



Chapter 8
Water

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8 WATER

8.1 INTRODUCTION

This chapter assesses the risks presented by the Project with respect to environmental values associated with both groundwater and surface water. Although the focus is on potential impacts and mitigation measures in relation to groundwater and surface water close to the Project footprint, the assessment considers broader aspects as required by the EIS guidelines. Some of these include matters of national environmental significance (MNES), which are addressed in detail in **Chapter 14**. The existing controls and new treatments that ERA will implement through project design, construction, operations and decommissioning to mitigate impacts on these values are also described.

The chapter is based on investigations and monitoring programs that have been undertaken over the past 30 to 40 years, as well as specific Project-related investigations and other supporting documents. These investigations and assessments include those undertaken by INTERA Incorporated (INTERA) (**Appendix 9; Appendix 10**) and Rio Tinto (**Appendix 11**). In particular, the assessment reflects an operating environment at Ranger mine that includes strict regulatory oversight, primarily by the Ranger Minesite Technical Committee (MTC), and review of the environmental performance of uranium mines in the Alligator Rivers Region by the Supervising Scientist (whom also provides technical and policy advice to the relevant Commonwealth Minister).

Assessment of potential impacts associated with the Project is undertaken using the risk assessment approach described in **Chapter 5**, with particular reference to existing water quality objectives for Magela Creek and annual load limits for certain chemicals in water that is released from Ranger mine. Specifically, this chapter includes:

- assessment approach (**Section 8.2**);
- existing environment (**Section 8.3**);
- ERA's current approach to water management (**Section 8.4**);
- assessment of risks (**Section 8.5**); and
- summary of the assessment (**Section 8.6**).

Chapter 2 contains general information concerning groundwater and surface water in and around the Ranger Project Area (RPA). Information that is more specific to the Project is contained in this chapter (**Section 8.3**). Other particularly relevant information is found in **Chapter 13**, which presents the findings of investigations concerning potential changes in water quality in Magela Creek up to 10,000 years after closure of the underground mine (and this is also discussed in **Section 8.5**). **Chapter 9** describes radiation risks to the environment, including aquatic plants and animals. Other chapters are referred to where appropriate.

8.2 ASSESSMENT APPROACH

8.2.1 Assessment Framework

The National Water Quality Management Strategy (ANZECC/ARMCANZ 1994) and Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) provide a framework for managing water resources across Australia and for implementing the national strategy at a local level. One of the early steps in determining an appropriate water quality management strategy is establishing management goals. The ecosystem surrounding the Ranger mine has been recognised as being a high conservation/ecological value system, as expressed in the Ranger Environmental Requirements that are prescribed in the Section 41 Authority. The primary environmental protection objectives defined under the Environmental Requirements are:

- maintain the attributes for which Kakadu National Park was inscribed on the World Heritage List;
- 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);
- protect the health of Aboriginals and other members of the regional community; and
- maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

The primary environmental value¹ that is specific to the Ranger mine (and hence is also applicable to the Project) and consistent with the above requirements has been identified through consultation with key stakeholders (primarily through the MTC) as the protection of the aquatic ecosystem, where the level of protection should recognise the high conservation status of this ecosystem. For most water quality variables, protecting the aquatic ecosystem is the most restrictive of the common environmental values. Protecting the aquatic ecosystem also represents the primary management aim, with a secondary aim being to minimise water quality changes downstream of the mine, consistent with the wishes of the Traditional Owners (Supervising Scientist 2005).

Given the nature of the Ranger mine and its setting, specific environmental concerns from a surface water and groundwater perspective include the potential ecological effects of mine-derived stressors such as uranium (U), magnesium (Mg), radionuclides and transported sediment on aquatic biota and human health (Bartolo, *et al.* 2013). This is based on a conceptual model² that has been developed by Supervising Scientist Division (SSD) to provide a risk management context for environmental impact issues beyond the Ranger mine site (Bartolo, *et al.* 2013). Particular consideration was given to the following pathways (although an underground mine was not part of the Ranger mine project description when that report was completed):

¹ The environmental values recognised in ANZECC/ARMCANZ (2000) are: aquatic ecosystems; primary industries (including aquaculture and human consumption of foods); recreation and aesthetics; drinking water; industrial water; and cultural and spiritual values.

² A conceptual model "is a written description and visual representation of predicted relationships between ecological entities and the stressors to which they may be exposed" (US EPA 1998).

- surface water to surface water;
- storm water runoff from non-mine site areas of the RPA;
- seepage to groundwater to surface water; and
- bioaccumulation and trophic transfer.

To ensure a high level of protection of the aquatic ecosystem, and in recognition that surface water releases are the main pathway by which Ranger mine may impact the downstream environment, a hierarchy of management or compliance trigger values for key variables has been established by SSD and incorporated into Ranger mine's regulatory requirements. These trigger values, which are based primarily on local biological effects test work and local reference site data and are applied at the primary regulatory compliance point MG009 located on Magela Creek downstream of the mine (**Figure 8-1**), have specific reporting and investigative responses (as detailed in **Section 8.2.2**). No equivalent compliance trigger values exist for groundwater. However, ERA is required to undertake monitoring and reporting at four statutory groundwater monitoring bores, as well as considerable additional groundwater monitoring in response to other regulatory commitments (refer **Section 8.2.2**). The trigger values are discussed in the following section.



Figure 8-1: Surface watercourses and selected monitoring points near Ranger mine

8.2.2 Assessment Criteria

8.2.2.1 Water Quality

The focus of water quality and related monitoring programs at the Ranger mine is on the early detection of short- and long-term changes that may arise from mine wastewaters. The results from these programs provide supporting information for the impact assessment herein in terms of effects associated with the Ranger mine to date.

Underground mining is expected to generate the same potential stressors of most concern (called key variables) as currently associated with operations at Ranger mine. As described in Supervising Scientist (2005), these include pH, electrical conductivity (EC), uranium (U),

turbidity, Mg, sulfate (SO₄), manganese (Mn), radium-226 (²²⁶Ra) and calcium (Ca). The relevance of these variables is that they (Supervising Scientist 2005):

- are specifically referred to in the Environmental Requirements (i.e. pH, EC and U);
- can significantly influence the extent to which the Environmental Requirements' secondary environmental objectives that are related to water can be met; or
- are important as 'master' variables or can influence the toxicity of other solutes (e.g. pH and Ca).

