1]
	Grass (semi-aquatic)	Olive Hymenachne	*Hymenachne amplexicaulis*[1]
	Forb	Flannel Weed	*Sida cordifolia*
		Hyptis	*Mesosphaerum suaveolens*
		Sicklepod	*Senna obtusifolia*
		Spinyhead Sida	*Sida acuta*
	Forb (aquatic)	Salvinia	*Salvinia molesta*
Other introduced flora	Grass	Annual Mission Grass	*Cenchrus pedicellatus*[1]
		Annual Spear Grass	*Sorghum spp.*[3]
		Barnyard Grass	*Echinochloa colona*
		Crowfoot Grass	*Dactyloctenium aegyptium*
		Guinea Grass	*Megathyrsus maximus*
		Red Natal Grass	*Melinis repens*
		Rhodes Grass	*Chloris barbata*
		Urochloa	*Urochloa humidicola*
		Urochloa	*Urochloa pubigera*[2]
	Grass (semi-aquatic)	Para Grass	*Urochloa mutica*[1]

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Relevant legislation / category	Growth form	Common name	Scientific name
	Shrub	Silver Wattle	*Acacia holosericea*[2]
	Forb	Buffalo Clover	*Alysicarpus vaginalis*
		Calopo	*Calopogonium mucunoides*
		Caltrop	*Tribulus spp.*
		Morning Glory	*Ipomoea quamoclit*
		Passionfruit	*Passiflora foetida*
		Rattlepod	*Crotalaria goreensis*
		Rosella	*Hibiscus sabdariffa*
		Sesame	*Sesamum indicum*
		Siratro	*Macroptilium atropurpureum*
		Stylo	*Stylosanthes spp.*
		Tick Weed	*Cleome viscosa*[2]
		Tridax Daisy	*Tridax procumbens*
		Wormroot	*Spigelia anthelmia*[3]
		Wynn's Cassia	*Chamaecrista rotundifolia*

[1] These introduced grasses are associated with the key threatening process 'Ecosystem degradation, habitat loss and species decline due to invasion of Northern Australia', listed under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999.*

[2] These species are native, however they are managed similarly to other introduced flora due to their transformative potential.

[3] Although Wormroot is not listed under the *NT Weeds Management Act 2001*, the Ranger Rehabilitation Project Team has committed to eradication of this species (refer Section 9.5.1).

Class A (NT *Weeds Management Act 2001*)

Gamba Grass has been recorded in the RPA. Closure criteria state that this species must be absent or eradicated. In accordance with section 10 of the *Weeds Management Act 2001* the statutory Weed Management Plan for Gamba Grass 2020-2030 outlines the legal requirements of landowners. The RPA is located within the class A (eradication zone) requiring all gamba grass to be destroyed.. Isolated Gamba Grass 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. There have also been reported potential sightings of Gamba Grass on a ramp entering Pit 1 and at the RWD, however these plants were 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.

Thatch Grass (*Hyparrhenia rufa*) has been detected within the RPA within this reporting period. In accordance with the *Weeds Management Act 2001* this new detection of a declared weed has been notified to the Northern Territory Government's Weed Management Branch (WMB). In consultation with the WMB, best practice survey and treatment options are being developed and will be implemented.

Class B (NT Weeds Act 2001)

The *Weeds Management Act 2001* (NT) states that Class B weeds must be controlled. Eight species that fall within this category are either actively managed within the RPA or considered at risk of being introduced in the future.

Other introduced flora

Although not declared under legislation, a number of other introduced flora are actively managed to control further spread. These 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 ecosystem 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.

Management methodologies

An overarching, strategic long-term approach to controlling and reducing weed loads on the RPA is currently under development as part of a new Ranger Rehabilitation Project (RRP) Weed Strategy. This strategy will identify key principles to guide management of weeds on the RPA, and will describe clear, achievable and measurable weed management goals and actions. Annual plans will still be used for planning specific, targeted weed management activities each weed season.

A wealth of knowledge has been developed around the ecology of the species listed in Table 9-5 and the effective control of these.

Weed control is generally conducted during the growth season (i.e. October to June), however this may be extended for irrigated areas. Commonly implemented control methods include:

- application of short acting herbicides during the growth stage;
- application of pre-emergent herbicides prior to seed germination;
- relative to circumstances, application of herbicide by mobile backpack unit, Quik Spray unit hose, vehicle-mounted boom, water-truck canon or drone;
- seed head cutting, used for minor infestations late in season;
- management of woody species (e.g. *Acacia holosericea*) during the dry season;
- manual removal, often conducted for isolated plants during adaptive management monitoring; and
- burning during the appropriate season (e.g. soon prior to fruiting).

Herbicides and their application on the RPA are summarised in Table 9-6.

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Table 9-6: Approved herbicides and target species

Herbicide and active ingredient	Label description and relevant recommended genera/species	Target species
Glymac Bio (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*
Galligan (Oxyfluorfen)	For selective weed control of broadleaf weeds and some grasses (*Cenchrus, Echinochloa, Urochloa*)	All (pre-emergent)
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*

9.3.4.2 Management Methodology - Introduced Fauna

Introduced fauna species can directly and indirectly impact or impede ecosystem rehabilitation, by:

- predating on native fauna;
- competing with native fauna for food, shelter, breeding habitat;
- further spread of weeds;
- disturbance of vegetation, including digging and overgrazing;
- introduction of disease.

These processes may also lead to further impacts associated with erosion and inappropriate fire regime.

The current Feral Animal Management Plan lists several species considered to present a risk to rehabilitation and the immediate surrounds. This is reproduced in Table 9-7, along with relevant legislative drivers. Active and responsive control methods include ground shooting, trapping, the application of pesticides and/or removal.

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Table 9-7: Introduced fauna species and control type

Relevant legislation/ category	Common name	Scientific name	Control type
Listed as a 'Key Threatening Process' under the EPBC Act 1999	Cane Toad	*Bufo marinus*	No known effective control method
	Cat	*Felis catus*	Opportunistic (via established programs)
	Pig	*Sus scrofa*	Planned or established control program
Territory Parks and Wildlife Conservation Act (2006)	Black rat	*Rattus rattus*	Responsive to presence, where potential for harm or nuisance
	Buffalo	*Bubalus bubalis*	Responsive to presence, where potential for harm or nuisance
	Cattle	*Bos sp.*	Responsive to presence, where potential for harm or nuisance
	Dog	*Canis familiaris*	Planned or established control program
	Donkey	*Equus asinus*	Opportunistic (via established programs)
	Flower-pot snake	*Rhamphotypholps braminus*	No known effective control method
	Horse	*Equus caballus*	Responsive to presence, where potential for harm or nuisance
	House gecko	*Hemidactylus frenatus*	No known effective control method
	House mouse	*Mus musculus*	Responsive to presence, where potential for harm or nuisance
Pest of National Significance	Browsing Ant	*Lepisiota frauenfeldi*	Eradication Program (managed by NT government, under the National Browsing Ant Eradication Program NT)

There is potential for additional species to be added to this list if they present a threat to rehabilitation, cultural heritage or human health and safety.

9.3.4.3 Adaptive Management Trials

Where there is a significant presence of weeds, introduced flora and/or introduced fauna in rehabilitation areas, this may be considered a 'deviated state', and additional management may be required to return to an acceptable trajectory for ecosystem development. Opportunistic adaptive management trials will be undertaken where this occurs, to inform ongoing rehabilitation planning, monitoring and maintenance.

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, including stands of Silver Wattle and a groundcover predominately of Buffalo Clover and Urochloa. Although immediately effective, without follow-up management, abundance of most weed species were observed to return rapidly with the exception of Silver Wattle.

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Learning from this, an adaptive management trial has more recently been conducted on Section 2 of the TLF. With the objective of sustainably transitioning the ecosystem from a weed-dominated groundcover to a more desirable, native groundcover, the trial comprised:

- broad-scale herbicide application in February 2024;
- a successful controlled low-intensity burn in June 2024;
- spot spraying with short-acting herbicides followed by seeding in November 2024 (noting that the use of pre-emergent herbicides was avoided, with suppliers advising of reduced effectiveness in the presence of ash, and also potential impacts to the success of follow-up seeding of native species); and
- in response to early observations, encouragement of successfully germinated native species by careful manual removal of weeds, conducted in March 2025.

Preliminary data from a survey conducted in April 2025 has indicated a successful transition (see Photo 9-2), with improved understorey species richness, diversity of functional groups and native species cover. Whilst the trial has shown that it is possible to transition a weedy, deviated state back to the desired ecosystem trajectory, it is noted that manual removal of weeds is less feasible at scale. To avoid this, early prevention of weed spread and active management of establishing ecosystems will be prioritised.

Photo 9-2: Section 2 of the TLF: June 2024 controlled burn (left) and successful seeding of native groundcovers, observed April 2025 (right).

9.3.5 Sustainability Processes (Including Resilience to Disturbance) and Recruitment

Of the woody species originally established on the TLF, all but two species 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). Documentation of recruitment, and early indicators such as flowering and fruiting, is important, particularly for species that experience senescence (e.g. Acacia spp. with generally shorter life span). Accounting for senescence and recruitment ensures the sustainability of target vegetation communities and has been considered in the calculation of initial planting/seeding densities (Appendix 9.1).

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Additional species, including weeds, are expected to naturally colonise through external pathways including fauna and wind. In March 2025, targeted meander surveys for understorey species, based on the Adaptive Management Monitoring program methods, were performed throughout each revegetation management area within all sections of the TLF, Pit 1, Stage 13.1, Stage 52, Ranger Mine Village (RMV), and Magazine. Based on the colonisation trajectories observed, understorey functional composition is likely to change over time as environmental conditions improve, and suitable micro-niches develop. Results (unpublished) indicate that the older revegetation sites (particularly TLF 'Sections 2 and 3', RMV, and Magazine), have a proportional species richness most similar to that of the OSS savanna reference sites, as described by Supervising Scientist (2021d). This is unsurprising considering the likeness of substrates in these areas to natural (i.e. either disturbed natural soil or waste rock mixed with laterite).

Although overall groundcover remained low in most of the revegetation areas, with the exception of TLF section 2 and Magazine, understorey species functional composition and richness is developing well in all revegetation areas. Active understorey species introduction via direct seeding and tubestock planting is planned for the upcoming wet season to ensure understorey cover continues to develop on a desirable trajectory.

9.3.5.1 Typical Nutrient Cycling for 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.

A synthesis of regional studies conducted by Richards and others (2021) listed the following key aspects of nutrient cycling in tropical savannas:

- low organic carbon and nitrogen content with limited inputs/outputs and high efficiency;
- higher levels of nitrogen availability (as nitrate and ammonium) during the beginning of the wet season;
- importance of mycorrhizal associations for plant nutrient uptake; and
- termites as a key driver of litter decomposition.

To support a study of waste rock nutrient cycling aspects at Ranger (Huang and You, 2018; Huang *et al.,* 2020), samples were collected from two natural reference sites. Analytical outcomes from these sites broadly support the above synthesis by Richards and others (2021), suggesting:

- 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.

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The influence of fire on nutrient cycling processes must also be considered. 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).

9.3.5.2 Nutrient Cycling and Soil Formation on Waste Rock

Two key processes that encourage nutrient cycling and soil formation 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 is not currently preferred by Traditional Owners as it impacts traversability. Further consultation with Traditional Owners on Cultural closure criteria (which include traversability and therefore surface preparation methods (i.e. deep ripping, scarification)) is planned as part of the ongoing and program specific consultation (see Chapter 11). Given the above with regards to conservation of topsoil and deep ripping, 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 compared to natural soils.

These studies further suggest that microbial communities, soil chemistry and litter decomposition will all be improved with increased presence of understorey vegetation, and particularly nitrogen fixing leguminous species. This recommendation was considered and has contributed to a shift in the ecosystem rehabilitation strategy to introduce understorey and a diversity of leguminous species in the initial stages (refer Appendix 9.1).

The addition of fertiliser at initial stages (i.e. first two years) is part of the ecosystem establishment strategy (Appendix 9.1) and was applied during the establishment of trials at the TLF and other areas. No additional nutrient additives have been applied to these areas since establishment. A preferred approach for fertiliser type and application method will be determined upon controlled implementation at subsequent rehabilitation areas and ongoing monitoring.

Several trials have since contributed to increased understorey cover at the TLF in recent years. A photographic survey of soil development indicators and soil fauna on the TLF (Sections 1A and 1B) and Pit 1 (west) was conducted in February 2025. The trials and survey indicated sustained vegetation growth, organic matter deposition and decomposition, colour changes in the top layer of substrate, rich invertebrate communities, and presence of fungi and lichen. A follow up survey was

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conducted in permanent plots of Section 1A in May 2025, with quantitative measurement of ground cover, litter depth and substrate colour.

The above results indicate that nutrient cycling and substrate development is occurring. Ongoing nutrient cycling, weathering and managed introduction of fire is expected to contribute to the development of rudimentary soils over time.

9.3.5.3 Resilience to Disturbance

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; 2013).
- A major wind event in 2019 that felled several trees, most of which have since re-shooted.
- Widespread infestation in 2022 by the subterranean termite (*Mastotermes darwiniensis*) and other invertebrate species, again prompting treatment with a targeted application of insecticide at the base of impacted trees. Where treatment has been applied, monitoring conducted in 2024 has indicated improvements in plant health, without an observable impact of this practice on desirable invertebrate communities.

Pit 1 and Stage 13.1 have also experienced widespread insect damage on some young shrubs and trees since 2023. The damage is believed to be caused by the tree boring larvae of a native moth (possibly *Maroga melanostigma*, however unconfirmed) and this is generally contained to a handful of species with *Acacia dimidiata*, *Acacia difficilis*, *Acacia oncinocarpa* and *Grevillea decurrens* being the most severely affected.

Based on field monitoring and trials, the development of a structured decision-making framework for the treatment of invertebrate pests has commenced and will be integrated into monitoring and adaptive management frameworks.

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9.3.6 Fire Resilience

9.3.6.1 Fire Regimes in the Regional Surrounds

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, as well as affecting 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. A recent study was conducted at Paradise Farm, an outstation within Kakadu National Park approximately 45 km south-west of the RPA. The Murumburr family clan of this area have been managing the land using a range of fire regimes for the past 40 years (and presumably for many generations prior). The recent study by Paramjyoti and others (2024) documents long-term effects on flora and fauna over four distinct fire management approaches:

- fire exclusion for over 20 years;
- planned burns in both wet and early dry season with fire interval of five to seven years with the aim of clearing patches of leaf litter to aid plant recruitment;
- planned annual wet and early dry season burns with aim of creating mosaic; and
- planned early dry season and occasional unplanned late dry season with aim of creating firebreaks to protect the western side of the highway.

Dr Peter Christophersen (resident of Paradise Farm, land manager and member of the Murumburr family clan) also leads the fire management program on the RPA, via Kakadu Native Plant Supplies.

Fire frequency

Publications of fire frequencies between 1980 and 2019 indicate that Kakadu National Park experienced a relatively high fire frequency, of three to seven fires per decade, with a frequency of one to three per decade for late dry season fires (Cook, 2021). This correlates with fire occurring over 50% of the lowlands of Kakadu National Park annually, and 40-60% of Kakadu National Park as a whole (Gill, 2020).

A high fire frequency leads to a simplification of vegetation structure, favouring large trees, an understorey of grasses, and *Eucalyptus* 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). Conversely, annually burnt portions of Paradise Farm (e.g. firebreaks) have favoured high cover of annual grasses (Paramjyoti *et al.*, 2024). 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.

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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 exclusion for longer periods (e.g. more than ten years) may contribute to increased leaf litter and limited understorey species richness and cover (Paramjyoti *et al.*, 2024).

Fire intensity

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.

9.3.6.2 Rehabilitation 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 since 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 establishment of species and community structure that are characteristic of the natural surrounds will ensure that resilience is achieved over time.

To support this concept in a project specific context, Dr Gary Cook, a renowned expert in fire ecology, was engaged to identify typical resilience mechanisms that are common to the rehabilitation strategy and specific planting compositions (Cook, 2021). These are listed in Table 9-8, along with typical establishment timeframes (Cook, 2021), learnings from trial burns at the TLF and Pit 1, including those documented by Wright (2019a; 2019b) and general observations. Understanding of this will

be significantly improved when the 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.

The practical implementation of controlled burning in rehabilitation areas at Ranger is outlined in Section 9.5.2.

Table 9-8: 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)
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)

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Growth form	Mechanism for fire resilience	Relevant species	Mechanism establishment timeframe
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

9.4 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 criteria that are described in Section 9.1. These are provided as Figure 9-3 through to Figure 9-9. 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 the 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.

