Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_069

Transforming Ranger's TSF to a process water storage facility

SM Paulka *Energy Resources of Australia Ltd, Australia*

D Staggs *Energy Resources of Australia Ltd, Australia*

G Ralls *Tetra Tech Coffey Pty Ltd, Australia*

K Sivarudrappa *Tetra Tech Coffey Pty Ltd, Australia*

J Sigda, *INTERA, United States of America*

Abstract

The former Ranger uranium mine above-ground tailings storage facility (TSF) is a recent addition to an ancient Northern Australian landscape. The Ranger Project Area is surrounded by, but separate from, the dual World Heritage listed Kakadu National Park – recognised for its cultural and natural values. The responsible and safe closure of the TSF is essential with the recent cessation of uranium mining activities. As part of the Ranger Rehabilitation Project, Energy Resources of Australia (ERA) recently converted the TSF into a process water storage facility. The newly named Ranger Water Dam (RWD) will continue to store process water until treatment is completed, following which any residual contaminated material will be managed, and the facility will be deconstructed and revegetated. This paper reviews several of the geotechnical, hydrogeological, and other challenges associated with tailings removal from the TSF and its conversion to the RWD.

ERA removed and transferred 27 Mt of uranium tailings to a nearby open pit for permanent storage. The transfer operation was unique and required specialist geotechnical input to plan and coordinate the tailings removal, including during dredging operations, final pump-out of contained process water, and mechanical removal of remnant tailings solids from the TSF. Methods employed by the mine's consultant dam engineer included a weekly remote review of site monitoring data, frequent site visits at the height of a global pandemic, and office-based computational assessments described in the paper to support activities. All this work successfully met stringent stakeholder requirements and ongoing closure objectives.

The original Ranger TSF design and construction was both a tailings and water storage facility; however, prior to conversion to the RWD a hydrogeological assessment was undertaken to quantify how the loading of groundwater solutes to creeks would change. The results showed that storage of process water would not impact the surrounding environment allowing stakeholders to approve the change in use of the facility.

Keywords: *tailings storage facility, water storage facility, closure, geotechnical, hydrogeology*

1 Introduction

Energy Resources of Australia Ltd (ERA) owned and operated the former Ranger uranium mine since the commencement of operations in 1980. The mine is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 km east of Darwin in the Northern Territory (Figure 1). Ranger's above-ground tailings storage facility (TSF), located in the southwest portion of the mine (Figure 2), is a recent addition to an ancient Northern Australian landscape. The RPA is surrounded by, but separate from, Kakadu National Park; a dual world heritage area listed for its cultural and natural values. The RPA is on Aboriginal land, the traditional lands of the Mirarr people.