Identification of these key variables, which underpins the monitoring programs implemented by both ERA and SSD (and described later in this chapter), has been re-visited over the past several decades by SSD. As described in Frostick *et al.* (2012), criteria used to determine the variables included in SSD's monitoring program are:

- their presence at higher-than-background concentrations in the Ranger mine's water management ponds and the downstream receiving environment;
- their potential for attenuation by natural physical and chemical processes; and
- their potential for biological impacts based on the concentrations that are present.

The recent re-assessment of the analysis suite at the Ranger mine undertaken by the SSD, which took into account ANZECC/ARMCANZ (2000) guidelines, site-specific toxicity data and comparisons between sites on Magela Creek that were upstream and downstream of Ranger mine, concluded that the metals/solutes³ that required the most attention were U, Mg, Mn and SO₄ Frostick, *et al.* (2012). Additional metals included in SSD's routine monitoring program are primarily for quality control purposes and are used to indicate sample contamination. Other metals are present in mine-derived waters at concentrations that pose negligible or low risks to the environment. As concluded by Frostick *et al.* (2012), the results of the study provided confidence that SSD's water quality monitoring program (and by inference ERA's program) includes all potential analytes that could be of concern from a toxicological or bioaccumulation perspective.

Water quality objectives that are based on these key variables were formally established by SSD for Magela Creek in the early 2000s. The current objectives, which will also apply to the Project and provide a basis for the impact assessment presented herein, are expressed as trigger values at a number of different levels, i.e. focus, action, guideline and limit (**Table 8-1**). The trigger values are based on a combination of water quality data from a reference site on Magela Creek (MCUS) (for pH and turbidity), site-specific data from toxicity tests (for EC, Mg, Mn and U), data from international and local toxicity tests (for total ammonia nitrogen (TAN)), and human radiological protection (for ²²⁶Ra). With the exception of ²²⁶Ra, these trigger values have been developed in accordance with the framework specified in ANZECC/ARMCANZ (2000).⁴ The current trigger values reflect recent changes by SSD that include:

³ Solutes in this context are substances (generally ions) dissolved in water.

⁴ Information concerning the derivation of these trigger values is provided in **Appendix 11**.

- Specifying water quality objectives for TAN (as noted above), since TAN is associated with treatment of process water by the brine concentrator and release of distillate, and has a potential ecological impact.
- Replacing the previous approach of using EC as a proxy for Mg with specific Mg values that were derived by site-specific toxicity testwork. These values take into account the potential toxicity of Mg pulses in the creek, where Mg concentrations rise and fall over a number of hours, often in response to changing flows in the stream.
- Revising the Mn trigger values based on site-specific toxicity testwork rather than reference site conditions.

Assessment of water quality in Magela Creek involves comparing monitoring data determined at MG009 with these trigger values.

Table 8-1: Water quality objectives (trigger values) for Magela Creek¹

Variable ³	Trigger values				Basis for trigger values
	Focus	Action	Guideline	Limit	
pH ²	5.9 to 6.5	5.6 to 6.7	5.0 to 6.9	N/A	Reference site data
Turbidity (NTU)	5	10	26	N/A	Reference site data
EC (µS/cm)	18	30	N/A	42 (≥72 hour limit)	Site-specific ecotoxicological data
Mg (mg/L)	1.0	2.0	N/A	3.0 (≥72 hour limit)	Site-specific ecotoxicological data
Mn (µg/L)	35	45	N/A	75	Site-specific ecotoxicological data
U (µg/L)	0.3	0.9	N/A	6	Site-specific ecotoxicological data
Total ammonia nitrogen (TAN) (mg/L)	0.1	0.3	0.7	N/A	International and local ecotoxicological data
Radium-226	N/A	N/A	N/A	10 mBq/L wet season median difference	Human radiological protection data

¹ Values used for compliance assessment in Magela Creek are based on dissolved concentrations.

² For pH, trigger values outside the range shown in the table are of concern.

³ Although still included in the water quality objectives, SO₄ has been found not to be a toxic agent in this context and not included in this table. Source: SSD (2014).

For those trigger values such as pH and turbidity that are based on natural variation, exceedances (monitoring results that do not meet the trigger values) are to be expected about 20% of the time for focus triggers, 5% of the time for action triggers and 0.3% of the time for guidelines (Supervising Scientist 2005) (with pH having lower as well as upper

trigger values and hence higher levels of exceedance). It is therefore important to note that exceedance of a trigger does not necessarily mean that the aquatic ecosystem of Magela Creek, the downstream wetlands or adjacent waterbodies is at risk. Instead, specific (and increasingly stringent) management responses are required when a focus level, action level, guideline or limit is exceeded. These range from maintaining a watching brief where values are between the focus and action levels through to providing a written report detailing relevant data and surrounding circumstances, corrective actions taken to date, and options for further corrective actions when limits are exceeded.

8.2.2.2 Additional Annual Load Limits

The Ranger Authorisation also specifies the need to comply with additional annual load limits (**Table 8-2**) from selected sources within the mine site. These apply specifically to dissolved Mn, phosphate (PO₄) and nitrate (NO₃), total uranium, ²²⁶Ra and polonium-210 (²¹⁰Po) to Magela Creek, and are based on human health and ecosystem protection considerations.

Table 8-2: Additional annual load limits at Ranger mine

Constituent	Unit	Additional annual load limit
Uranium (238+234)	GBq/y	88
Radium-226	GBq/y	13
Polonium-210	GBq/y	7
Manganese	t/y	6
Phosphate	t/y	2.8
Nitrate	t/y	4.4

8.2.2.3 Other Considerations

Although the focus of protecting the environmental values in Magela Creek and downstream is on water quality, maintaining aquatic ecosystem health requires consideration of other factors. These can include sediment quality, flow, habitat type, riparian zone quality, barriers to fish migration, and connections between the river, catchment and floodplain (ANZECC/ARMCANZ 2000). Taking into account the nature of both the existing Ranger mine and the Project, the latter poses no additional risk with respect to these factors. The water management system currently operates in accordance with a number of requirements that will be maintained during Project construction and operations. In particular, these include ensuring that:

- Water quality objectives in Magela Creek (as described above) are maintained by considering flows and water quality in both the creek and mine-derived wastewaters prior to releasing water from the site.