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Preventative Controls

C1 Final landform design, construction and verification
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 ecosystem vegetation establishment strategy, including appropriate species mix
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C36 Management of introduced fauna
Satisfactory

C37 Targeted pest and disease management
Satisfactory

C38 Addition of organic material from surrounds
Marginal

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

C29 Development of appropriate vegetation reference ecosystem/s
Satisfactory

C52 Administrative weed education, awareness and hygiene programs
Satisfactory

Corrective Actions

A2 Undertake earthworks to repair significant substrate limitations, gullying or eroded areas
Satisfactory

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Satisfactory

A19 Targeted introduced fauna management
Satisfactory

A20 Addition of organic material/s and or fertiliser beyond that planned
Marginal

A21 Targeted pest and disease management
Marginal

A26 Modified fire management
Satisfactory

Establishment of inappropriate vegetation species composition and/or abundance — C1 C30 C31 C32 C33 C34 C35 C36 C37 C38 C39 C29 C52

Landform and substrate characteristics limit vegetation growth and reproduction — C1 C33 C34 C38 C39 C29

Significant presence of external threats — C30 C31 C33 C35 C36 C37 C39 C52

Risk Event
Vegetation composition, abundance or community structure are on a deviated trajectory

Monitoring Program — A2 A11 A18 A19 A20 A21 A26

Stakeholders are not satisfied with vegetation composition, abundance and/or structure – relinquishment is delayed

Residual Risk
C. Possible
3. Moderate
Class III

Figure 9-3: Bow-tie diagram for vegetation composition, abundance and community structure (ES1)

Preventative Controls

C1 Final landform design, construction and verification
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 ecosystem vegetation establishment strategy, including appropriate species mix
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C36 Management of introduced fauna
Satisfactory

C37 Targeted pest and disease management
Satisfactory

C38 Addition of organic material from surrounds
Marginal

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

C41 Installation of appropriate habitat
Satisfactory

C40 Development of appropriate fauna CRE
Satisfactory

C52 Administrative weed education, awareness and hygiene programs
Satisfactory

Corrective Actions

A2 Undertake earthworks to repair significant substrate limitations, gullying or eroded areas
Satisfactory

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Satisfactory

A19 Targeted introduced 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

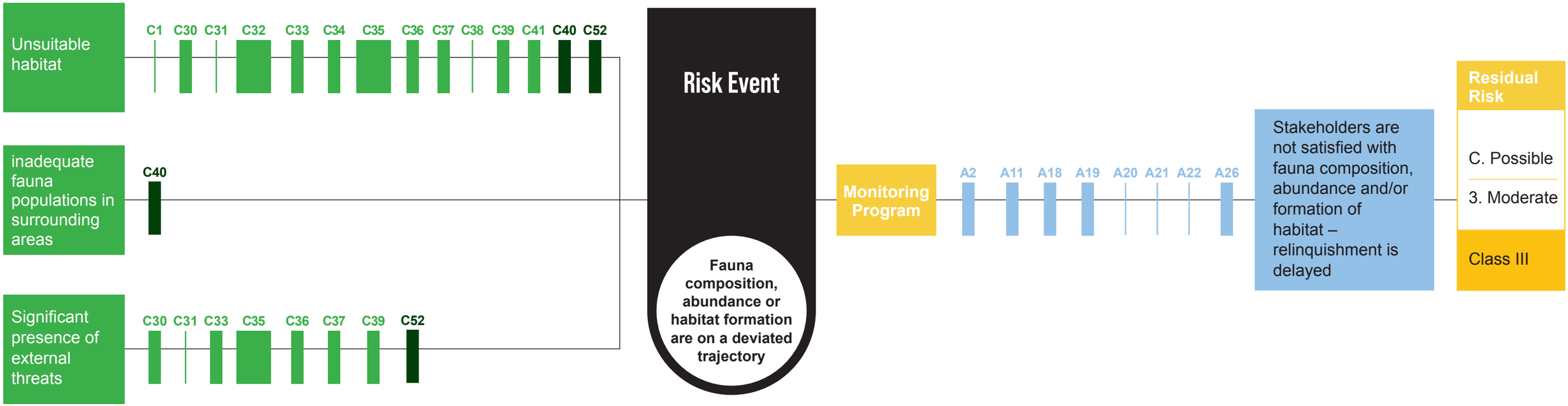

Figure 9-4: Bow-tie diagram for fauna composition, abundance or habitat formation (ES2)

Preventative Controls

C1 Final landform design, construction and verification
Marginal

C33 Implementation of suitable ecosystem vegetation establishment strategy, including appropriate species mix
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 Undertake earthworks to repair significant substrate limitations, 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

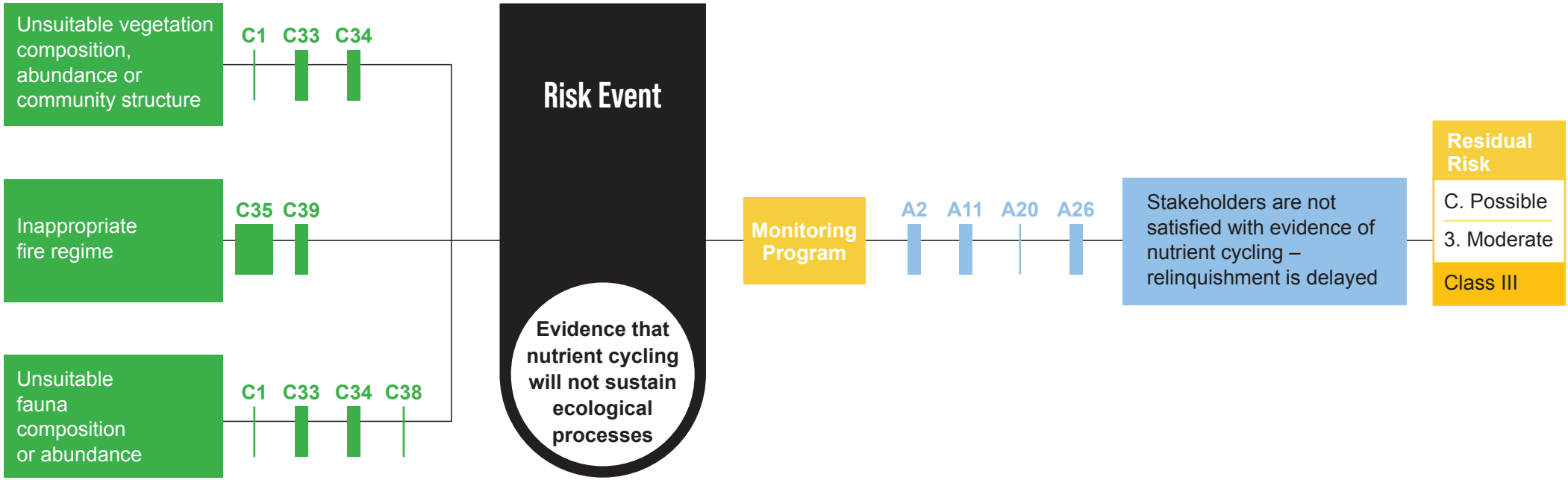

Figure 9-5: Bow-tie diagram for nutrient cycling (ES3)

Preventative Controls

C1 Final landform design, construction and verification
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 ecosystem vegetation establishment strategy, including appropriate species mix
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

C52 Administrative weed education, awareness and hygiene programs
Satisfactory

Corrective Actions

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Satisfactory

A26 Modified fire management
Satisfactory

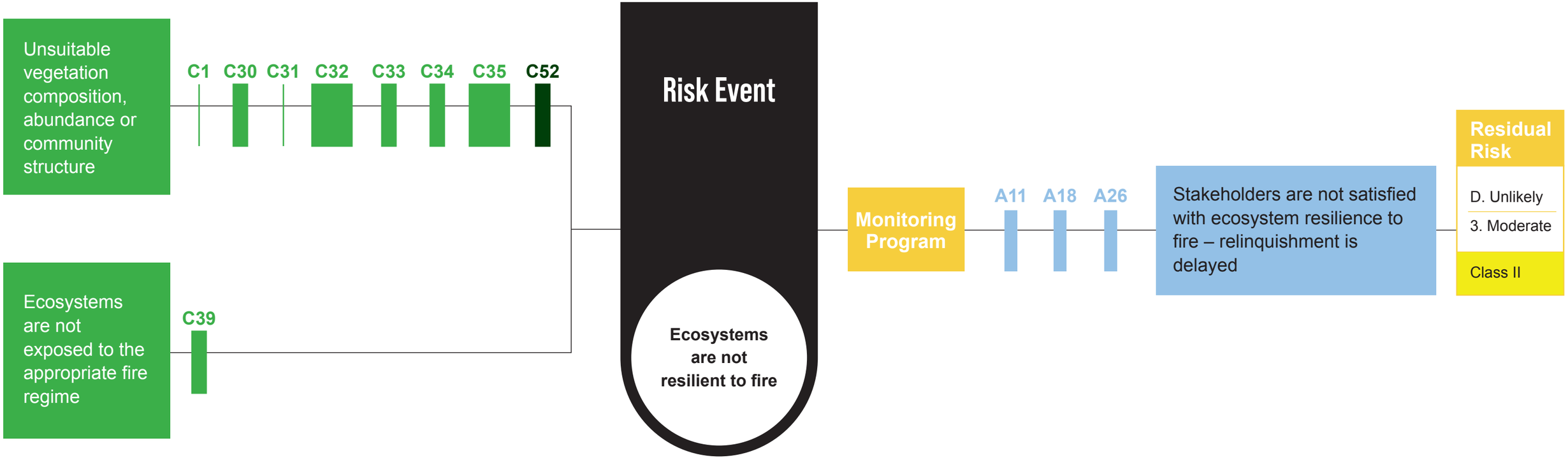

Figure 9-6: Bow-tie diagram for fire resilience (ES4)

Preventative Controls

C1 Final landform design, construction and verification
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 ecosystem vegetation establishment strategy, including appropriate species mix
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C36 Management of introduced fauna
Satisfactory

C37 Targeted pest and disease management
Satisfactory

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

C52 Administrative weed education, awareness and hygiene programs
Satisfactory

Corrective Actions

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Satisfactory

A21 Targeted pest and disease management
Marginal

A26 Modified fire management
Satisfactory

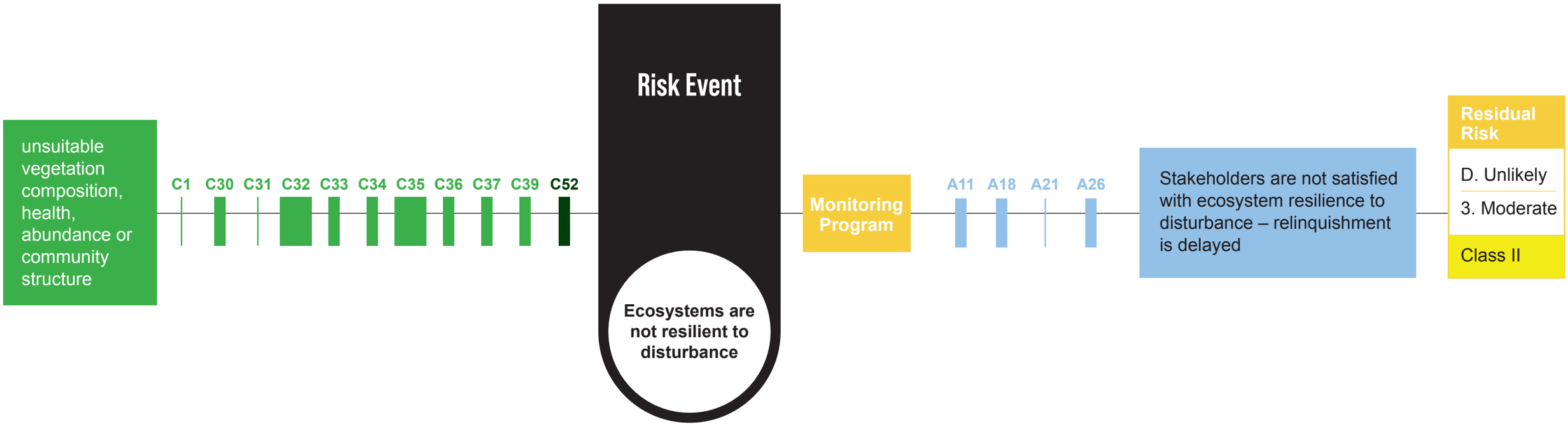

Figure 9-7: Bow-tie diagram for resilience to other disturbances (ES5)

Preventative Controls

C1 Final landform design, construction and verification
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 ecosystem vegetation establishment strategy, including appropriate species mix
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C36 Management of introduced fauna
Satisfactory

C37 Targeted pest and disease management
Satisfactory

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

C52 Administrative weed education, awareness and hygiene programs
Satisfactory

Corrective Actions

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Satisfactory

A21 Targeted pest and disease management
Marginal

A26 Modified fire management
Satisfactory

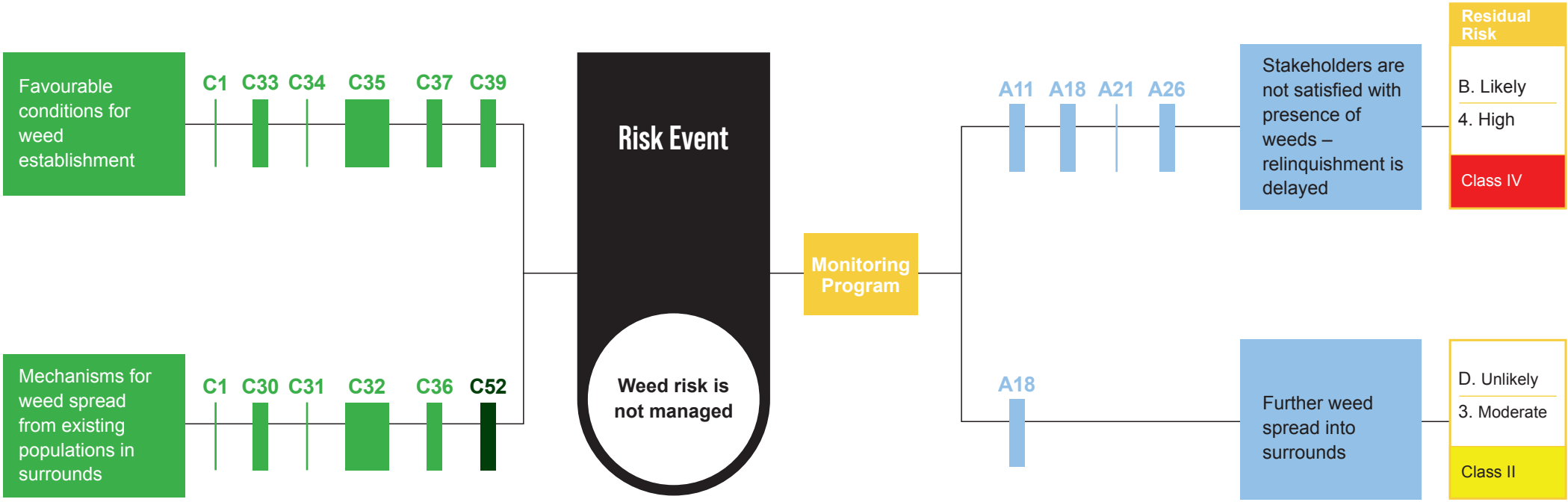

Figure 9-8: Bow-tie diagram for significant presence or abundance of weeds (ES6)

Preventative Controls

C1 Final landform design, construction and verification
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 ecosystem vegetation establishment strategy, including appropriate species mix
Satisfactory

C34 Provision of suitable irrigation
Satisfactory

C35 Fire management in non-waste rock areas within RPA
Strong

C36 Management of introduced fauna
Satisfactory

C39 Appropriate introduction of fire to rehabilitation areas
Satisfactory

C52 Administrative weed education, awareness and hygiene programs
Satisfactory

Corrective Actions

A2 Undertake earthworks to repair significant substrate limitations, gullying or eroded areas
Satisfactory

A11 Infill planting and seeding to maintain suitable vegetative cover on final landform
Satisfactory