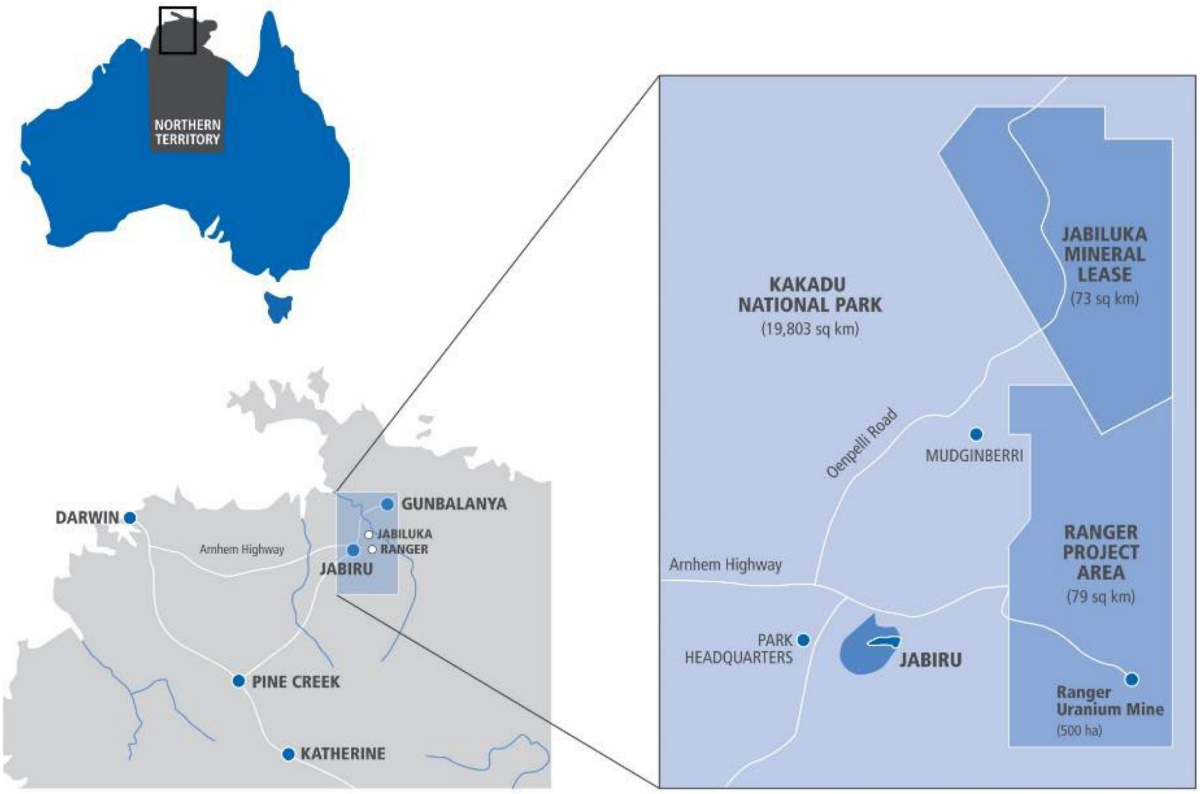

Figure 1 Ranger mine location

Operations at the former Ranger uranium mine ceased on 8 January 2021, with ERA's focus now on final rehabilitation and closure. The overall goal for rehabilitation of the RPA is outlined in the Environmental Requirement's stipulated in the legislation governing the RPA and state that: *the company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.*

ERA's rehabilitation strategy has been developed following extensive scientific research, engineering design and consultation with Traditional Owners and other stakeholders over the past 30+ years. The basis of the rehabilitation strategy is to ensure the environment surrounding by the mine will continue to remain protected after closure, as it has done for the entire 40 years of operations. A key element of this is the responsible and safe closure of the TSF. This is essential to ensure the long-term protection of the surrounding dual world heritage listed area. Tailings at the former Ranger uranium mine must be stored so that they are physically isolated from the environment for 10,000 years and any contaminants arising do not cause any environmental impact for 10,000 years. Models have been developed to assess impacts for 10,000 years for both the above ground and in-pit tailings disposal options; the latter being the only option that can ensure isolation of tailing for the required period.