- Using the mine site's land application areas (LAAs) for water management does not promote surface water flow on these areas.

A further consideration about the validity of the water quality triggers relates to the findings from the various monitoring programs undertaken by SSD. Although these are discussed in more detail in **Section 8.3.2**, it should be noted that:

- A detectable signal from mining on water quality downstream of Ranger mine was always expected (Fox, *et al.* 1977).
- Monitoring to date has shown that mine-induced variations in water quality generally reflect only small changes relative to low background levels.⁵ Supervising Scientist (2013) concludes that: "... *the extensive monitoring and research programs of the Supervising Scientist Division (SSD) confirm that the environment has remained protected through the period*" and that "... *the downstream aquatic environment remains protected from the effects of the mining of uranium at Ranger*".
- Hart and Taylor (2013) report that "... *the surface water management, monitoring and assessment work undertaken by SSD and ERA are of the highest quality, whose combined efforts have ensured the outcome of no identifiable adverse environmental or human health outcomes on downstream receiving environments or population.*"

It should also be noted that, from a broader perspective, Bayliss et al. (2012) show that non-mining landscape-scale risks such as those posed by weeds, pig damage and unmanaged fire are "... *several orders of magnitude greater than risks from mine water contaminants in the surface water pathway ...*". They also note that this conclusion should be re-visited with respect to the rehabilitation phase of the operation. This is addressed further in **Chapter 14**.

8.2.2.4 Summary

Given the above discussion, the assessment presented herein is based on the premise that the water quality compliance framework as currently applied to the Ranger mine will be equally applicable to the Project during construction and operations, and provides an appropriate basis for the impact assessment. If water quality in Magela Creek is maintained, as defined by the current water quality objectives, and the additional annual load limits are not exceeded, then the relevant environment values such as aquatic ecosystems and human health will also be protected. This, in turn, will ensure that water quality impacts from the Project will not adversely affect the world heritage values associated with Kakadu National Park or the health of the Ramsar wetlands, or other relevant MNES.

8.2.3 Supporting Information

As noted in **Section 8.1**, the impact assessment is supported by the findings of various investigations, ongoing monitoring programs and project-specific assessments. The main programs and assessments are described in this section.

⁵ Notwithstanding this finding, ERA's compliance monitoring and response framework is currently being reviewed so as to provide additional assurance to stakeholders concerning downstream environmental protection and to more fully reflect best (leading) achievable practice. This is consistent with the findings of the independent surface water working group (Hart & Taylor 2013), as discussed in **Section 8.3.2**.

8.2.3.1 Monitoring

ERA groundwater monitoring

The Ranger mine groundwater monitoring program, which is reviewed and approved annually by the MTC as part of the annual water management plan review and approval process, encompasses monitoring sites that are required under the relevant legislation (referred to as statutory sites) and sites that are monitored for operational purposes (referred to as operational sites) (**Figure 8-2**). The latter provide data that is used to validate and improve the environmental performance of the operation.



Figure 8-2: Groundwater monitoring bores (statutory monitoring sites are shown in orange)

The groundwater monitoring program includes analysis of samples for the following (at various sampling frequencies):

- water level;
- in situ EC, pH, temperature and free residual chlorine;

- turbidity, total suspended solids (TSS), total dissolved solids (TDS), major ions (Mg, sodium (Na), potassium (K), calcium (Ca), chloride (Cl), SO₄, bicarbonate (HCO₃), carbonate (CO₃));
- total and filterable metals (aluminium (Al), copper (Cu), iron (Fe), Mn, lead (Pb), U, zinc (Zn));
- nutrients (phosphate (PO₄), nitrite (NO₂), nitrate (NO₃), ammonium (NH₄));
- total and filterable ²²⁶Ra and ²¹⁰Po; and
- other microbiological and radiological variables.

Results of the monitoring program are reported by ERA in the annual Ranger groundwater report, which is submitted to the MTC (and data is also provided on a quarterly basis). This report includes data collected throughout the preceding 12 months. Reference to historical datasets allows water quality trends to be identified and assist in the interpretation of the groundwater chemistry and potential mine-related impacts.

ERA surface water monitoring

As with the groundwater monitoring program, ERA's surface water monitoring program is reviewed and approved annually by the MTC as part of the Ranger water management plan review and approval process. The main features of this program are:

- 10 statutory (excluding potable water sources) and more than 50 operational sampling locations, including both major discharge points (e.g. GC2, RP1W) and ambient locations such as those located within Magela Creek (MG009) and Gulungul Creek (GHC).
- Sampling and analysis for a range of variables including water level, in situ EC/pH/temperature, turbidity, major cations and anions, filterable Mn and U, total U, ²²⁶Ra, ²¹⁰Po, PO₄, total nitrogen, TAN and ionic balance, depending on the specific sampling site.
- Sampling frequencies ranging from continuous through to weekly, monthly, quarterly and annually, and also include 'special events' such as when release of water occurs from the site, again depending on the specific sampling site.
- A network of real-time continuous monitoring sites within Magela Creek, Gulungul Creek, Coonjimba Billabong and Georgetown Billabong. These sites have the capacity to continuously monitor pH, EC, temperature, turbidity and dissolved oxygen (DO).

The locations of statutory and selected operational surface water monitoring sites are shown in **Figure 8-3**.



Figure 8-3: Surface water monitoring sites

Water quality data is routinely reported in a number of documents, including:

- weekly reports during the wet season, with monthly reporting during the dry season;
- monthly reporting of groundwater levels at selected piezometer bores;
- a wet season report, which presents and discusses surface water quality data obtained over a given reporting year;
- an annual groundwater report, which presents and discusses groundwater quality data obtained over a given reporting year; and

- the annual environment report, which presents ERA's performance concerning environmental management for the period from 1 September to 31 August, and provides details on a range of matters including water and tailings management.

A water quality database of statutory water quality monitoring data is maintained and is accessible to stakeholders via the internet.

SSD surface water monitoring

The SSD conducts an independent ongoing surface water quality monitoring program that includes measurement of chemical and physical variables in Magela and Gulungul creeks, as well as other reference creeks and waterbodies in the region. The SSD formally commenced a full environmental monitoring program in the 2001 – 2002 wet season (SSD 2002), although data for a number of indicators had previously been obtained during various research programs. A preliminary monitoring program was implemented by SSD during the 2000 – 2001 wet season, with the finalised program commencing during the 2001 – 2002 wet season. The main risk that was identified was the dispersion of mine wastewaters to streams and shallow wetlands during the wet seasons. This resulted in the monitoring program focusing almost entirely on aquatic ecosystems.