A18 Targeted weed management
Satisfactory

A19 Targeted introduced fauna management
Satisfactory

A26 Modified fire management
Satisfactory

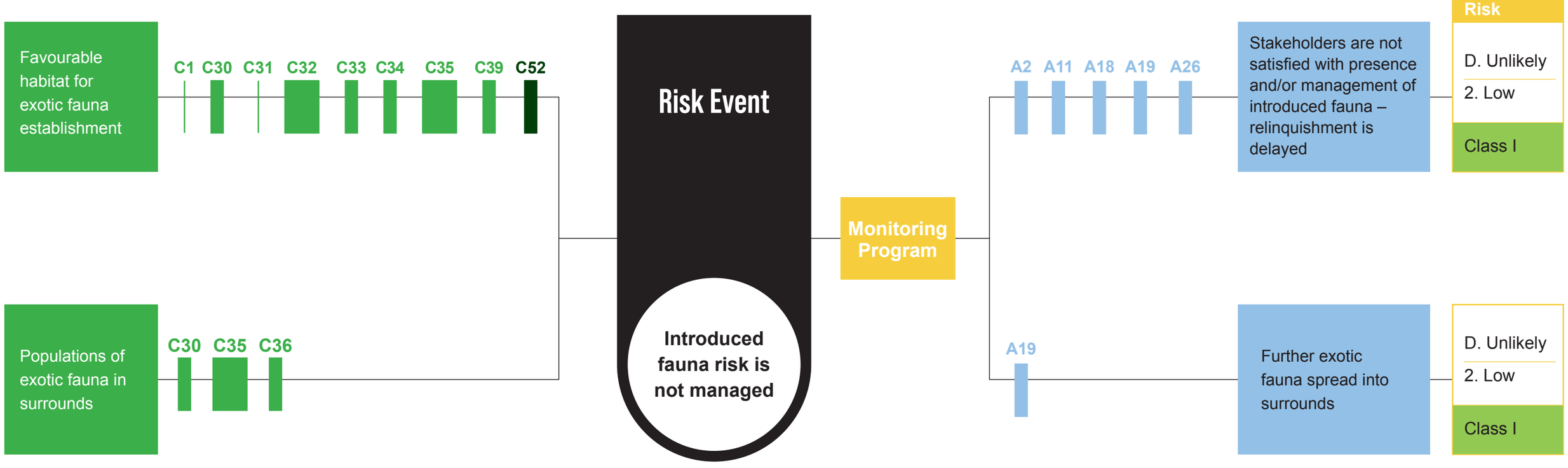

Figure 9-9: Bow-tie diagram for significant abundances of exotic fauna (ES7)

9.5 Preventive Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well the Ranger Rehabilitation Project Team 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 50% complete for the progress status relating to preventative controls and their effectiveness. This 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 9-9 outlines preventative controls along with status and effectiveness, and a reference to relevant knowledge base. Further information is provided below for the management of weeds and fire.

Table 9-9: Preventative controls for Ecosystem

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness	Studies / Knowledge Base Section Reference
'Active' controls				
C1	Final landform design, construction and verification	Marginal	Studies have confirmed that the proposed substrate can provide sufficient plant available water to support the development of broadscale savanna woodland. However, there remains uncertainty regarding the preparation of cut-to areas and the suitability of backfill material. Further investigations are planned.	Ecosystem Establishment Strategy (Appendix 9.1)
C30	Weed management in non-waste rock surrounds within RPA	Satisfactory	There is an active, accepted and successful current weed management program.	Section 9.3.4 Section 9.5.1
C31	Weed management on waste rock rehabilitation areas	Marginal	Effectiveness will be increased with the implementation of the RRP Weed Strategy (currently in development).	Section 9.3.4 Section 9.5.1
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.	Ecosystem Establishment Strategy (Appendix 9.1)
C33	Implementation of suitable ecosystem establishment strategy	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.	Section 9.3.3 and Ecosystem Establishment Strategy (Appendix 9.1)

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Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness	Studies / Knowledge Base Section Reference
C34	Provision of suitable irrigation	Satisfactory	Considerable learnings have been gained from previous application, however the effectiveness will be improved upon further application over subsequent areas of the final landform, and refined operational processes.	Ecosystem Establishment Strategy (Appendix 9.1)
C35	Fire management in non-waste rock areas within RPA	Strong	This control is well understood and actively managed as per the annual *Fire Management Plan.*	Section 9.3.6
C36	Management of introduced fauna	Satisfactory	Active and responsive control methods include ground shooting, trapping, pesticides and/or removal. Effectiveness is expected to improve with advances in regional control methods and as the program is implemented for developing rehabilitation areas.	Section 9.3.4
C37	Targeted pest and disease management	Satisfactory	Based on previous experience and ongoing field monitoring, preventative measures and/or corrective actions may include the use of pesticides and/or fungicides. The development of a decision-making framework will improve understanding in regard to the importance and effectiveness of this control for further application on rehabilitation areas.	Section 9.3.5.3
C38	Addition of organic materials from surrounds	Marginal	For ecosystem rehabilitation, 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. 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.	Ecosystem Establishment Strategy (Appendix 9.1)
C39	Appropriate introduction of fire to rehabilitation areas	Satisfactory	With several trial burns applied to the TLF this control is well understood and expected to be further improved with long-term implementation and monitoring. Further application will also include analysis of the influence of fire on soil development, nutrient cycling and habitat.	Section 9.3.6
C41	Installation of appropriate habitat	Satisfactory	Installation of artificial habitat features may have some merit but is considered of lower importance than other preventative controls, such as suitable vegetation establishment. Studies regarding the suitability of nest boxes have been completed. Further monitoring of rehabilitation areas and rockpiles is expected to improve understanding.	Ecosystem Establishment Strategy (Appendix 9.1)

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Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness	Studies / Knowledge Base Section Reference
'Knowledge-based / Administrative' controls				
C29	Development of appropriate vegetation reference ecosystem/s	Satisfactory	Whilst the broadscale Savanna Woodland CRE is well developed, other potentially applicable vegetation reference communities (e.g. seasonally inundated savanna) are still being considered.	Section 9.3.1
C40	Development of appropriate fauna reference ecosystem	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.	Section 9.3.2
C52	Administrative weed education, awareness and hygiene programs.	Satisfactory	A range of programs have been integrated throughout the Ranger Rehabilitation Project and will strengthen with long term implementation of the RRP Weed Strategy (currently in development).	Section 9.3.4 Section 9.5.1

9.5.1 Weed Management

The Ranger Rehabilitation Project Team 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. An overarching RRP Weed Strategy is currently being finalised, with the objective being to reduce existing weed loads and control the spread of weeds across the RPA as much as is practicably possible, to ensure that risk to rehabilitation and the surrounding environment is minimised. As described in Section 9.3.4.1 a range of target species and management methodologies have been developed through decades of work. Indicative seasonal timing for weed management is described in Table 9-10.

Table 9-10: Weed management indicative program

Season (and approximate timing)	Weed Management Activities
Late dry season (July to October)	Minimal weed control, focusing on irrigated areas and areas of dense *Acacia holosericea* scrub.
Build-up (October to December)	Boom-spray application for roads and tracks, blanket spraying of high density weed infestations, and focus on areas hard to access during the wet.
Wet season (December to April/May)	Peak weed management season, including application of wet season burns.
Early dry season	Seed-head cutting and dry season burns.

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One particular species is managed separately. Wormroot, also referred to as Spigelia (*Spigelia anthelmia*) 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 an abundance of the species across disturbed areas of the RPA, an eradication program was commenced, with progress and planning reported annually in the Spigelia Weed Management Report. Management of Spigelia includes the use of physical demarcation (e.g. bollards, star picket and chain), display signage at regular intervals and controlled access. Relevant controls for Spigelia management are also integrated into the Land Disturbance Permit (LDP) process to prevent further disturbance and spread.

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 a seed bank of 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.

To reduce the likelihood of an established weed seed bank on 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 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, prioritising weeds that are upwind of existing or planned rehabilitation sites. Since 2024, weed management teams have commenced targeted weed control programs for historically less-accessible waste-rock management areas. These areas are treated by water cart cannon (see Photo 9-3), with a maximum range of 47 m (implemented only with a maximum wind speed of 6 knots, to avoid herbicide drift).

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Photo 9-3: Weed management for stockpiles

Even with the effective implementation of this, weed incursion over planting areas will require ongoing management. If weed management is planned and 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 ecosystem establishment, active management is likely to substantially increase in later years and may contribute to decreased resilience of establishing vegetation to fire and other disturbances.

Measures to prevent the spread of weeds are integrated with the project culture. These are most applicable during the early stages of ecosystem establishment, where bare areas are less resilient to weed colonisation, and may be strategically adapted over time.

Design measures for control of weed spread include;

- early establishment of a suitable native groundcover, that is compatible with the Ecosystem Establishment Strategy;
- fences and lockable gates around rehabilitation areas;
- stop/check-point signs;

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- enforced weed and seed checks for persons, light/heavy vehicles and machinery; and
- vehicle washdown and/or boot wash stations at access points.

Administrative, and arguably the most important measures, are based on workforce education/awareness. This includes basic weed and seed identification, causes of weed spread and potential impacts, and is delivered via:

- a component of the general site induction;
- additional mandatory 'Weed Spread Prevention and Management' training;
- poster/banner campaigns; and
- regular correspondence during daily pre-start meetings.

Compared to weed management in remnant vegetation, such as in the non-waste rock surrounds, the Ranger Rehabilitation Project Team has less experience with weed management in revegetated areas, where selective and species-specific application of herbicides is more important, and less mature plants may be more vulnerable to particular herbicides. Further research into management methodologies, and the establishment of targeted training courses for environmental officers and contractors is ongoing, and will be essential for continued success.

9.5.2 Fire Management in Surrounds and Introduction to Rehabilitation Areas

This control includes the maintenance of firebreaks and management of surrounding area fuel loads, particularly in early stages of ecosystem development, and is actively managed as per the annual Fire Management Plan.

During operation, fire management on the RPA 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.

The annual Fire Management Plan and Emergency Response Plan also facilitate active response to wildfire, as required.

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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.

Several trial burns have so far been applied to different sections of the TLF, including Section 2 and Section 3 in 2016, 2018 and 2024, and Section 1A in June 2025. A targeted grass burning trial was also conducted at Pit 1 West in May 2025. Pre and post burn monitoring, and key learnings such as those documented by Wright (2019a; 2019b) 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 9.3.6. As rehabilitation areas mature (estimated 10–15 years), trial burns will be introduced after careful consideration of seasonality, weather conditions, fuel load, specific burn methods and monitoring data from previous burns in consultation with relevant stakeholders. Planned burns will also aim to promote and preserve specific habitat features, such as less common fruiting species, identified habitat trees, stags and logs.

Ongoing learnings will be incorporated into management plans and in the longer term, contribute to the gradual introduction of an appropriate fire regime. In partnership with Traditional Owners and traditional knowledge, planned fire regimes will focus on purposeful burns and a mosaic of fire frequencies, including longer unburnt areas where possible. Eventually, firebreaks can be removed and a regime that is similar to the surrounds will be extended to rehabilitation areas.

9.6 Monitoring Program

An Ecosystem Rehabilitation Monitoring Plan (or similar mechanism) is currently being developed, considering outcomes from a series of workshops held in April, May and July of 2024 with stakeholders and external subject matter experts. The plan will describe methods, location and scale, frequency and duration, and specific parameters to be measured, with regular updates to reflect monitoring outcomes and technological advancements. This is the focus of KKN ESR9A (Appendix 5.1).

Outcomes will be described in an annual report (e.g. Mine Closure Plan or Ecosystem Rehabilitation Monitoring Report), facilitating improvements in the Ecosystem Establishment Strategy, as well as the S&T model, ongoing monitoring, maintenance and associated TARPs.

The duration of the monitoring 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.

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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 13.1 and Stage 52, but also recognising that further development and implementation of appropriate methodologies and spatial extents is needed.

Indicative monitoring programs are proposed below, all of which are either currently implemented or have been the subject of several studies. These form the framework for development of ecosystem rehabilitation monitoring.

In addition to these, 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 adaptive management 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, which is reflected in the preliminary TARP (Section 9.8).

Monitoring will be conducted at an appropriate spatial scale, and parameters may include:

- flora (general health and abundance, evidence of flowering and fruiting, pests and disease, recruitment);
- weeds (species, density and location);
- fauna (opportunistic observations of both vertebrates and invertebrates); and
- nutrient cycling (evidence of decomposition, soil formation, etc.).

Frequencies for adaptive management monitoring will decrease over time and may also decrease with improved confidence for subsequent rehabilitation areas. In the meantime, the following indicative timeframes are presented, which consider current uncertainties and risk profiles (e.g. weed spread):

- monthly or bimonthly (every two months) 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).

Additionally, on-ground land management personnel capture regular area-based data on:

- weed species extent and abundance (cover);
- methods of control and herbicide usage; and
- annual change for defined management areas.

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Data from adaptive management monitoring (including that captured from land management personnel) will be used to update and improve knowledge around appropriate vegetation communities end-states, trajectories, TARP, substrate suitability, ecosystem establishment strategy, ongoing weed management and introduction of fire. Where ecosystem development appears to be deviated, the data will also provide a basis for further investigation and effective management (corrective action) of substrate limitations, exotic fauna, pests and disease. This process is currently underway for apparent poorer performing areas of Pit 1, Stage 13.1 and Stage 52.

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 during the wet season, 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.

A workshop to discuss appropriate monitoring metrics was held with stakeholders and subject matter experts in April 2024. Outcomes have informed a pilot trial for this type of monitoring, which commenced in April 2025 on Pit 1. The results of this trial will be used to develop a suitable Ecosystem Rehabilitation Monitoring Plan (or similar mechanism), with methodologies to be outlined in future iterations of the MCP.

Recorded data for each woody stem may include differential GPS tagging, species identification and size class. Recorded data for non-woody species (understorey) may include total percentage ground cover and species richness. Additional habitat formation indicators may include litter cover, coarse woody debris, dead standing trees and energy sources (flowering, fruiting and non-ant terrestrial invertebrates).

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. A training dataset for common savanna woodland tree species, published by Jansen and others (2023) and publicly available, may be used to improve this level of certainty, however it is acknowledged that this technology is currently in the early stages of development. With further advancement, remote sensing methods may eventually be a suitable replacement for some components of ground-based monitoring.

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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.

Work is also ongoing with the OSS Drone Operation and Technology Solutions (DOTS) team, to build on the above studies and related techniques for remote sensing of vegetation presence (including weeds), health and recruitment.

Indicative timing at this stage for the multispectral remote sensing is to start at three years, and then conduct the monitoring every three years, considering seasonal variations in plant health and flowering/fruiting, 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. Potential methods for the latter are described by Supervising Scientist (2025b).

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, but not yet confirmed, 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 will be conducted at the end of the wet season, at relevant stages in the rehabilitation trajectory, providing an understanding of the general trajectory of litter decomposition and nutrient cycling processes over time.

A workshop was held with stakeholders and subject matter experts in July 2024. Outcomes, including suitable methodology for this type of monitoring, are currently under discussion with stakeholders and subject matter experts and will be confirmed in future iterations of the MCP. An indicative monitoring program has been provided in Table 9-11.

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Table 9-11: Preliminary nutrient cycling monitoring program

Year	Analytes	Depth (cm)
0	Total nitrogen and total carbon (using dry combustion techniques) Microbial biomass and respiration Mineralisable nitrogen (ammonium and nitrate)	0–10
5	Total nitrogen and total carbon (using dry combustion techniques) Microbial biomass and respiration Mineralisable nitrogen (ammonium and nitrate)	0–10
10	Total nitrogen and total carbon (using dry combustion techniques) Microbial biomass and respiration Mineralisable nitrogen (ammonium and nitrate)	0–10
15	Total nitrogen and total carbon (using dry combustion techniques) Microbial biomass and respiration Mineralisable nitrogen (ammonium and nitrate) Litter decomposition	0–10 10–20 20–30
25	Total nitrogen and total carbon (using dry combustion techniques) Microbial biomass and respiration Mineralisable nitrogen (ammonium and nitrate) Litter decomposition	0–10 10–20 20–30

An appropriate spatial extent for sampling locations is currently under discussion with stakeholders and subject matter experts.

Additional and/or more frequent soil sampling may also be conducted in response to monitoring outcomes for other criteria. Analytes will be tailored to observed impacts and may include those listed above as well as particulate organic carbon (POC), pH, electrical conductivity (EC), cation exchange capacity (CEC), salts, sulfate, nutrients, metals and physical characteristics such as bulk density and particle size distribution (PSD). Corrective actions will be implemented as needed with additional monitoring to assess a return to desired trajectory.

It is further noted that methodology is likely to change over time, particularly for analysis of microbial communities (e.g. omics – which in broad terms studies the structure, function and mapping of genomes).