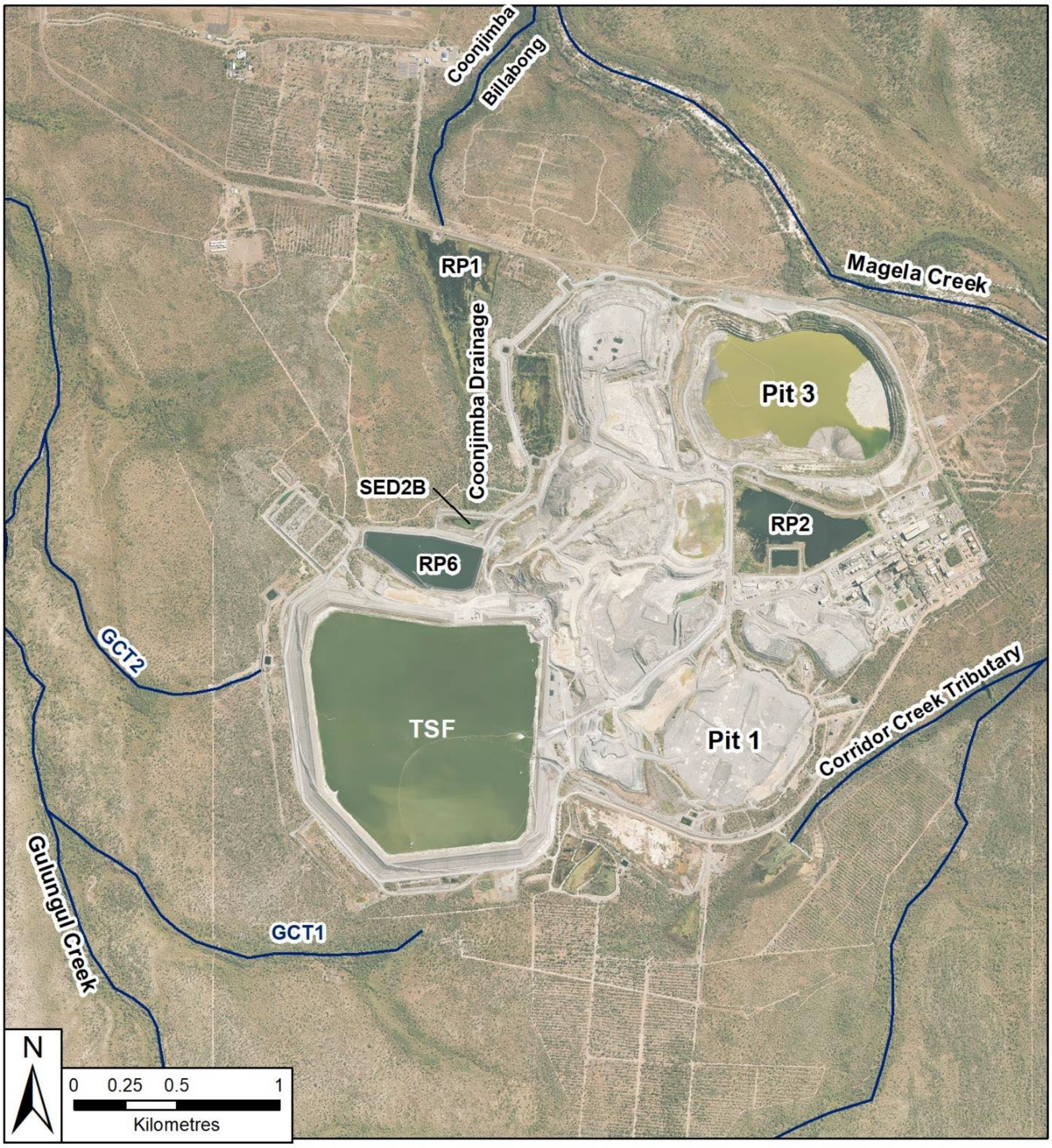

Figure 2 Location of the TSF at Ranger

Tailings management during operations involved the interim disposal into the above ground tailings storage facility with final disposal planned to occur into both mined out Pits 1 and 3, when available. Pit 1 received 25 Mt of tailings directly from the processing plant, transfer was completed in 2012. This pit has now been capped with waste rock and revegetated. Following completion of mining in Pit 3, 27 Mt of tailings from the TSF was transferred to the pit for final disposal, to add to the 20 Mt placed directly from the processing plant. The bulk of transfer from the TSF was undertaken using two cutter suction dredges (Figure 3) with the final remnants being transferred using load and haul trucking. All tailings were confirmed as removed from the TSF to the mined-out Pit 3 in December 2021.

The climate at the former Ranger uranium mine is wet dry tropics with on average 1.5 m of rain falling in 4-6 months of the year. This provides for unique water management challenges to ensure the surrounding areas of Kakadu National Park remain protected. Water capture and treatment is a central focus for the closure project. Following the completion of tailings transfer, ERA converted the TSF into a process water storage facility to allow for containment and storage of contaminated water prior to treatment. The newly named Ranger Water Dam (RWD) will continue to store process water until treatment is completed, following which any residual contaminated material will be managed, and the facility will be deconstructed and revegetated.

Figure 3 TSF dredging operations with Jabiru and Brolga I cutter suctions dredges

The remainder of the paper explores geotechnical and hydrogeological challenges involved in the removal of tailings and conversion to a water storage facility.

2 Geotechnical considerations

2.1 Design and operational background

The Ranger TSF was designed in the 1970s according to best practicable technology at the time as a zoned earth and rockfill structure with a 'clay core' cut-off keyed into weathered rock around the full dam perimeter (Figure 4). The minimum floor elevation is at approximate RL 20 m. The dam is described as a 'ring-dyke' dam, so named because it is a fully enclosing structure without an external catchment and is in the form of an approximate square with sides of about 1 km, giving an initial area of about 100 ha but gradually expanded with each 2-4 m downstream embankment lift to about 125 ha. Stage I construction to crest RL 36 m was completed in 1980, and the final Stage VIII lift to RL 60.5 m was completed in 2012. Mill tailings were continuously deposited, primarily sub-aqueously, into the facility throughout its active life, until 2015.

For conservatism, the dam was assessed under Australian National Committee on Large Dams (ANCOLD 2019) guidelines as having a High B to High A consequence category. The water retention function of the embankment is wholly dependent on the upstream sloping, rip rap protected clay core integrity. If a breach occurred in this zone, depending on the location of the failure, a rapid uncontrolled flow of process water could occur into one of the three adjoining catchments (Gulungul, Coonjimba and Georgetown Creeks) surrounding the dam, with all of them eventually leading to Magela Creek in Kakadu National Park.

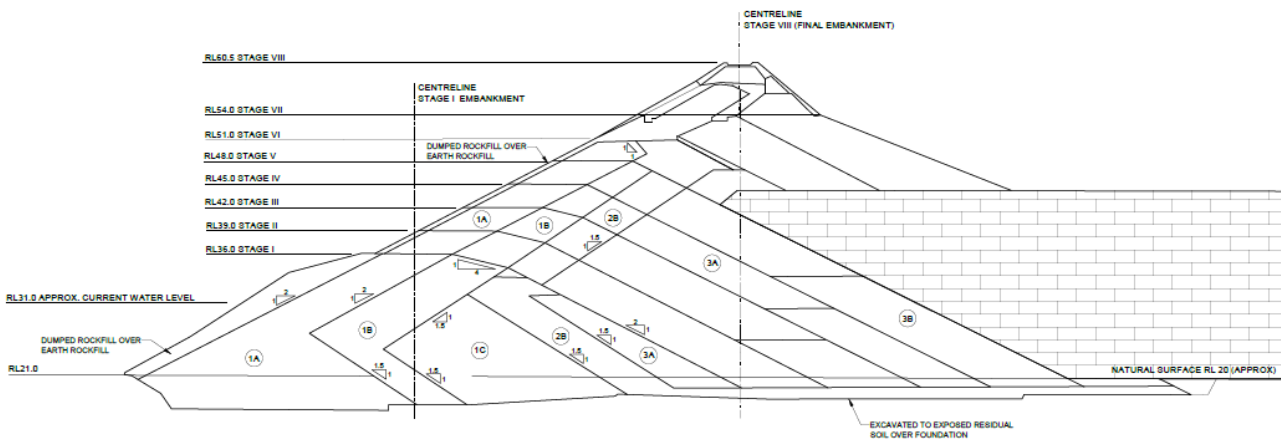

Figure 4 **Ranger TSF embankment cross-section**

The dam does not have a spillway, and elimination of overtopping risk is entirely reliant upon freeboard maintenance, which is controlled by ERA water management and adheres to the prescribed maximum operating level (MOL) for the season (dry or wet). The current MOLs under the Ranger Authorisation are derived from two different Probable Maximum Precipitation (PMP) storm event durations as determined by the Bureau of Meteorology (BoM) and currently set at:

- Dry season - 1 May to 30 November - 1.25 m below the certified crest height (based on 6-hr PMP); and
- Wet season - 1 December to 30 April - 2.72 m below the certified crest height (based on 120-hr PMP).