As with the water quality monitoring specified in the Ranger Authorisation, SSD's monitoring in Magela Creek has focused on two sites in each creek, one being upstream of mine-related influences and other being downstream (refer **Figure 8-1**). The current sampling sites on Magela Creek (Magela upstream (MCUGT) and Magela downstream (MCDW)) are in slightly different locations to those used in the period 2001 – 2008.

The SSD reviewed its surface water chemistry monitoring program over the 2010 dry season, resulting in some significant changes. Key aspects of the revised program, which involves monitoring of water quality during the period of creek flow (i.e. the wet and early dry season), are (SSD 2014):

- monitoring pH, EC, turbidity, temperature and stream height on a continuous basis;
- event-based sample (1 L) collection using automatic samplers to obtain water samples for chemical analysis (rather than weekly grab sampling) when pre-programmed EC or turbidity thresholds are detected by the continuous monitoring;
- two automatic samplers at the Magela downstream site, one being used for collecting higher EC samples and the other for collecting higher turbidity samples;
- grab samples for radium assessment and water chemistry QA/QC purposes;
- analysis of all samples for total metal concentrations; and
- posting continuous data for all sites to the SSD website weekly in arrears.

The continuous monitoring data has also been used to develop an annual mine 'solute budget', which essentially reflects Mg loads.

As well as the surface water chemistry monitoring program, biological monitoring programs have been developed and refined over the past 30 years by the Environmental Research Institute of the Supervising Scientist (ERISS) to more directly assess impacts from the

Ranger mine on downstream aquatic ecosystems. Two broad approaches are used, i.e. early detection studies and assessment of overall ecosystem-level responses. Early detection techniques involve assessing the responses of the freshwater snail, *Amerianna cumingi*, to Magela Creek water. Ecosystem-level responses are assessed using benthic macroinvertebrate and fish community data from Magela and Gulungul creeks sites. Additional information about these programs is provided in **Appendix 11**.

Other monitoring programs

In addition to the programs described above, the NT Department of Mines and Energy undertakes surface water check monitoring at selected sites around the RPA. The primary objectives of the monitoring are to assess (DoR 2012):

- the adequacy of monitoring data being collected by ERA; and
- potential influences of the mine site on downstream water quality.

The data has not been used in the assessment presented herein due to the more comprehensive nature of the ERA and SSD datasets.

Hydrology of Magela Creek is determined primarily by stream gauging stations. The most relevant of these is MG009 which, as noted previously, is the compliance point for the Ranger mine. This station (which has the formal designation of G8210009) has an upstream catchment area of 605 km² and a stream flow record starting in September 1971.

8.2.3.2 Modelling

Groundwater-related conceptual models previously developed for the Ranger mine and RPA are continually updated to incorporate new data and improved understanding of the processes involved (refer **Chapter 2**). Of particular relevance is the current classification of hydrogeological units in the groundwater flow model that underlies the predictive modelling for the Project (refer also to **Chapter 2**), these being:

- surficial units – ancestral Magela sands, creek sediments, weathered rock and waste rock; and
- bedrock units – Nanambu complex, lower mine sequence, upper mine sequence, hanging wall sequence, deeps water-producing zone, north upper mine sequence carbonate unit, lower mine sequence carbonate unit, MBL zone and Pit 1 permeable zone.

New hydrogeological units were introduced to represent the Project mine workings and mine backfill materials that will be used in closing the underground mine. Mine workings are categorised as stopes, tunnels, vent shafts, and the decline. The bedrock units within the model best represent the hydrogeology of the area and reflect recent bedrock hydraulic property data. Additional information about the hydrogeological units and the groundwater conceptual model for the site is provided in **Appendix 9**.

The updated conceptual models provided the basis for a computer model that was used to predict a number of Project groundwater-related impacts. These include:

- Movement of water and solutes such as Mg from the underground mine to Magela Creek. Given the time scale upon which such movement occurs, and the need for closure planning of the Ranger mine to examine a 10,000 year time period, this focused on the post-closure period.
- Interaction of water and solutes from the underground mine and from Pit 3, given that backfilling of the pit is part of the Ranger mine's closure strategy, as discussed in **Chapter 13**.
- Groundwater drawdown around the underground mine and consequent effects concerning groundwater discharge to Magela Creek and the time required for shallow groundwater to recover to 'no underground mining' conditions.

More specifically, the model was used to predict Project-related increases in average annual reactive solute loads to Magela Creek for Mg, U, Mn, ²²⁶Ra, TAN, NO₃-N, total-P, and ²¹⁰Po over a 10,000 year period (refer **Section 13.4**). Magnesium was considered to be a conservative solute, whereby its transport through the rock and surface material between the underground workings and Magela Creek is unlikely to be significantly reduced by geochemical reactions. The other variables were considered to be reactive solutes in the sense that their mobility in the rock and surficial deposits may be reduced by geochemical reactions.

As well as the work that was undertaken to address solute transport, INTERA undertook additional modelling to examine groundwater drawdown that might be associated with development of the underground mine. The model that was developed to predict solute egress from the underground mine was adapted to simulate future conditions and predict drawdown, changes in groundwater discharge to Magela Creek, and the time required for shallow groundwater levels to recover after mining ceases. Details are provided in **Appendix 10**.

The model is conservative and consistent with the approach previously used to evaluate closure scenarios at Ranger mine in the absence of the Project. Details of the model, which is based on the MODFLOW model developed by the United States Geological Survey, are provided in **Appendix 9**.

8.3 EXISTING ENVIRONMENT

8.3.1 Groundwater

A general description of groundwater is provided in **Section 2.4.7**; additional information is provided in this section.

8.3.1.1 Regional Perspective

From a regional perspective, aquifers have typically been divided into a shallow aquifer associated with the unconsolidated sediments overlying bedrock and a deeper fractured aquifer in the underlying bedrock. The bedrock generally has little or no primary porosity but fracturing and faulting has produced secondary permeability allowing these fractured zones to yield significant quantities of groundwater. The presence of numerous springs at the base of the Kombolgje Formation escarpment indicates that the sandstone has some potential as an aquifer. Good yields are also obtained in the region from the carbonate rocks in the Lower Cahill Formation (Kinhill Engineers 1996).