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 threatened and introduced species. Monitoring methods were discussed during a workshop with stakeholders and subject matter experts in May 2024 and will be trialled in planned surveys of developing rehabilitation areas, LAAs and reference sites. The adopted methodology will allow for systematic and repeatable surveys (considering expected advances in technology) and collection of suitable species-specific abundance data that can be compared against closure criteria.

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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 – as above) 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. Particular natural and artificial habitat features will be targeted.

9.6.7 Invertebrate Monitoring

Ants provide an important functional role for natural processes. As recommended by Oberprieler and others (2020), ant populations will be monitored in rehabilitation areas, with comparison against closure criteria and appropriate reference communities.

Methodology will be consistent to that described by Oberprieler and others (2020), commencing at five years after initial revegetation and at five-year intervals thereafter until relinquishment.

Other invertebrate groups may also be monitored opportunistically and/or via adaptive management monitoring

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 in 2016 (Wright, 2019a), 2019 (Wright, 2019b), 2024, 2025 and at Jabiluka in 2022 and 2023 (in collaboration with University of Queensland) included:

- quantitative ground cover assessment, including estimated fuel loads and post-fire recovery;
- midstorey and overstorey height and Diameter at breast height (DBH) 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, and may also include sampling and analysis of substrate in regard to nutrient cycling impacts. Depending on the planned and actual extent of the prescribed burn, appropriate sampling densities will be determined in consultation with subject matter experts.

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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 based on the extent and severity of the event, in consultation with stakeholders.

9.7 Corrective Actions and their Effectiveness

The spider web diagram at the beginning of this chapter assigns a subjective 60% complete for the progress status relating to ‘corrective actions’. This reflects remaining uncertainty around the effectiveness of corrective actions, which is expected to improve with further implementation on rehabilitation areas.

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 9-12, along with status and effectiveness.

Table 9-12: Corrective Actions for Ecosystem (all ‘Active’ Corrective Actions)

Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
A2	Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas	Satisfactory	As observed in particular areas of Stage 13.1 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 vegetation community, 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, it is well understood.
A11	Infill planting and seeding to maintain suitable vegetative cover on final landform	Satisfactory	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.

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Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
			Methods are well understood and have previously proven successful, with effectiveness expected to be improved with further implementation at scale.
A18	Targeted weed management	Satisfactory	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. Increased herbicide application may also present implications to catchment water quality, prompting investigation into alternative practices and/or additional water treatment. This action was effectively implemented for historically weed dominated areas at the TLF, and is expected to improve with further documentation and implementation of similar methodology in other areas.
A19	Targeted introduced fauna management	Satisfactory	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. 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	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 seed bank, enhance vegetation growth or improve nutrient cycling processes. Effectiveness will be improved with implementation at scale, if required.
A21	Targeted pest and disease management	Marginal	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, and may include the use of pesticides and/or fungicides. Effectiveness will be improved with implementation at scale, if required.
A26	Modified fire management	Satisfactory	This corrective action may include exclusion of fire from, or strategic introduction of fire to 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. With continued ecosystem development and increased fire resilience, the strategic introduction of fire over time will continue to strengthen those resilience mechanisms. Although exclusion of fire is well understood and actively managed, the introduction of fire to rehabilitation areas will be further improved with long-term implementation and monitoring.

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Unique Identifier	Corrective Action	Current Effectiveness	Status of Effectiveness
A22	Supplementation of habitat features and/or migration corridors	Marginal	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, chainsaw hollows, stag trees or habitat logs, may be considered. Effectiveness 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, closure criteria for most ecosystem similarity specify that particular parameters may be 'on a trajectory towards, that of the reference ecosystem(s)'. Therefore, quantitative states (and particular parameters) 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 to critically review and revise this model and develop a more 'fit-for-purpose' S&T model (UES, 2024). 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. Information from the S&T model developed by UES is being used to develop a Geographic Information System (GIS) tool, that enables specific ecosystem parameters to be recorded and tracked over time for defined rehabilitation management areas, allowing assessment as to whether an area is developing desirably or not. Preliminary operationalisation of the pilot monitoring tool began in 2025, with further refinement and use of the tool planned for rehabilitation monitoring in 2026.

With consideration of the current S&T model presented by UES (2024), 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). An indication of expected normal states, deviated states and the relevant corrective actions described in Section 9.7 are presented in Table 9-13 to Table 9-18. It is acknowledged that there are remaining gaps and a lack of specificity for some triggers. While qualitative triggers may be more appropriate for some parameters, justification of this or otherwise further development of quantitative trigger values will be included in subsequent iterations of the MCP, and upon continued implementation of monitoring programs.

Notably, this TARP is reliant on a single trigger or major threshold level, which was the approach suggested by UES (2024). This approach is based on the detection, investigation and correction of deviations at an early stage. The Ecosystem Rehabilitation Monitoring Plan (or similar mechanism) will include roles and responsibilities for monitoring over each period, and implementation of any required corrective actions. Where monitoring indicates a normal state or trajectory, no response will be required except for continued monitoring until relinquishment. Where monitoring indicates a deviated state (or trigger), an investigation and additional monitoring may be conducted to determine

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contributing causes and extent, and likely trajectory path. Particular corrective actions may be implemented until a normal state or trajectory is re-established.

As the S&T model is finalised and targeted, and onsite operational investigations are progressed over the next 12 months, it is expected that the Savanna Woodland TARPs will be much further refined and articulated in the 2026 MCP. The development of similar TARPs for other proposed vegetation communities (e.g. seasonally inundated savanna) will also be considered for future iterations of the MCP, where appropriate.

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Table 9-13: Trigger, Action, Response Plan for Savanna Woodland CRE (Establishment, 0–2 years)

Landform/ substrate	Vegetation (overstorey/midstorey)	Vegetation (understorey)	Fauna	Threats
Normal State (No response)				
• Growth medium is suitable. • No erosional impacts, with appropriate groundcover spreading from planted/seeded species. • Rockpiles constructed in appropriate areas. • Baseline (limited) nutrient cycling processes introduced from nursery tubestock.	• Early separation of overstorey strata from ground cover. • Minimum overstorey/midstorey density 600 stems/ha. • Richness greater than 12 spp./ha (ave.18) with Acacias grouped (min. 3 spp.).	• Minimum richness of 10, with appropriate composition.	• Pioneering fauna – a variety of invertebrate groups and visiting birds.	• Presence of weeds is less than 5%.
Deviated State (trigger)				
• Evidence of sustained surface water pooling. • Presence of erosion, or sparse groundcover. • Impacted vegetation growth.	• Less than 600 surviving stems/ha, or of poor health (including stunted Eucalyptus). • Richness less than 12 spp./ha (with Acacias grouped). • Inappropriate composition or relative abundance.	• Richness less than 10, or with inappropriate composition.	• Limited evidence of pioneering fauna.	• Presence of Class A weeds. • Presence of other weeds is greater than 5%, locally increasing or impacting rehabilitation. • Evidence of exotic fauna, pests or disease.
Action/Response (following additional investigation)				
• A2. Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform.	• A18. Targeted weed management. • A19. Targeted introduced fauna management. • A21. Targeted pest and disease management

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Table 9-14: Trigger, Action, Response Plan for Savanna Woodland CRE (Years 2–5)

Landform/ nutrient cycling	Vegetation (overstorey/midstorey)	Vegetation (understorey)	Fauna	Threats
Normal State				
• Scattered evidence of fungi and localised litter cover accumulation. • No erosional impacts.	• Minimum overstorey/midstorey density 550 stems/ha. • Development of vegetation stratification, with dominant trees trending to an average height of 4 m. • Canopy cover trending to an average of 10%. • Localised variations in composition aligning with landform features. • Richness greater than 11 spp./ha (ave.17) with Acacias grouped (min. 3 spp.).	• Appropriate groundcover from planted/seeded species. • Recruitment of additional understorey species increasing richness to a minimum of 15, with appropriate composition.	• Select and/or tolerant invertebrate groups and vertebrate species, including birds.	• Presence of weeds is less than 10% and stable.
Deviated State (trigger)				
• Erosional impacts are increasing. • Impacted vegetation growth.	• Less than 550 healthy stems/ha. • Inappropriate composition or relative abundance (e.g. proportion of Acacias). • Limited stratification, with dominant trees not trending to an average height of 4 m or canopy cover of 10%. • Richness less than 11 spp./ha (with Acacias grouped).	• Grass cover that competes with species richness and/or increases susceptibility to wildfire. • Inappropriate groundcover or species composition. • Richness less than 15, or with inappropriate composition.	• Limited vertebrate/invertebrate colonisation.	• Presence of Class A weeds • Presence of weeds is greater than 10%, locally increasing or impacting rehabilitation. • Wind or drought impacts developing rehabilitation. • Presence of exotic fauna, pests or disease is impacting rehabilitation.
Action/Response (following additional investigation)				
• A2. Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas. • A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A22. Supplementation of habitat features and/or migration corridors. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A19. Targeted introduced fauna management. • A21. Targeted pest and disease management.

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Table 9-15: Trigger, Action, Response Plan for Savanna Woodland CRE (Years 5–10)

Landform/ nutrient cycling	Vegetation (overstorey/midstorey)	Vegetation (understorey)	Fauna	Threats
Normal State				
• Litter cover increasing, with evidence of decomposition. • Localised increases in nutrient cycling processes. • No erosional impacts.	• Minimum overstorey/midstorey density 525 stems/ha. • Clear stratification with some heterogeneity, with dominant trees trending to an average height of 8 m. • Canopy cover trending to an average of 15%. • Localised variations in composition. • Richness greater than 10 spp./ha (ave.16) with Acacias grouped (min. 3 spp.). • Some flowering and fruiting.	• Appropriate groundcover from planted/seeded species. • Recruitment/ introduction of additional understorey species increasing richness to a minimum of 25, with appropriate composition.	• Early vertebrate colonisation with presence of some adaptable species from each fauna group. • Presence of invertebrate diversity (e.g. ants, grasshoppers, termites, beetles, wasps, spiders).	• Presence of weeds is less than 10% and stable.
Deviated State (trigger)				
• Limited evidence of nutrient cycling. • Erosional impacts are increasing. • Impacted vegetation growth.	• Less than 525 healthy stems/ha. • Inappropriate composition or relative abundance (e.g. proportion of *Acacias*). • Limited stratification, with dominant trees not trending to an average height of 8 m or canopy cover of 15%. • Limited localised variations in composition. • Richness less than 10 spp./ha (with Acacias grouped).	• Grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Inappropriate groundcover or species composition. • Richness less than 25, or with inappropriate composition.	• Limited vertebrate/invertebrate colonisation.	• Presence of Class A weeds • Presence of weeds is greater than 10%, locally increasing or competing with desired groundcover. • Wildfire impacts developing rehabilitation. • Wind or drought impacts developing rehabilitation. • Presence of exotic fauna, pests or disease is impacting rehabilitation.
Action/Response (following additional investigation)				
• A2. Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas. • A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A22. Supplementation of habitat features and/or migration corridors. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A19. Targeted introduced fauna management. • A21. Targeted pest and disease management. • A26. Modified fire management.

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Table 9-16: Trigger, Action, Response Plan for Savanna Woodland CRE (Years 10–15)

Landform/ nutrient cycling	Vegetation (overstorey/midstorey)	Vegetation (understorey)	Fauna	Threats
Normal State				
• Increasing rates of litter decomposition. • Evidence of increasing nutrient cycling processes, aligned with increased accumulation of leaf litter and coarse woody debris. • No erosional impacts.	• Minimum overstorey/midstorey density 500 stems/ha. • Clear vegetation stratification with increasing heterogeneity, with dominant trees trending to an average height of 12 m. • Canopy cover trending to an average of 25%. • Localised variations in composition. • Richness greater than 9 spp./ha (ave.15) with Acacias grouped (min. 3 spp.). • Most flowering and fruiting with some recruitment.	• Appropriate groundcover from planted/seeded species. • Recruitment/ introduction of additional niche understorey species increasing richness to a minimum of 30, with appropriate composition.	• 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.	• Presence of weeds is less than 10% and stable. • Evidence of increased resilience to fire, wind, drought, pests and/or disease. • Introduction of trial cool burns in a mosaic pattern to some areas.
Deviated State (trigger)				
• Evidence that nutrient cycling processes are not developing appropriately. • Erosional impacts are increasing. • Impacted vegetation growth.	• Less than 500 healthy stems/ha. • Inappropriate composition or relative abundance (e.g. proportion of *Acacias*). • Limited stratification and/or heterogeneity, with dominant trees not trending to an average height of 12 m or canopy cover of 25%. • Limited localised variations in composition. • Richness less than 9 spp./ha (with Acacias grouped). • Limited flowering and fruiting.	• Grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Inappropriate groundcover or species composition. • Richness less than 30, or with inappropriate composition.	• Vertebrate/invertebrate richness is not increasing.	• Presence of Class A weeds. • Presence of weeds is greater than 10%, locally increasing or competing with desired groundcover. • Wildfire impacts developing rehabilitation. • Wind or drought impacts developing rehabilitation. • Presence of exotic fauna, pests or disease is impacting rehabilitation.
Action/Response (following additional investigation)				
• A2. Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas. • A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A22. Supplementation of habitat features and/or migration corridors. • A20. Addition of organic materials and/or fertiliser beyond that planned. • A26. Modified fire management.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A19. Targeted introduced fauna management. • A21. Targeted pest and disease management. • A26. Modified fire management.

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Table 9-17: Trigger, Action, Response Plan for Savanna Woodland CRE (Years 15–25)

Landform/ nutrient cycling	Vegetation (overstorey/midstorey)	Vegetation (understorey)	Fauna	Threats
Normal State				
• Sustainable rates of litter decomposition. • Evidence that nutrient cycling processes are stabilising and supporting sustainable growth. • No erosional impacts.	• Minimum overstorey/midstorey density 440 stems/ha. • At least three vegetation strata with moderate heterogeneity, with dominant trees emergent and trending to an average height of 20 m. • Canopy cover trending to an average of 32%. • Localised variations in composition integrated with landscape features. • Richness greater than 8 spp./ha (ave.13) with Acacias grouped (min. 3 spp.). • Most flowering and fruiting with increased recruitment.	• Appropriate groundcover from planted/seeded species. • Recruitment/ introduction of additional niche understorey species increasing richness to a minimum of 40, with appropriate composition.	• Increasing vertebrate/invertebrate richness and abundance.	• Presence of weeds is less than 10% and stable. • Evidence of resilience to fire, wind, drought, pests and/or disease. • Continued introduction of cool burns in mosaic patterns.
Deviated State (trigger)				
• Evidence that nutrient cycling processes are not stabilising and supporting sustainable growth. • Erosional impacts are increasing. • Impacted vegetation growth.	• Less than 440 healthy stems/ha. • Inappropriate composition or relative abundance (e.g. proportion of *Acacias*). • Less than three strata and/or limited heterogeneity, with emergent Eucalypts not trending to an average height of 20 m or canopy cover of 32%. • Limited localised variations in composition. • Richness less than 8 spp./ha (with Acacias grouped). • Limited flowering, fruiting or recruitment.	• Grass cover, that competes with species richness and/or increases susceptibility to wildfire. • Inappropriate groundcover or species composition. • Richness less than 40, or with inappropriate composition.	• Vertebrate/invertebrate richness or abundance is not increasing.	• Presence of Class A weeds. • Presence of weeds is greater than 10%, locally increasing or competing with desired groundcover. • Intense wildfire impacts rehabilitation. • Wind or drought impacts developing rehabilitation. • Presence of exotic fauna, pests or disease is impacting rehabilitation.
Action/Response (following additional investigation)				
• A2. Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas. • A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A22. Supplementation of habitat features and/or migration corridors. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A19. Targeted introduced fauna management. • A21. Targeted pest and disease management. • A26. Modified fire management.