2.2 Post-operational phase as a TSF

2.2.1 Dredging and notching

Removal of the TSF tailings commenced in 2015 via a single dredge named 'Jabiru' (Figure 3) once Pit 3 became available for long-term tailings storage. The dredging created a need to continually lower the water level so that the dredger remained near the tailings surface. For effective operation of return water and brine concentrator pipelines, for contaminated water treatment, the static head had to be reduced and this was achieved in 2018 by locally reducing the TSF crest elevation from RL 60.5 m to RL 51 m, via an 'East Notch' on the eastern embankment. Works associated with a two-staged 'North Notch' embankment excavation were completed in 2019, to facilitate ongoing daily dredge operational and maintenance access, with the notch location selected based on the underlying natural topography and anticipated final dredge location at the lowest point on the dam floor. Construction of the Stage 2 North Notch to RL 45.1 m included a geotextile-reinforced rockfill pad for launch of a second dredge ('Brolga I') into the TSF via a 650 t crane.

A Stage 3 North Notch was planned and designed; however, the works were abandoned in favour of a rockfill ramp dubbed the 'Amex' ramp in recognition of the fact it would be used to launch a purpose-built amphibious excavator for use in the initial phase of working saturated tailings in the floor clean-up (Section 2.2.4).

The East and North Notch construction works were monitored with field testing and sampling for laboratory test work of the embankment materials undertaken to validate design assumptions. Under the dam's robust governance, independent reviews were conducted and construction compliance reports for the notches prepared in accordance with D5 Standard (Rio Tinto 2021) requirements.

To avoid damage to dredge cutter heads, a nominal 2 m standoff was maintained during dredging near the embankment with its rockfill rip rap protection. This led to remnant tailings 'hang-up' on the embankment and the need for an effective wall cleaning method, as all visible tailings had to be removed from the facility under stringent stakeholder requirements.

2.2.2 Wall cleaning

Various methods of wall cleaning were assessed, including a sprinkler trickle system and hydromining, with a trial of the latter at one point carried out. Neither was deemed effective, as the sprinkler system would not provide full coverage and a hydromining trial created airborne spray that could not be conducted effectively from the embankment, and an alternative method was required. An experienced earthworks construction supervisor with many years' prior experience working on the dam in its active depositional phase was brought back onto the job by the mine and it was rapidly assessed that internal rockfill working platforms constructed of excess rip rap from higher up the embankment slope would be a possible solution, for support of conventional excavation equipment.

In situ testing of exposed remnant tailings was conducted using a dynamic cone penetrometer and the results were interpreted in an assessment which showed that the working platforms would indeed be stable under anticipated loading conditions with the buttressing effect of tailings lower down the batter slope. Mechanical clean-out of remnant tailings using 30 t excavators working on the 1V : 2H upstream embankment face thus commenced in late 2019, with the design engineer's approval, whilst the facility was being actively dredged (Figure 5). Some 500,000 m^3 of tailings were ultimately safely removed from the embankment. Monthly drone flyovers of the facility were conducted during the works and the footage transmitted to and downloaded for review by the design engineer in Perth, Western Australia.

Figure 5 Excavator on temporary working platform inside the dam during dredging operations

2.2.3 Rapid drawdown assessments and monitoring

Several drawdown assessments were conducted during the TSF tailings removal. Maintenance of the clay core stability during continual TSF water level lowering was essential considering planned future use of the dam for process water storage. A range of drawdown rates between 250 and 500 mm/week to RL 26.5 m were considered, with final dewatering below RL 26.5 m to be carried out in either 20 days, or at 0.8 m/month (8-month pump-out) or 1.5 m/month (4.5-month pump-out). Three cases were assessed, Case A considering no geometric changes to the embankment, Case B no embankment geometric changes but leaving a supporting tailings slope (buttress) next to the clay core, and Case C with reduced potential for slope failure by lowering the TSF crest to nominal RL 50 m during dewatering. The end assessment was undertaken via Plaxis 2D finite element modelling using transient methods, with an acceptable factor of safety (FoS) of 1.2 deemed appropriate based on requirements of the D5 Standard (Rio Tinto 2021). All three cases gave results meeting the minimum FoS requirement, and Case A was recommended at a drawdown rate of 500 mm/week with monitoring during final drawdown over a 20-day period.