8.3.1.2 Groundwater Hydrology

As noted in **Chapter 2**, water exchange between Magela Creek and the subsurface depends on groundwater and surface water dynamics. Recharge is the most likely cause of the rapid rise in groundwater levels during the initial wet season months, given that it occurs across the site. Flooding in Magela Creek may also play a part in the rapid rise along the creek banks, especially as the wet season creek water level periodically exceeds the creek bank height near Pit 3 (**Appendix 9**).

Evapotranspiration is the likely cause of the rapid decline in groundwater level towards the end of the wet season. Subsurface flow may also be responsible, but this is likely to be minor during the first few dry season months because hydraulic conductivity values are low to moderate and gradients are relatively small.

8.3.1.3 Groundwater Quality

General groundwater quality in the RPA is discussed in **Section 2.4.7**. An indication of groundwater quality in the aquifers close to the Project footprint can be determined by referring to data obtained from selected monitoring bores. For example, bore 83_1DEEP is located at the north-western edge of the Magela LAA close to Magela Creek (refer **Figure 8-2**). This bore is used to monitor groundwater at approximately 90 m in depth, while the nearby bore 23562 is a shallow bore to a depth of 5.5 m below ground level. pH values for these bores (**Figure 8-4**) provide an indication of the different water quality in the respective aquifers, with EC values and concentrations of major ions such as Mg and Ca also varying between the two aquifers.

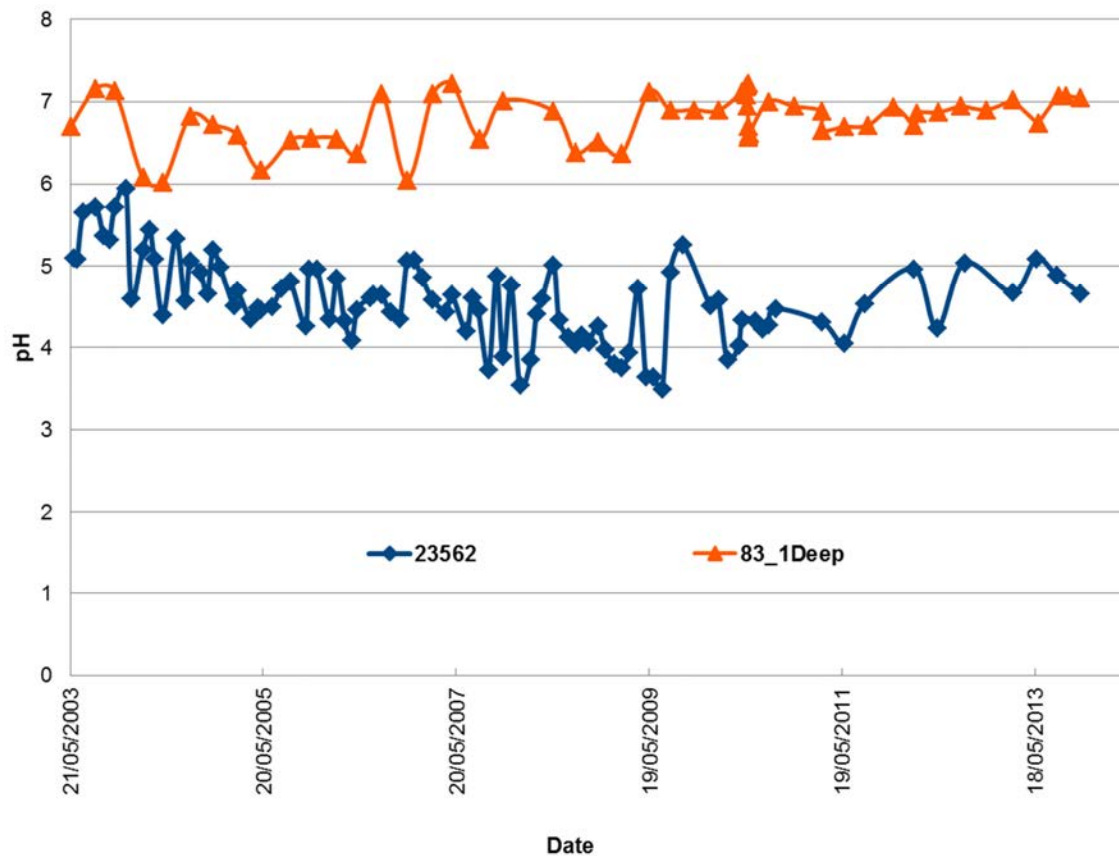


Figure 8-4: pH of groundwater at 83_1DEEP and 23562 shallow from 2003 – 2013

An indication of the quality of groundwater that will be intercepted during development of the proposed underground mine (at more than 300 m below ground level) is provided below. These data were obtained by analysing deep groundwater samples from the exploration decline resource drilling boreholes. Multivariate statistical analysis of 117 separate groundwater samples has, to date, resulted in two closely related but reasonably distinct groundwater types being identified, and these have been labelled D1 and D2 (**Table 8-3**).

In terms of physical chemistry, water type D1 is more alkaline (has a higher pH) and less saline (as measured by EC) than water type D2. While both deep groundwater types are similar with respect to HCO_3^- concentration, which influences the alkaline pH characteristics of these waters, water type D2 has higher concentrations of major cations and anions than water type D1.

This table also compares the two deep groundwater types with following water bodies on the RPA:

- Surface water from Magela Creek upstream of mine influences.
- Groundwater from several bores in the vicinity of the exploration decline, where the bores have been constructed and sampled from depths much shallower (≤ 90 m below ground level) in the geological profile than the underground exploration drilling program.

- Retention Pond 2 (RP2) that stores water on-site for subsequent recycling and reuse.
- Surface sump EDS002 which receives the drainage waters pumped out from the exploration decline, which since the beginning of 2014 have witnessed an average discharge rate of 13.5 L/sec.