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Table 9-18: Trigger, Action, Response Plan for Savanna Woodland CRE (Years 25+)

Landform/ nutrient cycling	Vegetation (overstorey/midstorey)	Vegetation (understorey)	Fauna	Threats
Normal State				

• Sustainable rates of litter decomposition.
• Evidence that nutrient cycling processes are supporting sustainable growth.
• No erosional impacts.
	• Minimum overstorey/midstorey density 440 stems/ha.
	• At least three vegetation strata with moderate heterogeneity, with characteristic Eucalypts emergent and dominant with an average height of at least 20 m.
	• Canopy cover ranging from 15–50% and averaging approximately 32%.
	• Localised variations in composition integrated with landscape features.
	• Richness greater than 6 spp./ha (ave.11) with Acacias grouped (min. 3 spp.).
	• All species flowering, fruiting and/or recruiting to fill gaps.
	• Potential early evidence of hollow development and/or demonstrated potential for this to occur.
		• 35–85% groundcover from planted/seeded species.
		• Minimum richness for each functional group:
		  ○ 1 x shrub (legume).
		  ○ 5 x shrub (non-legume).
		  ○ 4 x grass (perennial).
		  ○ 7 x grass (annual).
		  ○ 5 x forbs/vines (legume).
		  ○ 24 x forb (non-legume).
		  ○ 4 x vine (non-legume).
			• Increasing vertebrate richness and abundance.
			• Increasing invertebrate richness and abundance with several distinct ant taxonomic groups.
				• Presence of weeds is less than 10% and stable.
				• Proven resilience to fire, wind, drought, pests and/or disease.
				• Established fire management program, including mosaic burning.

Deviated State (trigger)				

• Evidence that nutrient cycling processes are not supporting sustainable growth.
• Erosional impacts are increasing.
• Impacted vegetation growth.
	• Less than 440 healthy stems/ha.
	• Inappropriate composition or relative abundance (e.g. proportion of *Acacias*).
	• Less than three strata and/or limited heterogeneity, with emergent Eucalypts averaging substantially less than 20 m in height or 32% canopy cover.
	• Limited localised variations in composition.
	• Richness less than 6 spp./ha (with Acacias grouped).
	• Limited flowering, fruiting or recruitment.
		• Less than 20% groundcover or lack of accumulated organic materials
		• Grass cover, that competes with species richness and/or increases susceptibility to wildfire.
		• Minimum richness for each functional group is less than:
		  ○ 1 x shrub (legume).
		  ○ 5 x shrub (non-legume).
		  ○ 4 x grass (perennial).
		  ○ 7 x grass (annual).
		  ○ 5 x forbs/vines (legume).
		  ○ 24 x forb (non-legume).
		  ○ 4 x vine (non-legume).
		• Ongoing fire management program is not established.
			• Vertebrate/invertebrate richness/abundance is not increasing and/or expected taxonomic groups are not present.	• Presence of Class A weeds.
				• Presence of weeds is greater than 10%, locally increasing or competing with desired groundcover.
				• Intense wildfire impacts rehabilitation.
				• Wind or drought impacts rehabilitation.
				• Presence of exotic fauna, pests or disease is impacting rehabilitation.

Action/Response (following additional investigation)				
• A2. Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas. • A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A22. Supplementation of habitat features and/or migration corridors. • A20. Addition of organic materials and/or fertiliser beyond that planned.	• A11. Infill planting and seeding to maintain suitable vegetative cover on final landform. • A18. Targeted weed management. • A19. Targeted introduced fauna management. • A21. Targeted pest and disease management. • A26. Modified fire management.

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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. Future work for each of the metrics shown in the spider web diagram is described below.

9.9.1 Closure Criteria

Work towards closure criteria is currently at 80%. Based on relevant studies and consultation with stakeholders and subject matter experts, further clarification and development of closure criteria will be undertaken, including development of measurable performance indicators and statistical methods to demonstrate achievement, for Ministerial approval via future iterations of the MCP.

9.9.2 Relevant Studies and Knowledge Base

Work on relevant studies and an appropriate knowledge base is currently at 70%. Projects listed against KKNs are outlined in Appendix 5.1. Studies that are currently planned or being progressed by the RRP include:

- Investigation into potential waste rock substrate constraints to ecosystem establishment, including any feasible mitigation and/or amelioration options (linked to KKN ESR7D).
- Consideration of applicable alternative vegetation communities, including ‘seasonally inundated savanna’ and others as needed, and further related work that may be required (linked to KKN ESR3A).
- Monitoring data from rehabilitation areas consolidated and used to update the SERP, which will be used to further refine the Savanna Woodland CRE, S&T model and the Ecosystem Establishment Strategy (linked to KKN ESR3A).
- Finalise review of natural habitat features and potential enhancements, including integration into the Ecosystem Establishment Strategy (linked to KKN ESR2B).
- Development of monitoring methodologies for fauna (vertebrate, invertebrate and introduced) and habitat formation, including for existing rockpile habitat to help inform future design and implementation across the final landform (linked to KKN ESR5B).
- Development of a structured decision-making framework to inform invertebrate pest management (lined to KKN ESR5B).
- Development of a fire implementation and management plan for the final landform (lined to KKN ESR8A).
- Finalisation of the S&T model framework for the proposed broadscale Savanna Woodland CRE, and quantitative indicators for flora, fauna, habitat formation, nutrient cycling and sustainability metrics at specific points in time (linked to KKN ESR5B).

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9.9.3 Preventative Controls

Work on development of effective preventative controls is currently at 50%. Further development of these is subject to the completion of relevant studies, and continued rehabilitation planning. Key works include:

- If the second erosion and sediment trial progresses (see Chapter 6, Section 6.3.1.4), investigation of opportunities for increased density and/or alternative species mixes to promote early ground cover establishment and help reduce erosion from the newly constructed landform.
- Targeted research trials for important species which are data deficient, and/or have had limited success.
- Finalisation of the Savanna Woodland CRE, particularly regarding understorey composition.
- Further development of schedule for final landform construction, initial planting of large areas and connectivity to surrounds, documented in an operational plan, procedure or similar.
- Continued development of a multi-year Weed Strategy to manage weeds across the RPA using a best-practise, targeted, risk-based approach.
- Continued documentation of threatening weed and introduced fauna species on rehabilitation areas, including their ecology, potential impact to rehabilitation and effective management.
- Further implementation of effective controls for preventing weed spread to rehabilitation areas and surrounds.
- Dedicated resource planning, and training for weed management in revegetation areas.
- Development of guidance note for bulk material movement planning regarding ideal substrate characteristics for growth layer of the final landform.
- Optimisation of methods and timing for fertiliser re-application.
- Further investigation into the decomposition rates of biopots used in previous research areas.
- Staff training on entomology, pests, pathogens and disease for improved identification, sampling and proactive treatment.

9.9.4 Monitoring Program

Development of the ecosystems monitoring program is currently at 60%. Further development of these is subject to the completion of relevant studies, and further consultation with stakeholders. Key components include:

- Reporting of monitoring data, as a foundation for the required annual Ecosystem Rehabilitation Monitoring Report.
- Continued implementation and refinement of adaptive management monitoring, with appropriate spatial scale and frequency across all rehabilitation areas.
- Development of appropriate and repeatable plot size, frequency and methodology for vegetation ground survey.

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- Development of methodologies for assessment of nutrient cycling and litter decomposition on waste rock.
- Development of an Ecosystem Rehabilitation Monitoring Plan and Ecosystem Rehabilitation Monitoring Report (or similar mechanisms to track and report progress), in consultation with stakeholders.
- Continue to build understanding of ant community trajectories in rehabilitated ecosystems.
- Continued support of remote sensing methods, which are likely to increase efficiencies and confidence in future.

9.9.5 Corrective Actions

Work on development of effective corrective actions is currently at 60%. Further development of these is subject to the completion of relevant studies, and ongoing monitoring. Key components include:

- Further development of triggers in the TARP to inform corrective actions, where appropriate.
- Further development of S&T Model for deviated states, with detailed corrective actions.
- Further exploration of strategies for reducing weeds in revegetation areas whilst preserving the development of desirable species.
- Further definition of quantitative triggers for when invertebrate pest management should be implemented, and optimal methods for control.

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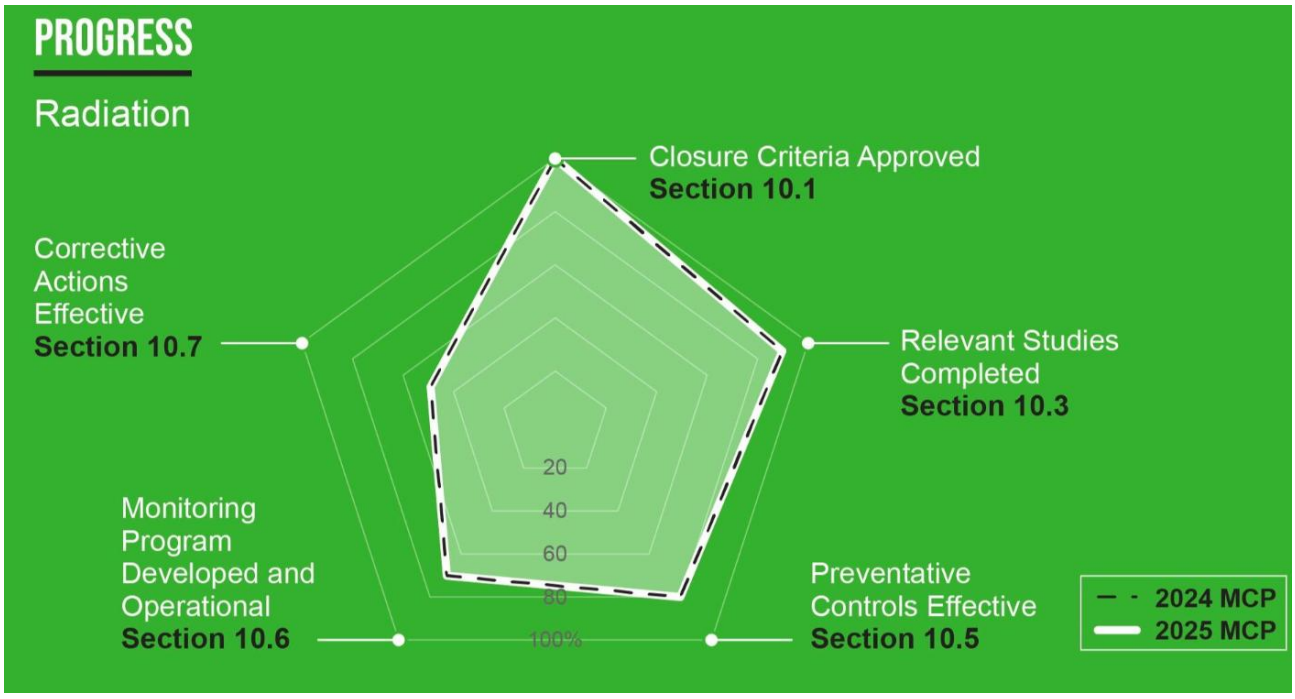
10 RADIATION

The purpose of this chapter is to consolidate information relevant to radiation with regards to the closure of Ranger. There are two ERs specifically 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. The dose assessment was updated in the 2024 MCP to include the whole of site rather than just Pit 3. Following OSS review of the 2024 dose assessment, additional work is occurring to better quantify exposure from cover material (90%, Section 10.3).
- Preventative controls to manage post-closure radiation doses 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).



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10.1 Closure Objectives and Criteria

Table 10-1 lists the ERs specifically related to the radiation theme.

Table 10-1: Radiation theme: Environmental Requirements

Environmental Requirement	ER Reference
1 Environmental Protection *1.2 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.*	*1.2(c*
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)
4 Air Quality *4.1 Emissions of gaseous and particulate contaminants must conform with Australian law, and, taking into account the most recently published and relevant Australian standards, codes of practice, and guidelines, be managed to minimise the effects of particulate and gaseous contaminants from the point of view of all possible radiological, physical and chemical hazards.*	4.1
5 Radiological Protection *5.1 The company must implement a system to control the radiological exposure of people and the environment arising from its mining and milling activities. The system and the dose limits applied must comply, at the minimum, with relevant Australian law taking into account the most recently published and relevant Australian standards, codes of practice, and guidelines. Subject to clause 5.3, the company must achieve the following outcomes:* *(b) Radiation doses to people who are not company employees or contractors must be kept as low as reasonably achievable and must always remain less than the dose limit for members of the public.* *(c) Ecosystems surrounding the Ranger Project Area must not suffer any significant deleterious radiological impacts.* *5.2 The company must comply with any dose constraints established or amended by the Supervising Authority or the Minister with the advice of the Supervising Scientist to take account of other anthropogenic radiation sources such that subject to clause 5.3, the total radiation dose received by members of the public does not exceed the applicable dose limit.*	5.1(b) 5.1(c) 5.2
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.

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Table 10-2: Radiation – approved Closure Criteria

Objective	Outcome	Parameter	Closure 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.

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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 is described in Section 4.8.2.
- Whilst the majority of uranium was extracted from the mineralised ore, some uranium and other decay products remain 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, 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 in soils or cover materials.

10.3.2 Natural Background Levels

The pre-mining radiological conditions for Ranger were investigated and reported by OSS (Bollhöfer *et al.,* 2014). Average radium-226 concentrations in materials above 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).

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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

The Ranger Rehabilitation Project Team 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 is 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.

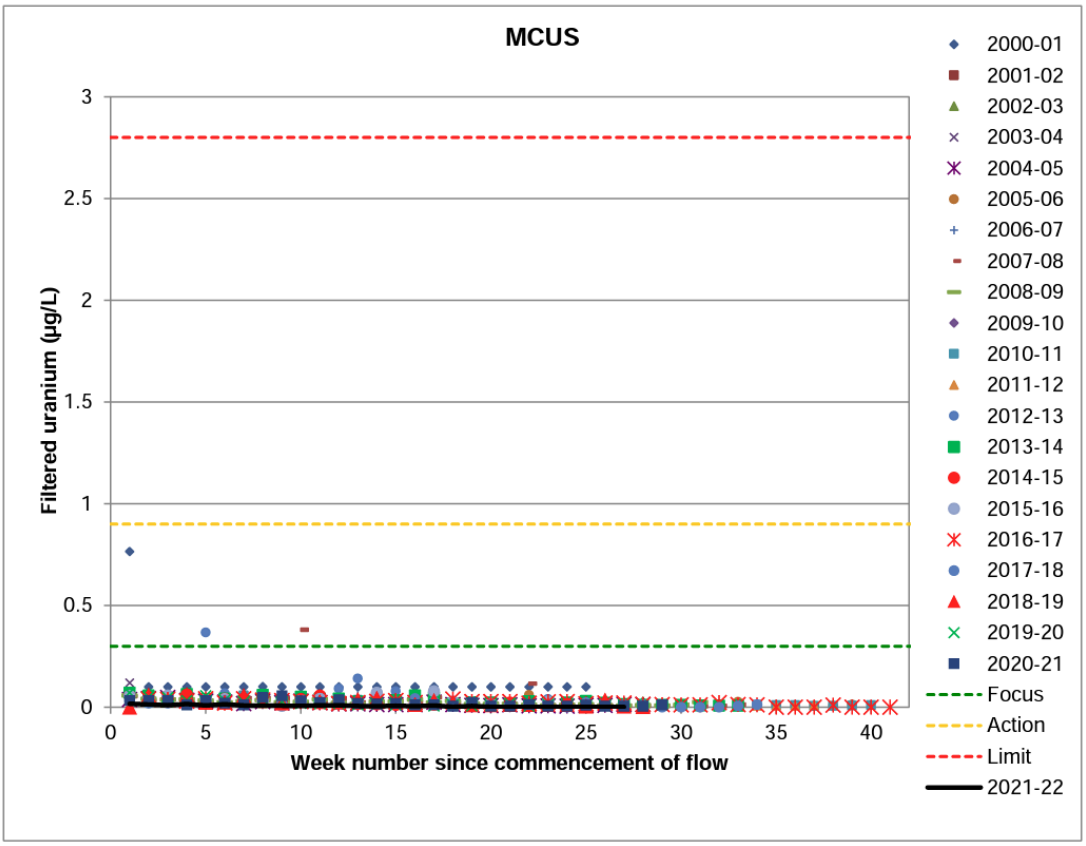

Figure 10-1: Dissolved uranium concentrations in Magela Creek Upstream of Ranger

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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.

10.3.3 Factors that Affect the 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

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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.

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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.

The scope of the assessment is whole of final landform. Having said that, the assessment will be updated in accordance with feedback received from the OSS with regards to cover material and after groundwater plume management has been determined. The BPT information will inform a future update to the surface water modelling, which in turn will provide revised CoPC concentrations for an updated whole of final landform radiation dose assessment. It is also noted that a review of the water quality modelling is being undertaken to more accurately define the potential ingestion impacts of Ra226 and Po210.