A geotechnical engineer was present onsite to visually inspect the embankment during final drawdown along the critical northern embankment, with twice-daily (morning and afternoon) walkovers conducted on the TSF crest and internal embankment slope working platforms to assess for signs of potential instability. In addition, surveying using laser scanning techniques was selected as a cost effective and appropriate monitoring method, using an I-Site 8200 bracket-mounted on a Toyota Landcruiser driving the TSF crest or Polaris all-terrain vehicle for access to the lower working platforms. The surveying was commenced prior to the contained water level reaching RL 26.5 m, and every two days during the final drawdown below this level. The results were assessed by ERA's surveyor and forwarded to the design engineer. Trigger action response plan (TARP) limits were applied based on the Plaxis modelling assessment, with 0-25 mm being the normal or expected range ('green' zone) for movements. Based on the modelling, embankment instability was not anticipated, and measured displacements were in fact well within the normal range.

2.2.4 Floor access and cleaning

Two ramps were built to access the TSF floor once it became exposed, one at the south-west corner of the facility and the other in the north-east corner. Conventional limit equilibrium stability analyses using the computer programme 'Slide' were adopted to evaluate the FoS for circular failure in soil and rock slopes. The single-lane north-east ramp was considerably larger than the south-west ramp due to the fact the underlying natural terrain slopes downwards to the north and the north-east ramp was designed as the main route into and out of the TSF to accommodate fully laden CAT 785 dump trucks, which would be loaded via large excavators and haul the dried tailings from the TSF floor to a tip head at Pit 3. Both ramps were constructed of coarse mine waste rockfill. The north-east ramp construction had a nominal 12 m wide crest including safety windrow, 8% gradient, three benches with side slopes of approximately 40°, and berms at RL 44 m and RL 38 m (Figure 6). It was completed in mid-2021.

Figure 6 Image from drone flyover, showing north-east ramp construction in May 2021

An estimated 1.77 Mm^3 of material was removed from the TSF floor, which included an estimated 0.37 Mm^3 of TSF subfloor, with the work completed over a 6-month period and finished by mid-December 2021. An inspection by stakeholders confirmed the work had been undertaken adequately, with the design engineer providing validation that the facility would be suitable for process water storage.

2.3 Current phase

2.3.1 Use as process water storage facility

A rockfill scour protection apron was designed and constructed at the pipe inlet to the floor of the facility and water transfer from Pit 3 commenced in January 2022. At that point, the facility ceased being a TSF and was renamed RWD. At an estimated peak water storage volume of 8 GL, the water within the facility is expected to reach an elevation of approximately RL 35 m, which is more than 7 m below the wet season MOL. The possibility of a dam breach is exceptionally unlikely, as process water will not encroach upon the MOL and the facility will have significant excess storage capacity.

The dam is operated under strict governance and according to an operations and maintenance manual (OMM), which is updated annually and includes details of the dam design and construction history, its monitoring and surveillance requirements, and a comprehensive dam safety emergency action plan.

2.3.2 Wave-induced upstream erosion

During the remnant tailings clean-up on the upstream embankment face, some of the protective rip rap was disturbed and removed, and not replaced. In operation as RWD, wind-generated, wave-induced erosion of the upstream clay core initially occurred along the waterline. The remedy upon observation of the erosion was floating HDPE pipes at the water and embankment interface, which was immediately effective in mitigating attrition of the upstream clay core. The magnitude and rate of erosion were measured through the 2022-23 wet season by drone surveys to understand ongoing dam integrity requirements, with the finding that due to the presence of more 8 to 9 m of engineered clay core, there is no significant increase in seepage or impact on the embankment factor of safety. Some work continues to be done to mitigate minor wave and rainfall runoff induced erosion for dam integrity maintenance during ongoing facility operation.

3 Hydrogeological considerations

A review of historical and current site conditions, data and existing water management infrastructure was conducted to understand the main hydrogeologic considerations and assess the risks for transitioning the TSF to a water storage facility. Included in the review were historical groundwater level and quality data, current observations of the TSF floor, the difference in the storage duration and water depth in the TSF for the proposed water storage period relative to the tailings storage period, and the layers of control currently in place to detect and intercept seepage.

Copious historical groundwater data from an extensive monitoring well network (Figure 7) indicated that seepage occurred from the TSF during the 41-year-long tailings storage period. Groundwater showed effects from tailings seepage locally around the TSF and preferentially down two primary pathways, the Coonjimba drainage and Gulungul Creek Tributary No. 2 (GCT2) (Figures 2 and 7). The receptors along these pathways are Coonjimba Billabong and Gulungul Creek, respectively.

Transfer of all tailings from the TSF to Pit 3 enabled evaluation of floor conditions. Observations suggested that the TSF floor has low permeability. During the period of final bulk tailings movement, water seeped from the tailings as they were handled. Active and passive methods were required to manage this water that collected on the TSF floor rather than infiltrating. Large volumes of water ponded on the TSF floor after rainfall events, indicating little infiltration. Near the end of 2021, five holes were drilled to a depth of 9 m in the TSF floor. Water inflow was observed at 3 m in one drill hole and at 6 m in another drill hole. In the remaining three holes, no water inflow was observed. The presence of ponded water, lack of infiltration, and little to no water inflow into the drill holes all indicate that the permeability of the TSF floor is low.