Table 8-3: Chemistry of deep groundwater compared to other water bodies¹

Physical chemistry	Surface water	Shallow groundwater ²	Retention Pond 2	Exploration decline water type D1	Exploration decline water type D2	Surface sump EDS002
pH	5.9 – 6.2	6.2 – 7.2	8.1 – 8.7	8.5 – 8.7	8.1 – 8.4	8.6 – 9.0
Electrical conductivity ($\mu\text{S}/\text{cm}$ at 25°C)	18 – 22	186 – 318	1790 – 2057	855 – 990	1176 – 1587	1349 – 1569
Calcium (mg/L)	0.46 – 0.56	7.6 – 18.1	59 – 69	3.2 – 4.7	16.9 – 22.4	39 – 57
Chloride (mg/L)	1.7 – 2.0	6.9 – 14.6	11 – 18	94 – 143	173 – 314	134 – 192
Potassium (mg/L)	0.15 – 0.24	1.2 – 3.8	10 – 12	4.5 – 5.7	10.2 – 12.2	15 – 25
Magnesium (mg/L)	0.87 – 1.22	9.4 – 19.2	218 – 264	1.9 – 3.4	15 – 23	34 – 49
Sodium (mg/L)	1.34 – 1.58	9.6 – 41.5	42 – 63	174 – 200	222 – 293	155 – 180
Sulfate (mg/L)	1.05 – 2.08	0 – 26.7	992 – 1200	41 – 60	76 – 124	304 – 388
Uranium ($\mu\text{g}/\text{L}$)	0.1 – 0.2	N/A	3090 – 4790	117 – 348	267 – 603	2030 – 7420
Bicarbonate (mg/L)	3.7 – 5.5	76 – 155	2.3 – 13.2	180 – 313		108 – 165

¹ Concentration ranges represent the 95%ile values around the average concentration.

² Shallow groundwater represented from bores in the vicinity of the Project.

Reference data from areas unaffected by the Ranger mine have been used to identify the upper threshold values of relevant variables expected to occur naturally in groundwater, which is consistent with the framework described in ANZECC/ARMCANZ (2000). **Table 8-4** lists the threshold values for these variables, as identified by Frostick *et al.* (2012) for Ranger mine, as well as for EC which is a useful field parameter.

Referring to **Table 8-3** and **Table 8-4**, both deep groundwater types are significantly more saline (in terms of EC) when compared with groundwater in shallow bores in the vicinity of the exploration decline, as well as in comparison with surface water and shallow groundwater in fractured rock aquifers from the Nanambu – gneiss and Nanambu - pegmatite. Both deep groundwater types feature elevated concentrations of SO_4 , Na and Cl with respect to the shallow groundwater. Uranium concentrations are elevated in both deep groundwater types when compared with background concentrations in shallower groundwater, as would be expected from groundwater near a mineralised orebody.

The water quality of the deep groundwater types is such that they are directed to RP2 and subsequently reused on-site for purposes such as dust control, processing and underground operations, or treated using the existing water treatment plants.

Table 8-4: Threshold values for selected variables in groundwater at Ranger mine¹

Rock type	Aquifer	EC ($\mu\text{S/cm}$)	Filtered Mn ($\mu\text{g/L}$)	Filtered U ($\mu\text{g/L}$)	Mg (mg/L)	SO ₄ (mg/L)
Alluvium/colluvium	Alluvium/colluvium	166	30	0.19	3.7	1.2
Nanambu - gneiss	Weathered rock	271	132	4.6	25	0.8
Nanambu - pegmatite		405	76	7.4	26	1.5
Cahill - carbonate		N/A	4	4.6	31	0.6
Cahill - chlorite		633	11	14	52	0.94
Nanambu - gneiss		411	385	0.86	28	0.4
Nanambu - pegmatite	Fractured rock	436	274	1.6	5	0.7
Cahill Formation – muscovite schist		N/A	194	1.81	18	1.34

¹ Threshold values represent the highest concentration of selected variables, excluding naturally occurring outliers, which would be reasonably expected to occur as background concentrations.

8.3.1.4 Impacts of Current Mining Operations on Groundwater

This section addresses the EIS guidelines' request for a discussion concerning changes to groundwater systems as a result of mining and mining-related activities. Given that no underground mining has occurred to date within the RPA, the following discussion refers to observed changes that can be attributed to open cut mining.

Following the commencement of mine operations more than 30 years ago, groundwater levels and flow patterns changed due to:

- construction of the tailings dam and stockpiles, which resulted in groundwater mounding (local elevation of the water table beneath these structures); and
- open cut mining, which generated groundwater sinks (areas into which groundwater flowed).

A block diagram of groundwater movement across the Ranger mine, indicating where groundwater quality remains at baseline levels or has been affected by mine operations, is shown in **Figure 8-5**⁶.

⁶ Arrows in the figure indicate the direction of flow and are sized proportional to the relative flow velocities. Blue arrows and shading represent water that is not impacted by mining operations. Green tinted arrows and shading indicate water that is impacted by mining.