For the radiation assessment:

- The post-closure air quality modelling results from SLR (2018) are used for dust inhalation and radon decay product inhalation doses. Noting:
    - the exhalation rate used in the calculation was 0.37 Bq(Rn222)/m^2.s per Bq(Ra226)/g (this was based on the average of the 'rain' and 'no rain' values provided in Bollhöfer and Doering, 2016);
    - the average 'night time concentration' was calculated to be 46 Bq/m^3 and the average day time concentration was calculated to be 5 Bq/m^3 (noting that both of these estimates are above natural background levels and relate directly to the emission of radon from the cover materials);
    - it is assumed that most public activity occurs during the day, therefore an incremental value of 10 Bq/m^3 was used as the closure increment for public doses (noting that for this assessment the UNSCEAR dose factor of 9 nSv per Bqh/m^3 has been used).
- The basis of the ingestion dose assessment is the changes in radionuclide concentrations in soils and water that can be taken up into plants and animals and then consumed. 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 50% exceedance) water quality data have been used (see Section 7.3.3 for details). For both cases, the contaminant concentrations at peak loads and 10,000 years post closure have been assessed. As noted above, the inputs to the ingestion dose assessment are being reviewed and will be included in future iterations of the MCP (likely the 2026 MCP).

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- For gamma radiation, the following criteria have been applied:
    - accumulation of radionuclides in soil from dust deposition is based on a mixing depth of 10 mm (Karste, 2007);
    - placement of cover material containing 0.73 Bq/g of U238 decay chain radionuclides on all of the active mine site (~800 ha) but not for the land application areas (as noted above, the inputs to the gamma dose assessment associated with cover material are being reviewed and will be included in future iterations of the MCP (likely the 2026 MCP);
    - an increment of 0.08 Bq/g of Ra226 on the LAA's (Safe Radiation, 2013);
    - no natural gamma background subtraction;
    - a gamma dose factor of 0.50 µGy/h per Bg(Ra-226)/g (noting that this value is for specific purposes including age dependency and characteristics of the radionuclides in the material).

10.3.4 Predicted Radiation Dose to the Public

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 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 whole of final landform 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) as the current dose constraint and 1 mSv/y as the public dose limit.

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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	0.072	0.019	0.115	0.023
5Y	0.070	0.016	0.113	0.020
10Y	0.095	0.014	0.155	0.020
15Y	0.181	0.017	0.298	0.026
Adult	0.046	0.009	0.074	0.012
Scenario 2: Resident at Mudginberri – 1,040 hours on mine area – 11.9% of bush tucker from mine area				
1Y	0.144	0.101	0.184	0.105
5Y	0.139	0.095	0.179	0.099
10Y	0.160	0.092	0.215	0.097
15Y	0.237	0.094	0.343	0.103
Adult	0.113	0.083	0.139	0.086
Scenario 3: Resident at Mudginberri – 1,040 hours on mine area – 50% of bush tucker from mine area				
1Y	0.188	0.163	0.216	0.166
5Y	0.170	0.143	0.197	0.146
10Y	0.169	0.128	0.206	0.132
I 15Y	0.210	0.124	0.280	0.131
Adult	0.120	0.102	0.138	0.105
Scenario 4: Resident at Mudginberri – 1,040 hours on mine area – 100% of bush tucker from mine area				
1Y	0.246	0.243	0.257	0.246
5Y	0.209	0.205	0.220	0.208
10Y	0.180	0.174	0.193	0.177
15Y	0.175	0.163	0.197	0.168
Adult	0.130	0.127	0.138	0.129
Scenario 5: Resident at Mudginberri – 1,040 hours on mine area – bush tucker from wider Magela Creek				
1Y	0.198	0.162	0.229	0.166
5Y	0.179	0.142	0.210	0.146
10Y	0.183	0.128	0.225	0.132
15Y	0.239	0.124	0.319	0.132
Adult	0.126	0.102	0.147	0.105

* Current dose constraint = 0.3 mSv/y; Public dose limit = 1 mSv/y.

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10.3.5 Radiation Effects on Terrestrial and Aquatic Biota

The assessment considered the published soil (Doering and Bollhofer, 2016a) and water (Doering *et al*., 2019) guideline values for the radiation protection of non-human biota.

Reference values for soil of 1,000 Bq/kg of Ra226 and water increments above natural background of 14 mBq/L (filter fraction) or 22 mBq/L (total fraction) were published. These guideline values were calculated from the closure criteria dose rates of 100 uGy/h (terrestrial organisms) and 400 uGy/h (freshwater organisms) using site-specific CR data where available and 95th percentile values (i.e. conservative approach).

For soils, the highest incremental changes are due to the placement of the rehabilitation cover material, which is expected to contain 730 Bq/kg of Ra226. For water, Table 10-7 shows the predicted Ra226 modelled incremental concentrations at the modelled receptor locations (using P90 groundwater load and P50 water concentrations).

Table 10-7: Modelled Ra226 Increments

Location	Ra-226 (mBq/L)	
	Peak	Year 10,000
End RPA	1.3	<0.1
Mudginberri	0.1	<0.1
MG003	0.1	<0.1
MG005	0.1	<0.1
MG009	1.0	<0.1
Reference Value (filter fraction value)	14	14

For both terrestrial and aquatic non-human species, the reference values are not exceeded.

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 bow-ties, 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 the risk acceptance threshold and will be the subject of further work to reduce uncertainty, strengthen the preventative controls, and/or strengthen the corrective actions.

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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

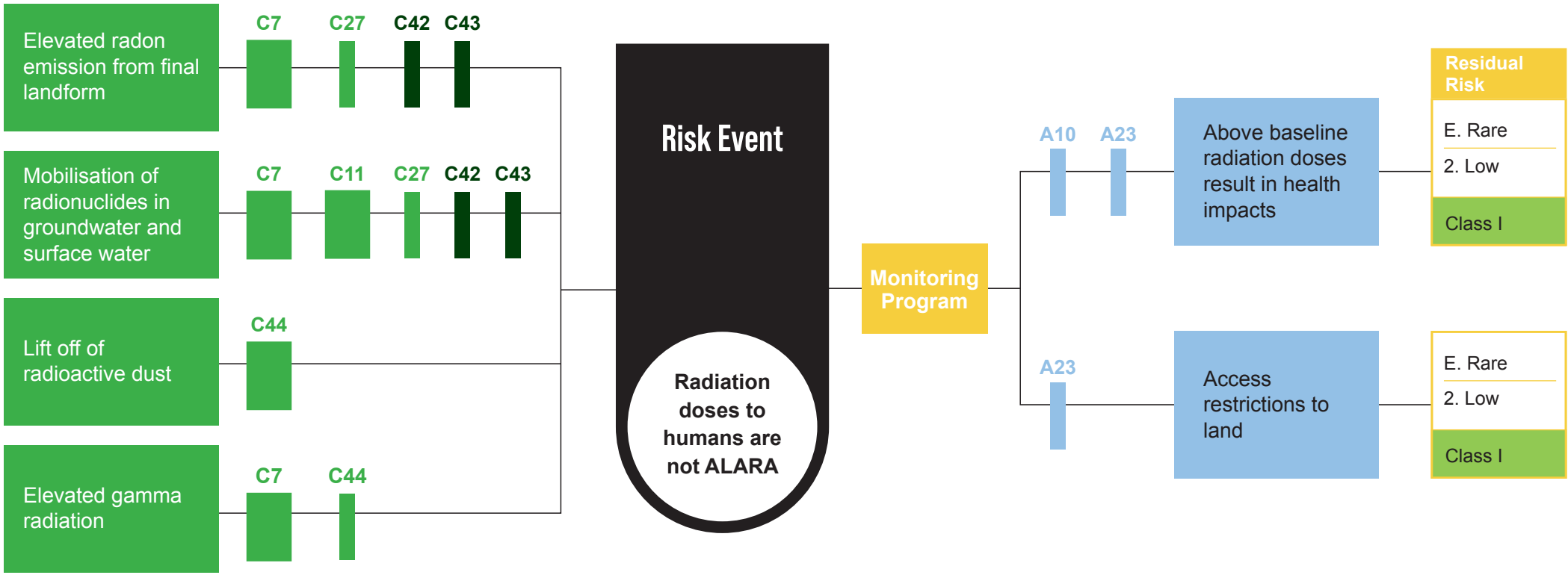

Figure 10-2: Bow-tie diagram for radiation doses to humans (R1)

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 ecosystem establishment strategy
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

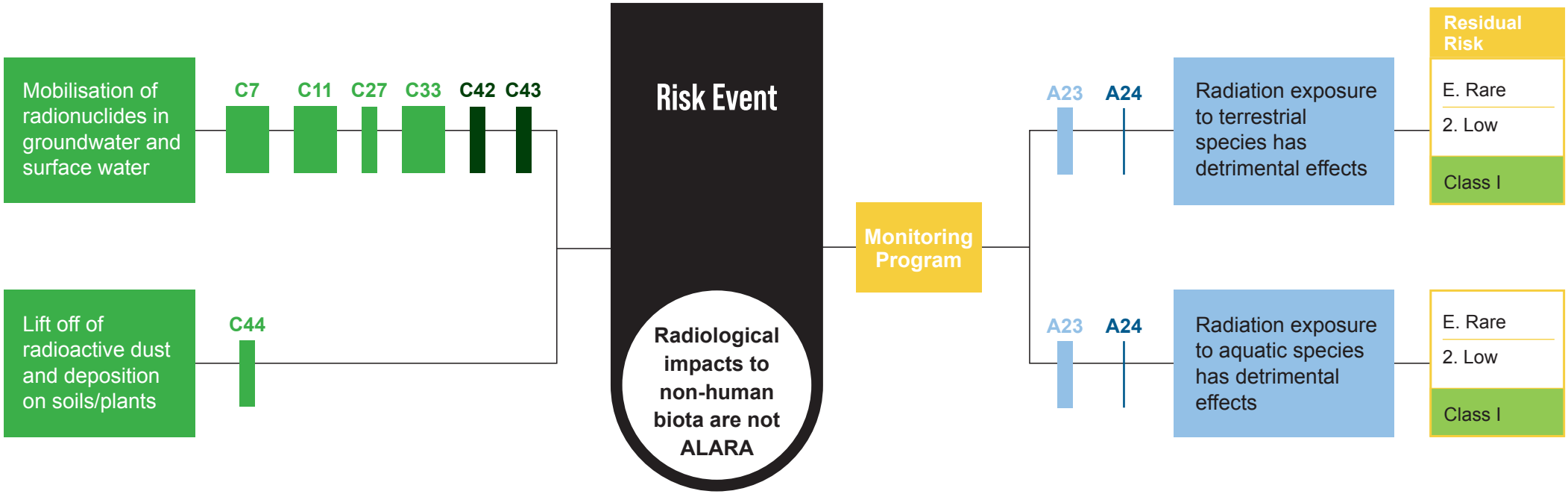

Figure 10-3: Bow-tie diagram for radiation doses to non-human biota (plants and animals)(R2)

10.5 Preventative Controls and their Effectiveness

As described in Chapter 5 of this MCP, this section describes how well the Ranger Rehabilitation Project Team 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 whole of landform doses well below the public dose limit under the base case (P50) and worse case (P90) scenarios (i.e. less than 1.0 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 Pit 1 and Pit 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) has been (Pit 1) or will be (Pit 3) buried below the conservative long-term average water table.
C11	Pump and treat from Pit 1 and Pit 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, or if at all required, until the 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.

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Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
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. 2016b, 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 2023 (ERA, 2025) 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.

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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 final landform 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	Duration and frequency ad hoc, depending on monitoring target. As areas of the mine reach final landform and then several years after Final Landform at a time suitable to confirm stabilised radon exhalation from waste rock.
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	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 for 2 years after Pit 3 decant wells turned off.

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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 TARP. This TARP will be updated as required in future iterations of the MCP.

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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

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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.

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10.9 Future Work

The current radiation impact assessment shows that doses are below dose limits for human and non-human biota. Nevertheless, further engineering design of closure activities and additional remediation actions are planned, which will then inform an update to the whole of final landform radiation dose assessment. The following future work relevant to radiation is planned:

- reviewing the radionuclide content of the final landform cover material and its spatial placement to better define gamma dose estimates;
- reviewing the water quality modelling to more accurately define potential ingestion impacts of Ra226 and Po210;
- the radiation assessment will be re-run for the whole of final landform after the following has occurred:
    - the review of the cover material radionuclide content;
    - the review of the water quality modelling regarding Ra226 and Po210;
    - the review of the surface water quality modelling has generated revised CoPC concentrations including representation of any required groundwater plume management remediation.

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 Final Landform application is submitted, they will be included in the update to the radiological impact assessment.

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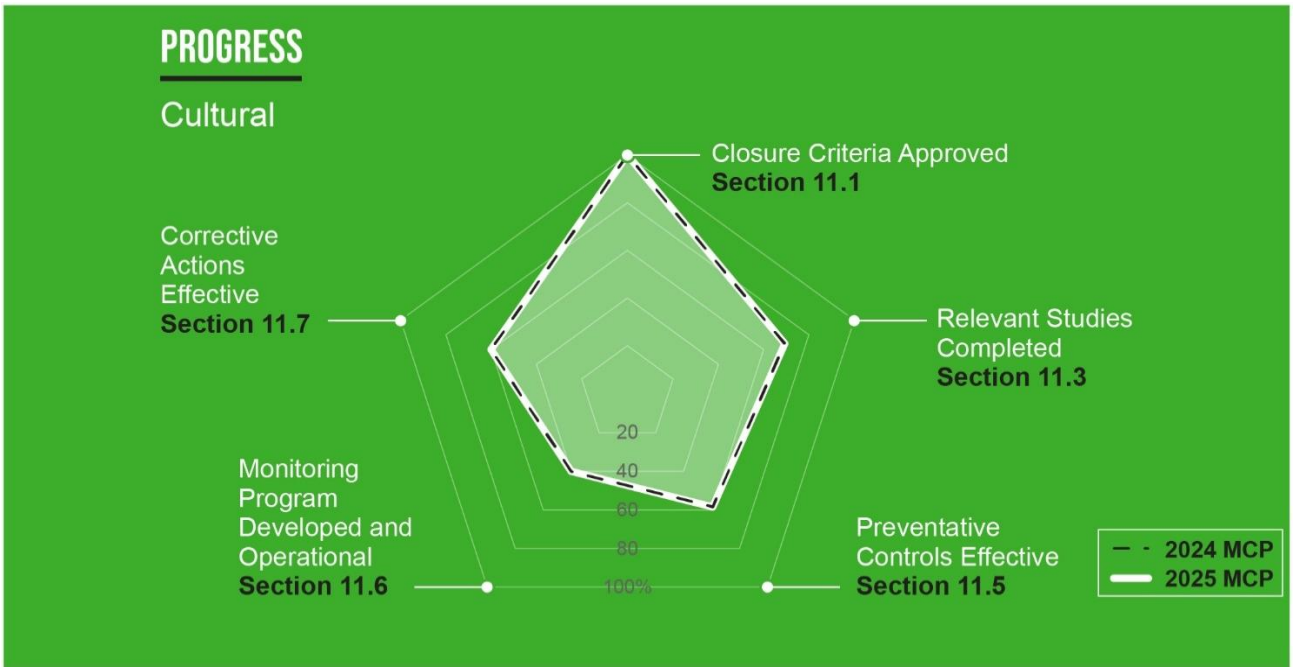
11 CULTURAL

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. Ministerial approval for the cultural closure criteria was approved via the 2023 MCP (100%, Section 11.1).
- There is a substantial body of knowledge that has been generated 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 planned (60%, Section 11.5).
- The mechanism for facilitating a cultural closure criteria monitoring program has yet to be agreed. A triennial cultural heritage audit program began during operations and is continuing through rehabilitation (40%, 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).



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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 Rehabilitation 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. The Traditional Owners raised a major 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.

Other matters raised by Traditional Owners included, 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. 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 the Ranger Rehabilitation Project Team.

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Table 11-1: Cultural Closure Criteria – approved via 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 Rehabilitation 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

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Objective	Outcome	Parameter	Summary of criteria[1]
	Traditional Owners are observing improvement in biodiversity on the landform	Natural species numbers and diversity appropriate for stage of rehabilitation	≥7 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
	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/or 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.

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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. The Garde (2015) report 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.

Aboriginal cultural heritage management on the RPA is governed by both NT and Commonwealth legislation including the *Heritage Act 2011* (NT), the *Northern Territory Aboriginal Sacred Sites Act 1989* (NTASSA), the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (*Cth) and the EPBC Act.

The Heritage Act protects all Aboriginal (and Macassan) archaeological sites. The Heritage Act requires prior approval where proposed works may knowingly disturb an archaeological site or object, including where proposed works may require the site or object to be relocated.

All sacred sites in the Northern Territory are protected by the NTASSA 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. Under the *Aboriginal Land Rights (Northern Territory) Act 1976* (Section 23 (1) (ba)), the NLC functions 'to assist Aboriginals in the taking of measures likely to assist in the protection of sacred sites on land (whether or not Aboriginal land) in the area of the Land Council'.