Any seepage that does occur during the water storage period is expected to be significantly less than that during the tailings storage period. Both the storage duration and maximum water depth for the water storage period will be far smaller than the storage duration and maximum water depth for the tailings storage period (Figure 8). Water will be stored for 5 years compared to the 41 years of tailings storage, a factor of 8.2 shorter. The maximum water depth above the floor during the water storage period will be 14 m, which is a factor of 2.7 lower than the maximum water depth of 38 m during the tailings storage period. The water depths were calculated from the minimum floor elevation of about 20 m.

Simulations of water infiltration and vertical downward flow into the underlying weathered rock revealed process water migration after transition of the TSF to the RWD will be limited to an average vertical seepage distance of about 0.1 meter over most of the footprint. Results from the three-dimensional flow model also indicated limited areas along the RWD perimeter where the average seepage distance will be about 1 m and a much smaller area along the north and eastern walls where the average seepage distance is 4 m. The volume of process water seepage predicted to occur is very small compared to the historical seepage volume from the tailings. Even so, the volume and depth of process water seepage were used to develop solute source terms for flow and transport modelling being conducted to develop the RWD deconstruction plan for closure.

Layers of control currently in place are expected to detect and intercept seepage along the two primary pathways well before it can reach the receptors. A new bore drilled between the RWD north wall and Retention Pond No 6 (RP6) and screened in the original Coonjimba Creek sediments is expected to provide early detection along the Coonjimba drainage. Water management pond SED2B (Figure 2) is expected to provide a mechanism for intercepting shallow seepage, if necessary. Along the GCT2 alignment, to the west of the RWD, infrastructure was constructed between 2010 and 2015 to reduce additional seepage from the tailings and capture impacted groundwater. This GCT2 interception system is expected to provide the means to detect and intercept any seepage that might occur down this pathway during the water storage period.

Bores located near the RWD wall and currently monitored for groundwater level and quality are expected to provide early detection of seepage that may occur away from the two primary pathways (Figure 7). Many were constructed as nested bores to monitor several vertical intervals at the same location. The spatial and vertical coverage provided by the bores, and a recommended increase in monitoring frequency at several bores, are expected to provide early detection of any localised seepage that may occur during the water storage period. Based on the limited migration distances during the tailings storage period, interception of seepage during the significantly shorter water storage period is not considered necessary in these areas.