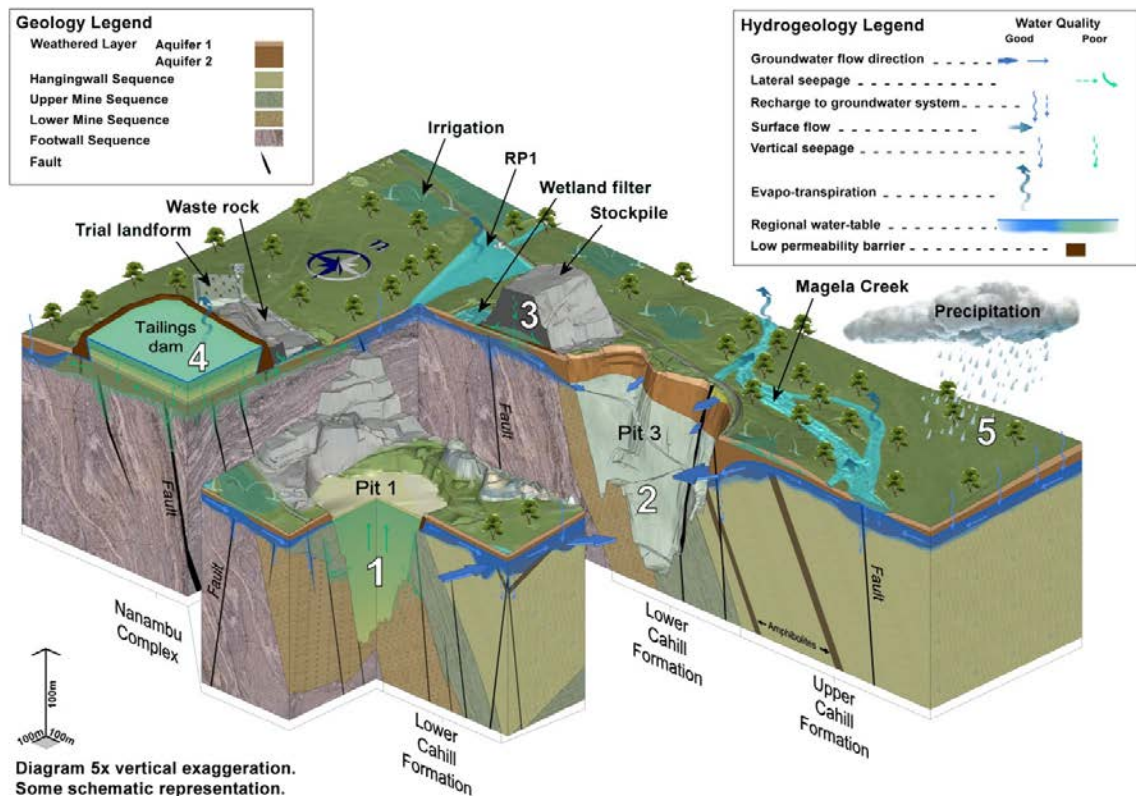


Figure 8-5: Drivers of groundwater movement across Ranger mine

Most of the flow across the site is in the upper weathered aquifer, and the figure shows a number of mining-related impacts that include the following (where the numbers below are also shown in the figure):

1. The groundwater gradient from Pit 1 is to the south-east and groundwater flow prior to mining was in this direction. During mining of this pit from 1980 to 1995, substantial groundwater flowed into this pit through the south-east corner, resulting in a reversal of flow gradients. A constructed in-pit seepage limiting barrier provides a physical constraint to groundwater movement.
2. The excavation of Pit 3, which is currently being backfilled, created a groundwater sink. The post-closure groundwater flow pattern is expected to resemble the pre-mining groundwater flow pattern given that the current closure strategy is to develop a final landform that resembles pre-mining topography.
3. The stockpiles have created a mound of elevated groundwater and are a source of mining-impacted water due to infiltration through the stockpile material and potential saturation of the base of the stockpiles.
4. The tailings dam has created a mound of elevated groundwater and has impacted local groundwater quality via seepage of water with elevated SO_4 and Mg concentrations. This seepage is the main source within the Ranger mine of these and other variables reporting to groundwater. However, it has not lead to a noticeable change in groundwater flow patterns or gradients (Weaver, *et al.* 2010). Monitoring data shows

isolated areas of potential tailings water seepage extending outwards from the tailings dam, which is subject to further investigation. These areas are restricted close to the dam's footprint and are well inside the RPA boundary.

5. Historical land application practices have created localised short-term groundwater mounds in these areas.

After mining operations have finished and closure and rehabilitation of the site has been completed, including backfilling of both pits and removal of the tailings dam (refer **Section 13.2.1**), groundwater flow patterns are expected to progressively return to those that existed prior to mining.

8.3.2 Surface Water

8.3.2.1 Hydrology

A general description of Magela Creek hydrology is provided in **Section 2.4.6**; additional information is provided in this section.

The Magela Creek catchment discharges to the Magela Creek floodplain and, ultimately, Van Diemen Gulf via the East Alligator River. The seasonal pulse of the wet season monsoon controls the regional hydrology (Wasson 1992) with flows beginning in an average year in mid-December, after the onset of the monsoonal wet season which usually occurs in November. The sand aquifers in the channel of Magela Creek in the middle catchment fill with shallow groundwater and begin flowing as interflow⁷ within the creek channel, before surface flow commences in the creek.

The relatively high permeability of the interflow zone and the low permeability of underlying lateritic clays cause flow in the watercourse to be modulated, but it is still strongly related to rainfall. Following a flood event when flow from direct surface runoff has ceased, an exponential decline of the flow with time is typical (Chapman 1990). Water can flow in the creek during 8 to 9 months of each year, but the flow rates can vary by up to four orders of magnitude at gauging station MG001 (see **Figure 8-3**). Surface flow in Magela Creek near the Ranger mine can persist for up to several months into the dry season, with most of the flow restricted to narrow channels within the wider, braided creek bed. Flows in a 'typical' wet season at MG009 are shown in **Figure 8-6**.

Overbank flow occurs during moderate to high flows and induces local flooding, causing backflow into surrounding billabongs and tributaries. The sandy bed of Magela Creek and its vegetation produces a changing creek bed alignment for the channels and levee banks, which can be markedly different from year to year. The current Magela Creek alignment appears to have shifted its flow pattern, based on ground-truthing exercises, where obvious changes to palaeochannels are observed within 200 m to the east and west of the current creek bed.

⁷ Rainfall that infiltrates the soil and moves laterally through the upper layers of the soil above the water table.