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:

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- 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 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

The internal Ranger Rehabilitation Project Cultural Heritage Management System (CHMS) is a multi-faceted system used for onsite operational purposes. The CHMS will be reviewed on finalisation and implementation of a formal Cultural Heritage Management Agreement (CHMA). The agreement will provide for:

- 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 (including demarcation and signage).
- Land disturbance permit process, involving:
    - Assessment of proposed works outside the former operations boundary with respect to previously surveyed areas, site locations 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. Additional measures can also be designed on a case-by-case basis depending on the proposed works in the vicinity and the potential for impact to the site.
    - Review/confirm controls in the field before work is undertaken.
    - On-site monitoring during works, where agreed.
    - 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).
- Mandatory cultural heritage training for all Ranger Rehabilitation Project personnel, Category 1 contractors and other contractors completing work outside the former operations boundary.

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- Audit schedule for cultural heritage site condition and review of Cultural Heritage Management System effectiveness and consistency with the Cultural Heritage Management Agreement.

In 2006, ERA and GAC (on behalf of the Mirarr Traditional Owners) developed a protocol for cultural heritage management on the RPA. The protocol applies only to the area outside the former operations boundary due to the significant level of previous disturbance within that area. The protocol includes an undertaking that a formal Cultural Heritage Management Agreement (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 RPA has undergone extensive cultural heritage investigation since 2006 with approximately 75% of the lease area subject to systematic pedestrian survey (refer to Section 11.5 for further discussion). A total of 139 cultural heritage sites have been recorded on the RPA, with approximately 70 background artefact scatters also recorded.

As part of the 2019 Feasibility Study, a review of ERA's internal CHMS 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.

As part of the CHMS, ERA developed an internal closure and rehabilitation cultural heritage management plan. The draft management plan, which has been provided to GAC for review is not approved and is subject to the proposed Cultural Heritage Management Agreement.

ERA's internal plan includes proposals for 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 CHMS; and
- transfer of cultural data to Traditional Owners.

In 2021, Rio Tinto updated their principles of cultural heritage management to ensure co-management of the CHMS with Traditional Owners, with the aim of all Rio Tinto sites (and Rio Tinto managed sites) achieving co-management by 2026. The principles of co-management will be included in the formal Cultural Heritage Management Agreement. In addition, in May 2024, Rio Tinto issued an updated template, with guidance, for Cultural Heritage Management Plans. The template was developed to address previous cultural heritage audit findings and take a holistic approach to

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protect cultural heritage. Further work, discussed in Section 11.9, is required for the Ranger CHMS (including the Cultural Heritage Management Agreement) to achieve these principles and guidance.

11.3.2 Post-closure Use and Diet

ERA began engaging with the Mirarr People, the NLC and GAC on their plans for the future of the rehabilitated site in 2006. The Traditional Owners indicated that the area will most likely be utilised for both recreational and cultural use as freehold Aboriginal land. 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 define habitation, use of traditional plants and animals and the assumed post closure bush food diet (Paulka, 2016). Further consultation with Traditional Owners to refine the types and amounts of post-closure bush food sourced from the RPA is welcomed.

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 billabongs on the RPA (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 re-form 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. The fauna detailed by Garde (2015) are either aquatic based or likely to gather in the riparian areas around water and food sources.

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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 (Garde, 2015). 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) (Garde, 2015).

The majority of the floristic species identified in the Garde (2015) 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, the related cultural criteria outcome that they may affect and where these potential impacts are addressed in this MCP. The impact assessment was based on the cultural activity descriptions provided by Garde (2015). No direct consultation with the Mirarr Traditional Owners has yet taken place as part of the preliminary assessment presented in Table 11-2.

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 and relevant closure criteria. 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. As above, no direct consultation with the Mirarr Traditional Owners has yet taken place as part of the risk assessment and residual risk ratings.

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Table 11-2: Preliminary Assessment of the Potential impacts to future cultural land use activities (ongoing consultation with Traditional Owners required)

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 impact to hunting and food gathering is predicted from the planned closure and rehabilitation 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 between Pit 3 and Mudginberri Billabong if manganese concentrations remain at predicted levels post-closure and Pit 3 is no longer acting as a groundwater sink.	7.3.11
Seasonal camping (extended camping)	20 days per person per year	Magela Creek and associated riparian zones (e.g. camp MG009)	No impact to seasonal camping (extended) predicted from the planned closure and rehabilitation 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; 7.3.9
		Billabongs[2]	No impact to seasonal camping (extended) predicted from the planned closure and rehabilitation activities.	
Recreation	10 days per person per year	Magela Creek and associated riparian zones (undisturbed)	No impact to recreational visits predicted from the planned closure and rehabilitation 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; 7.3.9
		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 impact predicted to ritual visits from planned closure and rehabilitation activities. However, Traditional Owner perception may impact ritual land use. Further consultation is 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).

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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 ecosystem vegetation establishment strategy, including appropriate species mix
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 Collaborate with Traditional Owners to understand acceptance of proposed works and outcomes
Marginal

Corrective Actions

A1 Maintenance of erosion and sediment control measures
Satisfactory

A2 Undertake earthworks to repair significant substrate limitations, 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

A28 Early notification and consultation with Traditional Owners and implementation of agreed mitigation
Satisfactory

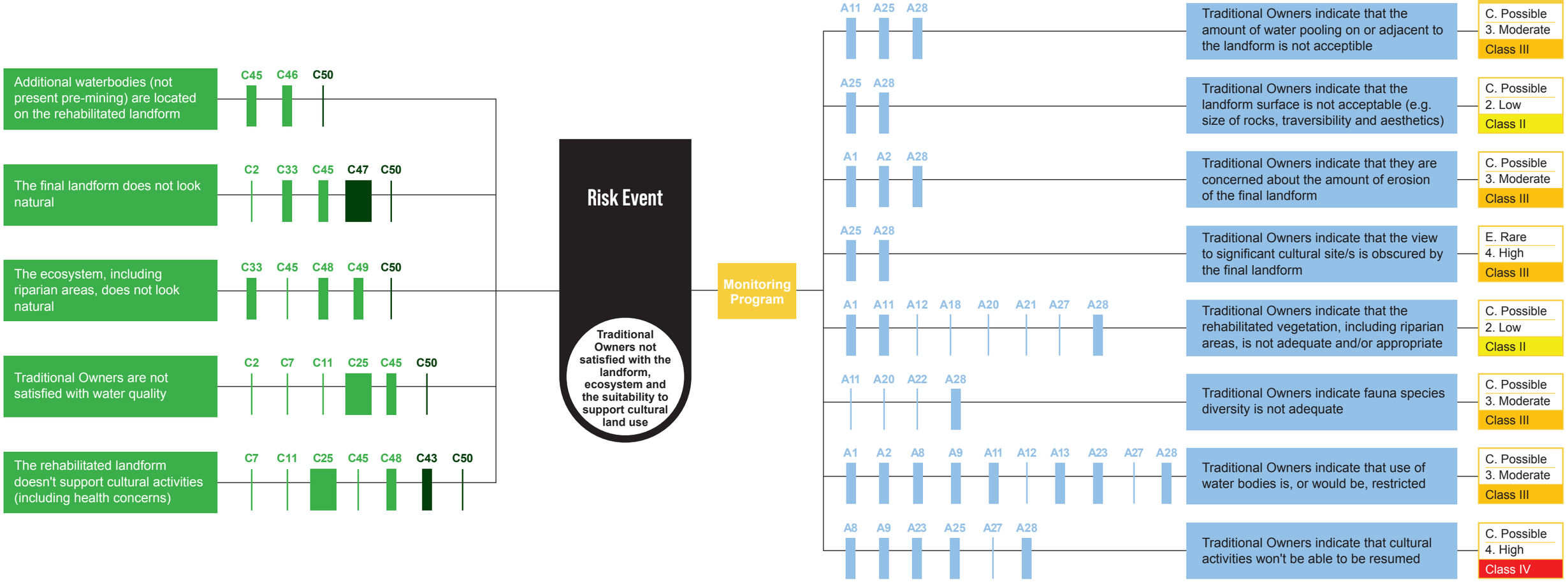

Figure 11-1: Bow-tie diagram for meeting Traditional Owner requirements (CL1)

Preventative Controls

C1 Final landform design, construction and verification
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

C50 Collaborate with Traditional Owners to understand acceptance of proposed works and outcomes
Marginal

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

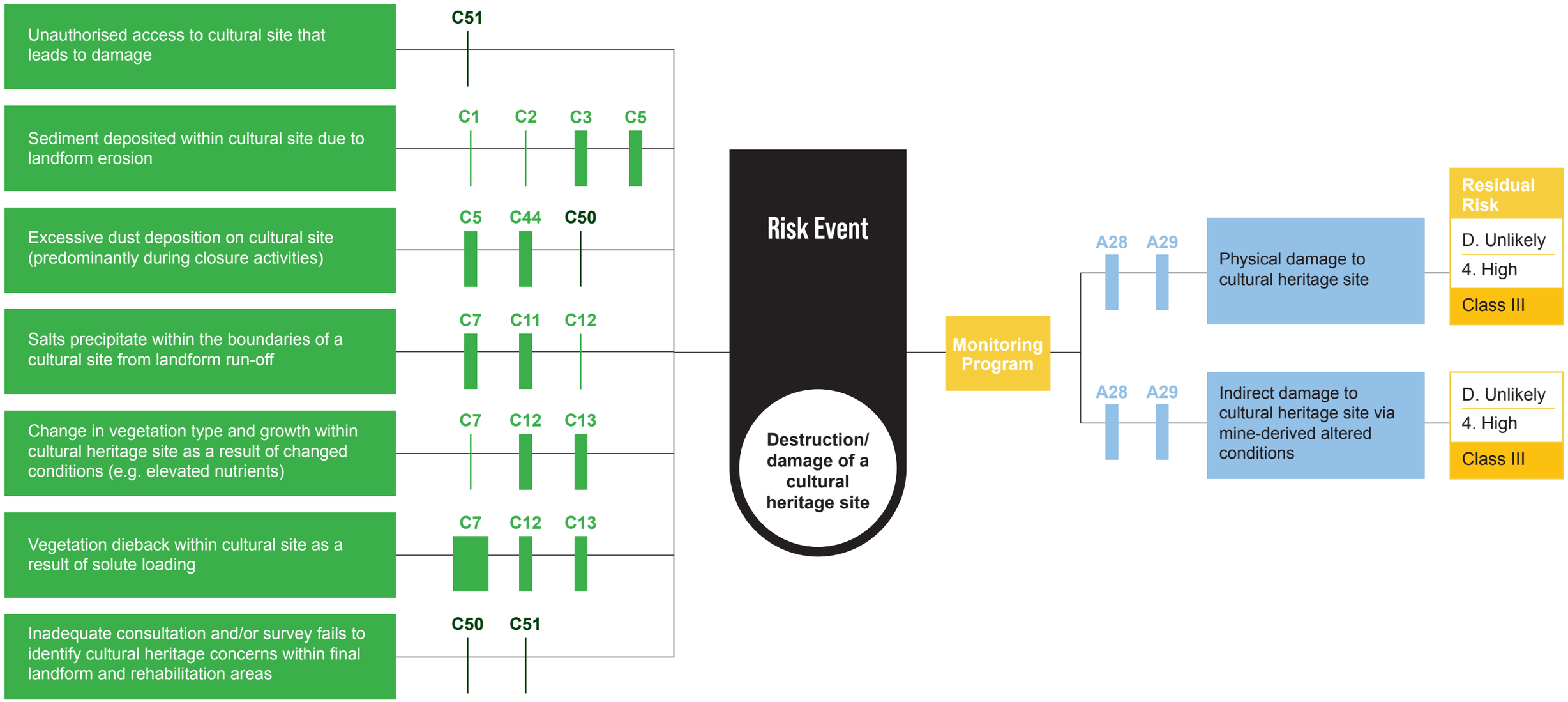

Figure 11-2: Bow-tie diagram for cultural heritage management (CL2)

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 the Ranger Rehabilitation Project Team 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.

During the life of the Project, cultural heritage sites have been identified in proximity to the footprint of the current final landform (i.e. FLV7). Further consultation with the Mirarr People will occur on the footprint of the final landform as its design progresses, and on any resulting impacts to cultural sites.

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.

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For the Mirarr Traditional Owners, maintaining the visual aesthetic and the environmental health within a cultural site is also very important. A line of site assessment was undertaken for an earlier version of the landform design (version 5, current version is 7), which indicated that there will be visual connection between key cultural areas across the landscape (as reported in Garde 2015). Further consultation with the Mirarr is planned as the landform design progresses to better understand potential impacts to cultural sites in close proximity, the visual amenity of those localised areas, and case by case controls that may be required. 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.

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Table 11-3: Preventative controls for Cultural

Unique Identifier	Preventative Control	Current Effectiveness	Status of Effectiveness
'Active' controls			
C1	Final landform design, construction and verification	Marginal	Further work is planned to refine the final landform design to further reduce erosion and denudation rate and to understand the cultural heritage consideration associated with the final landform tie-in. 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 Pit 1 and Pit 3	Marginal to Strong	All tailings gave been deposited at depth into both Pit 1 and Pit 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 Pit 1 and Pit 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
C23	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 ecosystem establishment strategy, including appropriate species mix	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 9.3.3.

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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 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, introduced fauna, fire, pests and natural disturbances	Satisfactory	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. Active and responsive introduced fauna control methods include ground shooting, trapping, pesticides and/or removal. Effectiveness is expected to improve with advances in regional control methods and as the program is implemented for developing rehabilitation areas. For further details refer to Section 9.3.4.
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	Despite challenges such as the absence of topsoil, more than 70 native species have been actively established on the final landform. Outcomes are promising, with monitoring ongoing and used to inform adaptive management requirements. For further details refer to Section 9.3.
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 up to 2.5 GL against the planned production of 1.9–2.1 GL of brine. Refer to Section 7.5 for more details.

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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*., 2016b, 2019) has established transfer factors in bushfoods and further studies may occur. 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	Collaborate with Traditional Owners to understand acceptance of proposed works and outcomes	Marginal	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 closure to ensure the final landform will meet these expectations.
C51	Implement Cultural Heritage Management System	Marginal	The Ranger Rehabilitation Project 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.

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11.6 Monitoring Program

The spider web diagram at the beginning of this chapter assigns a subjective 40% 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 Owners attitudes towards aspects of the cultural closure criteria.

As noted by Garde (2015), 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 should be undertaken annually (as a minimum) and will determine whether 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

The Cultural Reconnection Steering Committee (CRSC) was established by the NLC in 2021. This was funded by the NLC until 2023 with no further source of funding having been identified beyond this period.

At this time, the instrument for monitoring the cultural closure criteria following the rehabilitation of the final landform has not been determined. The Ranger Rehabilitation Project welcomes the opportunity to collaborate with Mirarr Traditional Owners and their representatives on developing a suitable monitoring process. During the rehabilitation phase, further work and consultation to develop a culturally appropriate monitoring program is needed. 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.

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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. Traditional Owners have had several on-site visits to provide feedback on the rehabilitation, revegetation and habitat recreation plans.

Ongoing consultation with the Mirarr Traditional Owners throughout the closure phase is needed and will be a key aspect of the cultural criteria monitoring program. Closure monitoring for cultural criteria will be conducted to 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.

In addition to proposed monitoring for cultural closure criteria, a monitoring program of cultural heritage sites is in place to ensure that sites are protected from direct and indirect impact from the Ranger Rehabilitation Project. During the rehabilitation phase, the cultural heritage monitoring program will follow a similar structure to the established operations process at Ranger. 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 the Ranger Rehabilitation Project through 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 the Ranger Rehabilitation Project and the GAC Board by the external cultural heritage specialist.
- Rio Tinto audits will also be completed 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 GAC, Mirarr Traditional Owners and supported by the Ranger Rehabilitation Project'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 closure criteria and cultural heritage monitoring programs will be informed by engagement with the custodians of the cultural heritage and provide opportunities for 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. Consultation with Traditional Owners and their representatives on the potential corrective actions will be undertaken, allowing Traditional Owners to make fully informed decisions and to allow for rapid response if required.

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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 substrate limitations, 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 (e.g. water and sediment impacted by exposed tailings)	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 are observed. Methods are well understood and have previously proven successful, with effectiveness expected to be improved with further implementation at scale.
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	This action relates to targeted treatment and facilitation of recovery for deviated ecosystem development and is expected to improve with further implementation at scale, if required.