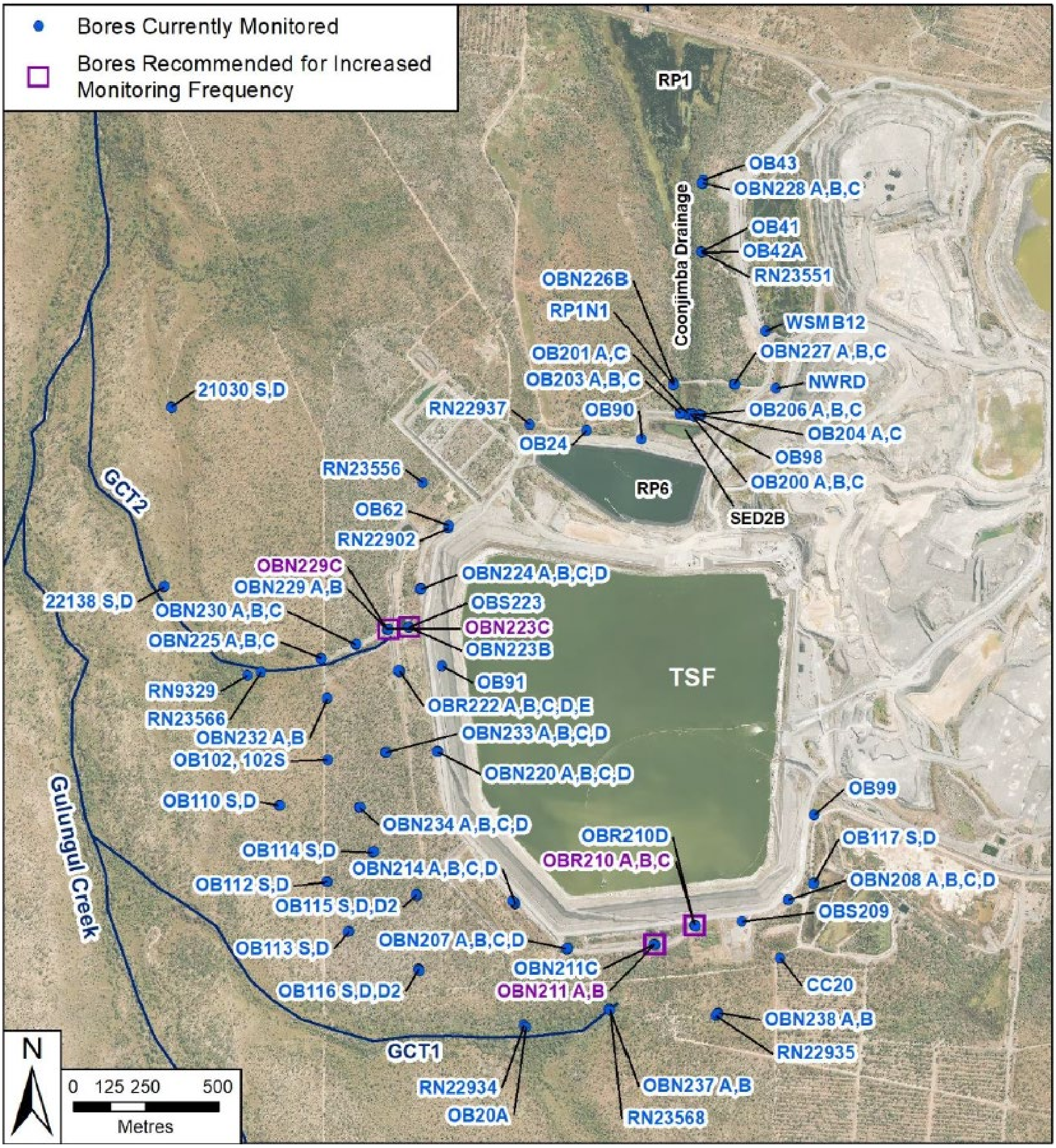

Figure 7 Bores around the TSF / RWD that were monitored for groundwater level and quality and those recommended for increased sampling frequency (purple label) during the water storage period

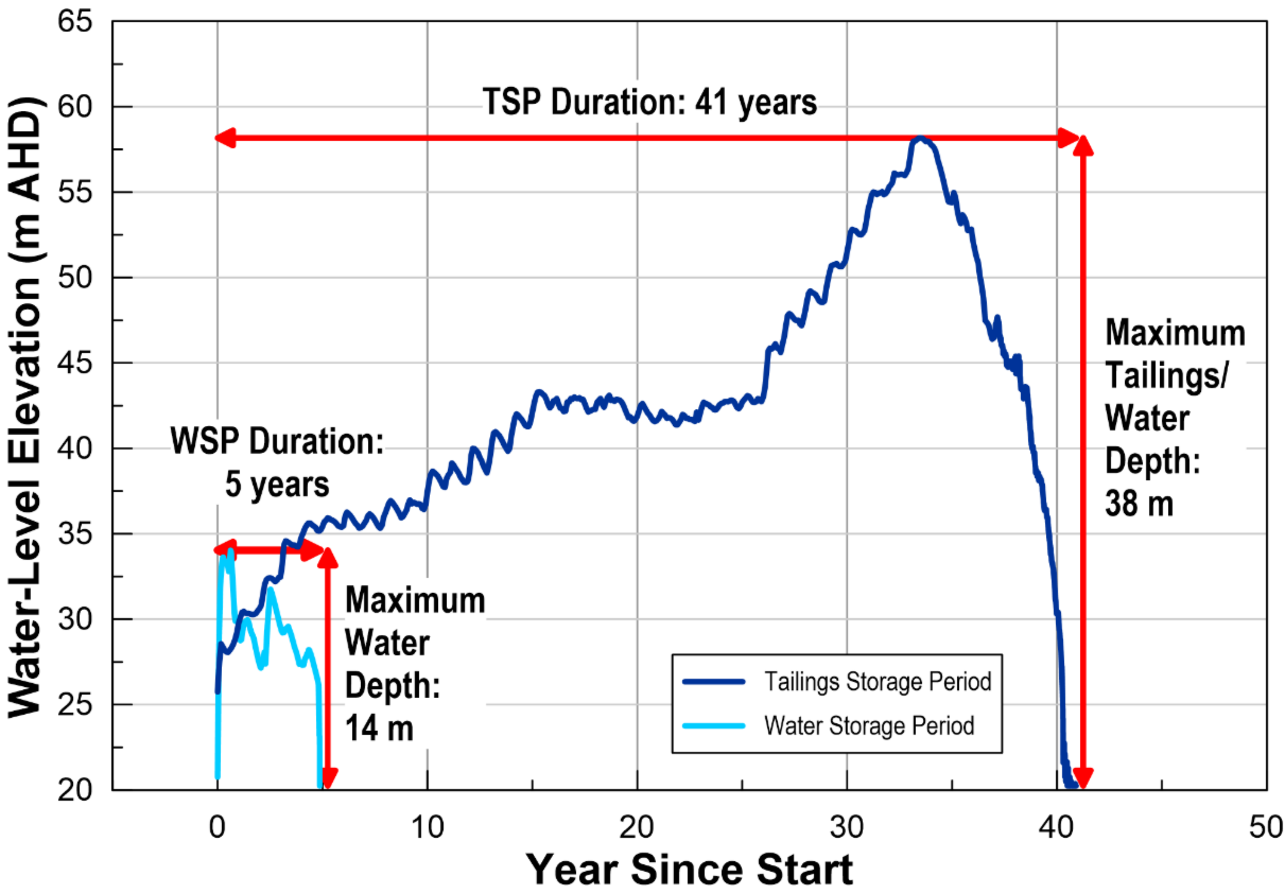

Figure 8 The storage duration and maximum water depth for the water storage period (WSP) are a factor of 8.2 (5 years versus 41 years) and 2.7 (14 m versus 38 m) less, respectively, than that for the tailings storage period (TSP)

The assessment concludes that:

- Some seepage is likely to occur during the water storage period across the TSF, but at rates that are low relative to the tailings storage period.
- The entire TSF floor will be covered with water for only a short period of time (less than 1 year) at the beginning of the water storage period. During the remainder of the period, the lower water levels will result in little hydraulic driving force for seepage to the west, southwest, east, and southeast.
- Some localised areas could experience elevated seepage as evident from historical monitoring that has identified preferential pathways along the Coonjimba drainage and down the GCT2 alignment.
- Recommended increases in the frequency of groundwater sampling in some bores located west and south of the TSF is expected to provide early detection if seepage does occur in these areas.
- Monitoring of the new bore installed north of the TSF between the wall and RP6 is expected to provide early detection down the Coonjimba drainage.
- The interception infrastructure already in place is considered appropriate and sufficient to capture any seepage along the two primary pathways identified.
- Based on the data and information evaluated, hydrogeologic conditions and available infrastructure already in place are expected to protect receptors resulting in little to no risk.

4 Conclusion

The closure of the former Ranger uranium mine presents unique challenges on how to safely close a uranium mine, return it to a condition that it could be incorporated into the dual world heritage listed Kakadu National Park and demonstrate that the surrounding environment will remain protected for 10,000 years.

The rehabilitated landform must have the above ground tailings storage facility removed; however, the facility is required to safely store process water for closure to be achieved. ERA has successfully managed geotechnical risks to remove all tailings from the above ground tailings storage facility and demonstrated through hydrogeological modelling that the facility can be used to contain process water with little to no risk to the environment. An important lesson learned is that through a combination of practical construction knowledge, robust engineering design assessments and considered implementation, a large TSF can be safely dredged and mechanically cleaned out to make it suitable for an alternative use prior to its future deconstruction.

ERA's closure journey continues. We are committed to creating a positive legacy, achieving world-class, sustainable rehabilitation and proudly restoring landscapes for those who will walk after us.

Acknowledgement

Energy Resources of Australia acknowledge the Mirarr people who are the Traditional Owners of the land where the Ranger Rehabilitation Project operates, and the Larrakia people who are the Traditional owners of the land where our Darwin head office is located.

We pay our respects to Elders past and present, and extend that respect to all Aboriginal and Torres Strait Islander peoples.

References

Australian National Committee on Large Dams 2019, 'Guidelines on Tailings Dam: Planning, Design, Construction, Operation and Closure', Revision 1, July 2019.

Coffey Services Australia Pty Ltd 2017, 'Ranger Mine Project, Eastern Perimeter Embankment Notching and MOL Adjustment Design Report', 20 December 2017 (unpublished).

Coffey Services Australia Pty Ltd 2018, '2018 TSF Rapid Drawdown Assessment, Ranger Mine TSF', 5 November 2018 (unpublished).

Coffey Services Australia Pty Ltd 2019, '2019 TSF Rapid Drawdown Assessment, Ranger Mine TSF', 9 September 2019 (unpublished).

Coffey Services Australia Pty Ltd 2019, 'TSF Crest Access – Wall Cleaning, Ranger Mine', 10 December 2019.

Coffey Services Australia Pty Ltd 2020, 'TSF Floor Cleanup – Southeast and West Access, Ranger Mine', 15 April 2020 (unpublished).

Coffey Services Australia Pty Ltd 2021, 'Rapid Drawdown Monitoring Report', 26 April 2021 (unpublished).

Coffey Services Australia Pty Ltd 2020, 'TSF Ramp Stability – Hydromining, Ranger Mine', 12 November 2020 (unpublished).

Energy Resources of Australia Ltd, 'Tailings Quantity Reconciliation', 11 April 2022 (unpublished).

INTERA (2022), Technical Memorandum, Groundwater Assessment for Transitioning of the Tailings Storage Facility into a Water Storage Facility, 20 January 2022 (unpublished)

Rio Tinto 2021, 'Group procedure – D5 – Management of tailings and water storage facilities v1.2'.

Tetra Tech Coffey Pty Ltd 2021, 'Ranger Mine – TSF North-East Ramp – CAT 785 Truck Access', 1 July 2021 (unpublished).

Tetra Tech Coffey Pty Ltd 2021, 'Ranger Mine – TSF NE Access Ramp Construction Compliance', 30 August 2021 (unpublished).

Tetra Tech Coffey Pty Ltd 2021, 'Ranger Water Dam – Energy Dissipator for Pipe Outlet', 16 November 2021 (unpublished).

Tetra Tech Coffey Pty Ltd 2021, 'Ranger Water Dam (formerly TSF) OMM, Operations and Maintenance Manual Update', 24 December 2021 (unpublished).

Tetra Tech Coffey Pty Ltd 2022, 'Ranger Mine – Water Dam (former TSF) Inspection, 25 November 2021', 24 January 2022 (unpublished).

Tetra Tech Coffey Pty Ltd 2022, 'Ranger Water Dam, Annual Inspection 2022', 28 September 2022 (unpublished).