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Unique Identifier	Corrective Actions	Current Effectiveness	Status of Effectiveness
A22	Supplementation of habitat features and/or migration corridors	Marginal	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. Effectiveness 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. It is noted that the effectiveness and strength of this control is dependent on the timing of when the issue is identified, with greater success likely if identified through early consultation (e.g. occur prior to planting).
A26	Modified fire management	Marginal	Although exclusion of fire is well understood and actively managed, the introduction of fire to rehabilitation areas will be further improved with long-term implementation and monitoring.
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.

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With regards to cultural sites, the internal Cultural Heritage Management System has been developed as multi-layered protection against impact to cultural heritage sites. However, in the 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. 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 Geographic Information System 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, a Ranger Rehabilitation Project 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.

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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 ongoing consultation and monitoring program.	Traditional Owners identify an issue through ongoing consultation and monitoring program.
Responsible Person	**Action/Response**	**Action/Response**	**Action/Response**
Site Cultural Heritage Officer (or delegate)		Update site protection measures in line with site protocols and as outlined in the draft 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).
Manager CSP		Assess issue to determine appropriate actions. May require re-design or changes to closure 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.

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Future work for the Cultural theme will consist of five work packages. The work packages are described below

The Ranger Rehabilitation Project welcomes the opportunity to engage with GAC, NLC and the Mirarr Traditional Owners on the following programs.

Consultation on a formal cultural heritage management agreement

As discussed in Section 11.3.1, the Ranger Rehabilitation Project does not have a formal cultural heritage agreement with the Mirarr Traditional Owners. In 2006, an interim cultural heritage protocol was developed with an undertaking that it would be replaced by a Cultural Heritage Management Plan (Agreement). However, The interim protocol remains the guiding document on cultural heritage management at Ranger. A formal Cultural Heritage Management Agreement for rehabilitation is under negotiation and the Ranger Rehabilitation Project Team commits to finalising and implementing the agreement.

Review and update Cultural Heritage Management System

The second work package is to review and update the internal Cultural Heritage Management System subject to the above mentioned CHMA.

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. The Ranger Rehabilitation Project has applied for a new AAPA Certificate for rehabilitation. 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 timeframe for the new AAPA certificate is unknown.

Ongoing cultural heritage management

Cultural heritage management will be ongoing on the RPA. 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

ERA and GAC have been undertaking Cultural Heritage Audits periodically (every three years), which have identified a number of mitigation measures to ensure that protection of cultural heritage sites is adequate. The mitigation measures have been undertaken throughout 2023 and 2024 and will be completed in 2025 following a targeted program of wet season burning.

Ongoing consultation with Mirarr Traditional Owners and their representatives throughout the closure and post-closure phases is critical for the success of the Ranger Rehabilitation Project 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.

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Ongoing and program specific consultation

The final landform design will be reviewed to understand any possible interaction with recorded cultural heritage sites. This will be done in accordance with the CHMA.

As the final landform design is refined, the line of site between significant places within the cultural landscape will be considered and verified. In accordance with the CHMA, the Project team will consult with Traditional Owners where the landform is near significant cultural sites, to understand and address potential impacts to the visual amenity of these localised areas.

Other specific consultation programs will be developed for specific rehabilitation aspects as the Ranger Rehabilitation Project progresses, for example, refining types and amounts of post closure bush food sourced from the RPA.

Additional consultation with, and input from, Traditional Owners is also needed on the cultural criteria, the assessment of the potential impacts to future cultural land use activities, the preventative controls and corrective measures to ensure the controls and measures are suitable.

The Ranger Rehabilitation Project, NLC, GAC and the Mirarr Traditional Owners are aligned on the desire to support Traditional Owners in capacity building to continue the Cultural Reconnection Steering Committee (CRSC) and to conduct some of the monitoring described in this MCP. The exact nature of this support requires further discussion; however, open and transparent consultation will be key for planning the transition of management responsibility to the Mirarr Traditional Owners at final site close-out/relinquishment.

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12 CONSOLIDATED RISK ASSESSMENT

Photo: Initial capping works on Pit 3 surface (2025)

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 Rio Tinto 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. 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.

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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 Rio Tinto risk management framework are to improve execution and reduce risk exposure. To achieve these objectives, Rio Tinto 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 and have updated the Archer risk register accordingly. Under the Management Service Agreement (refer Section 1.1), Rio Tinto manage all aspects of the rehabilitation of Ranger, including the assessment and monitoring of risks via the Archer platform. Accordingly, the consequence (Table 12-1), likelihood (Table 12-2) and risk rating (Table 12-3) tables provided in this chapter and used throughout the MCP align with the Rio Tinto Risk Evaluation Scheme 2024.

The risks captured within the Archer risk register that are relevant to the protection of the environment and the achievement of ERs have been incorporated into the bow-tie diagrams.

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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.

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.

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Table 12-1: Risk assessment consequence table

Consequence	Very Low	Low	Moderate	High	Very High
Health	Acute or chronic health exposure (physical or psychological) that results in illness requiring only first aid treatment for full recovery	Acute or chronic health exposure (physical or psychological) that results in illness requiring medical treatment with full recovery	Acute or chronic health exposure (physical or psychological) that results in illness which leads to a single case of restricted duties, lost time and/or non-life-altering permanent impairment (<30%)	Acute or chronic health exposure (physical or psychological) that results in illness which leads to a single fatality or permanent life-altering impairment (>30%)	Acute or chronic health exposure (physical or psychological) that results in illness leading to multiple (<5 people) fatalities or permanent life-altering impairment (>30%)
Radiation (employees, contractors or public)	Measurable increase in radiation dose with outcomes remaining below dose constraints	Increase in radiation dose above the dose constraints but still below international limits	Increase in radiation dose to above international limits	Radiation doses above 100 mSv to an individual and likely to significantly increase the risk of cancer to that individual	Radiation doses to multiple individuals above 100 mSv or acute radiation syndrome to an individual
License to Operate / Stakeholders (reputation with external stakeholders)	Stakeholder actions resulting in minimal operational or commercial impacts Localised public expressions of concern from stakeholder/s Minimal residual loss of trust and reputation	Stakeholder actions resulting in noticeable operational or commercial impacts equivalent in value to days to weeks of operational inefficiency Localised public expressions of disapproval from stakeholder/s Noticeable residual loss of trust and reputation at the local level with potential to accumulate over time	Stakeholder actions resulting in low level operational or commercial impacts equivalent in value to days to weeks of production Organised local action/prolonged formal high profile disapproval from stakeholders influencing policy, regulation, commercial and/or social and civil society activism at the local level Low level reputation damage requiring local management support to rectify Prolonged local stakeholder scrutiny contributing to cumulative reputation damage	Stakeholder actions including taxation, expropriation, or the imposition of additional delay or regulatory cost resulting in major operational or commercial impacts equivalent in value to weeks to months of production, but not compromising financial viability Organised action influencing relevant policy, regulation, commercial and/or social and civil society activism at the national level Reputation damage on a national scale level (~6 months), credibly constraining future business activities due to prolonged stakeholder scrutiny	Stakeholder actions including taxation, expropriation, or the imposition of additional delay or regulatory cost resulting in major and sustained operational or commercial impacts equivalent in value to months to years of production, compromising the financial viability of the operation and driving a minor formal impairment disclosure Organised action at the international level influencing relevant policy, regulation, commercial and/or social and civil society activism across multiple jurisdictions Reputation damage on an international (~1 year) or national (multiple years) scale, credibly preventing realisation of a major future opportunity or prolonged scrutiny of the Group's operations and business activities and/or requiring transformational change in strategy/leadership

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Consequence	Very Low	Low	Moderate	High	Very High
Communities	Unplanned, temporary, repairable impact with minimal harm to people or physical aspects of a community, or inability to meet social obligations or agreements Impact to cultural heritage of low local cultural or community value (for the people or group impacted) Resolved or compensated within weeks to months	Unplanned, temporary, repairable impact with minor harm to people or physical aspects of a community, or inability to meet social obligations or agreements Impact to cultural heritage of medium local cultural or community value (for the people or group impacted) Resolved or compensated in several months	Unplanned, temporary, repairable impact with medium harm to people or physical aspects of a community, or inability to meet social obligations or agreements Impact to cultural heritage of high local cultural or community value (for the people or group impacted) Difficult to resolve or compensate through routine procedures and takes 6 months to 1 year to rectify	Unplanned, substantial irreparable impact or harm to people or physical aspects of a community, or inability to meet social obligations or agreements Impact to cultural heritage of high regional level cultural or community value (for the people or group impacted) Temporary negative impact on communities' economic viability Difficult to resolve or compensate through routine procedures and can take 1–3 years to rectify Single fatality or permanent life-altering human health impacts to a community member	Unplanned, major and sustained irreparable impact or harm to people or physical aspects of a community, or inability to meet social obligations or agreements Impact to cultural heritage of national level cultural or community value (for the people or group impacted) Major loss of communities' economic viability Difficult to resolve or compensate through routine procedures and takes > 3 years to rectify Multiple fatalities or permanent life-altering human health impacts to communities (<5 people)
Environment	An unplanned, unpermitted or unintended event; resulting in: Harm to the environment that is confined to the operating footprint, affects no locally recognised receptors and can be rectified or reversed within a week	An unplanned, unpermitted or unintended event; or a series of chronic or cumulative events resulting in: Harm to the environment that may extend outside the operating footprint, affects no locally recognised receptors and can be rectified or reversed within 6 months of work effort or natural recovery	An unplanned, unpermitted or unintended event; or a series of chronic or cumulative events resulting in: Harm to a locally recognised receptor that can be rectified or reversed within 6 months to 1 year of work effort or natural recovery or exposure to contaminant of concern above acceptable limits Incident may be difficult to resolve functionally, requiring escalation to a broader internal team	An unplanned, unpermitted or unintended event; or a series of chronic or cumulative events resulting in: Harm to a regionally recognised receptor that can be rectified or reversed within 1–3 years of work effort or natural recovery; or Irreversible harm to a locally recognised receptor; or Acute or chronic exposure causing permanent life-altering human health impacts to a single person	An unplanned, unpermitted or unintended event; or a series of chronic or cumulative events resulting in: Harm to a nationally recognised receptor that can be rectified or reversed with >3 years of work effort or natural recovery; or Irreversible harm to a regionally recognised receptor; or Acute or chronic exposure causing permanent life-altering human health impacts

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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 20-50% of monitoring events over proposed timeframe*	Detected deviations in 5–20% of monitoring events over proposed timeframe*	Detected deviations in less than 5% of monitoring events over proposed timeframe*
General description	Almost certainly will occur	More likely to occur than not	Fairly likely to occur	Unlikely to occur	Extremely unlikely or virtually impossible

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 III**	**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 within the risk threshold and do not require active management
Class II	Risks that lie on the risk threshold and require active monitoring
Class III	Risks that exceed the risk threshold and require proactive management
Class IV	Risks that significantly exceed the risk threshold and need urgent and immediate action

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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. High	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. High	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
ES6 (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
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 III
L1 (Landform) – Erosion characteristics of the rehabilitated landform vary significantly from comparable landforms	Impact of sediment to surrounding ecosystems	C. Possible	3. Moderate	Class III
L2 (Landform) – Tailings are exposed within 10,000 years	Environmental and health impacts at the point of exposure	E. Rare	4. High	Class III
L2 (Landform) – Tailings are exposed within 10,000 years	Tailings are transported out of the pits	E. Rare	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

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Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
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
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	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
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

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Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
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
ES6 (Ecosystems) – Significant presence or abundance of weeds	Further weed spread into surrounds	D. Unlikely	3. Moderate	Class II
ES4 (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
ES5 (Ecosystems) – Ecosystems are not resilient to disturbance	Stakeholders are not satisfied with ecosystem resilience to disturbance – relinquishment is delayed	D. Unlikely	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
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

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Risk Event	Consequence description	Likelihood	Consequence	Residual Risk Rating
ES7 (Ecosystems) – Significant abundances of exotic fauna	Stakeholders are not satisfied with presence and/or management of introduced fauna – relinquishment is delayed	D. Unlikely	2. Low	Class I
ES7 (Ecosystems) – Significant abundances of exotic fauna	Further exotic fauna spread into surrounds	D. Unlikely	2. Low	Class I
R1 (Radiation) – Radiation doses to humans are not ALARA	Above baseline radiation doses result in health impacts	E. Rare	5. Low	Class I
R1 (Radiation) – Radiation doses to humans are not ALARA	Access restrictions to land	E. Rare	5. Low	Class I
R2 (Radiation) – Radiological impacts to non-human biota are not ALARA	Radiation exposure to terrestrial species has detrimental effects	E. Rare	3. Low	Class I
R2 (Radiation) – Radiological impacts to non-human biota are not ALARA	Radiation exposure to aquatic species has detrimental effects	E. Rare	3. Low	Class I

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13 TIMING AND FINANCIAL PROVISION FOR CLOSURE

Photo: Water lily (*Nymphaea violacea*)

13.1 Rehabilitation Provision

The Energy Resources of Australia Ltd (ERA) rehabilitation provision as at 30 June 2025 was $2.4 billion. 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 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 2025 of the preferred plan and represents management's best estimate of cost. The 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 the value of these costs, this has then been discounted at 2.5% to calculate a closure provision.

The provision is allocated between current and non-current liabilities based on the anticipated timing of expenditure, as informed by updated cash flow forecasts. The ultimate cost of rehabilitation is uncertain and can vary in response to many factors including regulator and stakeholder requirements, technological developments, weather variability and market conditions.

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A significant increase to the provision was recorded in the 2024 MCP informed by findings from the 2022 Feasibility Study. Activities beyond 2027 are subject to ongoing studies, which will help to further refine both cost estimates and scheduling.

13.2 Government Agreement

Under the Government Agreement between the Commonwealth and ERA, originally established in 1980, ERA is required to provide financial security for the rehabilitation of the Ranger Project Area. This security is held in the form of cash in the Ranger Rehabilitation Special Account (Trust Fund), administered by the Commonwealth, and supported by bank guarantees.

As at 30 June 2025, the Trust Fund holds $548 million in cash. In addition, bank guarantees totalling $125 million, procured by ERA, are held by the Commonwealth as additional security.

The current level of security was established in 2020, based on ERA's 44th Plan of Rehabilitation (i.e. prior to the reforecast of the cost of the Ranger Project Area rehabilitation). The Plan of Rehabilitation is separate to the Mine Closure Plan. ERA may be required to submit a 45th Plan of Rehabilitation to the Commonwealth. Once accepted by the Minister, the Plan is costed by an Assessor appointed under the Government Agreement. This cost estimate forms the basis for determining the level of security ERA must provide.

A review of the Government Agreement is underway in parallel to the development of a new Section 41 Authority.

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14 MANAGEMENT OF INFORMATION AND DATA

Photo: Black Kites (*Milvus migrans*) and Whistling Kite (*Haliastur sphenurus*)(bottom right)

This chapter provides an overview of the information management systems used by the Ranger Rehabilitation Project 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, the Ranger Rehabilitation Project Team 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.

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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).

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- 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 the Ranger Rehabilitation Project 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 the Ranger Rehabilitation Project maintains these datasets within its various document and data management systems.

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Table 14-1: Indicative data collection types

Type	Storage / software	Reporting	Objective (s)
As built records (drawings)	• Data viewer • Server and centralised data storage systems.	• 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 • Server and centralised data storage systems	• Periodical reports (developed internally and externally) • Ranger Mine Closure Plan (MCP) • ARRTC	• To record and demonstrate progressive remediation and rehabilitation • To inform revegetation strategy
Geochemical QA/QC	• Laboratory Information Management System (LIMS) • 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 • Propeller (surveying tool) • Server and centralised data storage systems	• Internal • Ranger MCP	• Manage and measure changes to works • To record and demonstrate progressive remediation, rehabilitation and erosion control • To inform closure criteria • To input into modelling
Geotechnical testing	• Datamine Discover Geospatial • 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

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Type	Storage / software	Reporting	Objective (s)
Radiation dose (including related Raster, LiDAR and/or drone imagery)	• Labware LIMS Radiation • Server and centralised data storage systems •	• 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)	• Server and centralised data storage systems • ArcGIS	• 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 • Goldsim	• 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/Propeller • 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 • GoldsSIM	• Rehabilitation Progress Report	• To record and demonstrate progressive remediation and rehabilitation • To meet regulatory compliance requirements • To develop and validate water balance model
Incident notification	• Enablon	• Annual Report • Periodical reports (developed internally and externally) • Minesite Technical Committee (MTC)	• To maintain and record incident related information

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