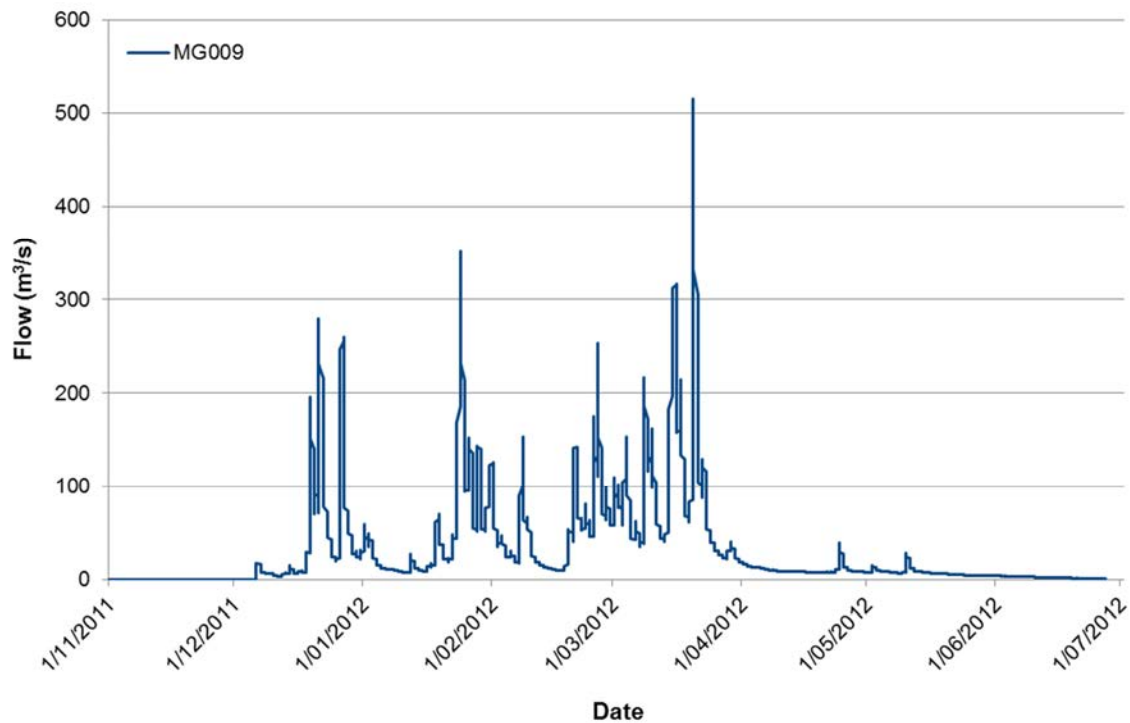


Figure 8-6: Flow in Magela Creek in the 2011 – 2012 wet season

In the lower catchment, flow within Magela Creek changes from being constrained by a channel system to being consistent with a broad wetland floodplain, where aquatic vegetation density through the entire water column damps flow response. Very low flow velocities occur on the floodplain, and wetland vegetation density retains water for a substantial period after rainfall and flow in the main channel has ceased.

The average annual flow in Magela Creek at MG009 is 382 Mm³ (Moliere, *et al.* 2008). Predicted annual recurrence intervals at the same site are 1:100, 1:200 and 1:1000 are 2,190 m³/s, 2,560 m³/s and 3,520 m³/s, respectively (Williams, *et al.* 2013). For a 1:2 year event, peak flows are expected to be about 422 m³/s.

8.3.2.2 Water Quality

Notwithstanding the intensive monitoring that has been undertaken in and near the RPA over the past several decades, a study that provides a useful summary of water quality in Magela Creek in the early operational years of Ranger mine is Hart *et al.* (1987). Several flood events were sampled at MG009 during a single wet season, with additional samples being taken from billabongs in the Mudginberri Corridor and from water flowing out from the Magela Creek floodplain.

The findings from this study focused on changes in water quality as the wet season progressed. The 'first flush', i.e. the first water to flow down the creek and across the floodplain, was acidic (pH 4.8 to 5.8), with elevated conductivity (750 µS/cm) and sulfate levels (200 mg/L). Water quality subsequently improved during the rest of the wet season, with the water generally being slightly acidic (pH 5.2), with low conductivity (5 to 17 µS/cm) and low concentrations of suspended solids (4 to 59 mg/L), major ions and trace metals such as Fe, Mn, Cu, Pb, Zn and U. These changes in water quality were attributed to an

'exhaustion effect', where the availability of material was greater early in the wet season, and the influence of rainwater. The dominant cation in all floods was Na, with the relative cation dominance being $\text{Na} > \text{Mg} > \text{Ca} > \text{K}$. The relative anionic dominance was $\text{Cl} > \text{SO}_4 > \text{HCO}_3$ in the first flood, changing to $\text{SO}_4 > \text{Cl} > \text{HCO}_3$ in subsequent flood events. Radionuclide activity was considered to be low.

Klessa (2000) derived baseline water quality data for Magela Creek based on data from a number of sources. As summarised in **Appendix 11**, baseline median values for specific water quality variables were:

- Mg – 0.64 mg/L;
- NH_4 – 0.01 mg/L;
- NO_3 – 0.03 mg/L;
- U – 0.10 $\mu\text{g/L}$;
- Mn – 5.60 $\mu\text{g/L}$; and
- ^{226}Ra – 3.0 mBq/L.

As further noted in **Appendix 11**, and based on information in Klessa (2005), changes in EC and Mg concentrations in Magela Creek reflect the hydrological regime of the creek. The levels of these variables decrease at the start of the wet season and reach a minimum near the middle, and then increase as the wet season progresses. The overall result is that EC and Mg concentrations in surface water are similar at the start and end of the wet season.

Analysis of SSD's surface water quality monitoring program for Magela Creek is presented in **Appendix 11** for key variables. As noted therein, Mg concentrations in water samples that were automatically collected closely follow the EC continuous monitoring data. Except for peaks in EC that occurred over short durations, EC values remained around 20 $\mu\text{S/cm}$ both upstream and downstream of the mine, and were well below the 42 $\mu\text{S/cm}$ limit (which corresponds to 3 mg/L Mg).

Other key findings from the SSD data include (**Appendix 11**):

- Total Mn concentrations in water samples upstream and downstream of the mine site for the past three wet seasons have been substantially lower than the limit (75 $\mu\text{g/L}$), as well as being below the action level of 45 $\mu\text{g/L}$ (even at the peak EC events).
- Total U concentrations were generally $<0.2 \mu\text{g/L}$ downstream of the mine. Although higher concentrations were evident during peak EC events, these values were substantially lower than the 6 $\mu\text{g/L}$ limit, as well as being less than the action level of 0.9 $\mu\text{g/L}$. These concentrations are similar to the filterable uranium concentration results from previous years.
- Wet season median differences for ^{226}Ra from 2001 to 2013 were close to zero, indicating that most ^{226}Ra is coming from natural sources located in the catchment upstream of the mine. The wet season median difference for the entire monitoring period (2001 – 2013) was only 0.1 mBq/L.

Data from ERA's 2012 – 2013 wet season sampling program,⁸ which assesses changes in water quality between sites upstream and downstream of Ranger mine inputs, also allows an assessment of recent water quality near the mine.

Potential mine-derived contaminants in surface waters must pass through either MG009 (on Magela Creek) or GCH (on Gulungul Creek) prior to the lower Magela Creek and associated wetlands. Potential impacts from the Project are restricted to Magela Creek; therefore, the following discussion focuses on ERA sourced data for MG009 and comparison with the upstream sites or trigger values as appropriate.

The 2012 – 2013 wet season was somewhat atypical in that flow in Magela Creek was dominated by a large flood event in early April 2013 (**Figure 8-7**). Nevertheless, flows throughout the rest of the wet season were such that ERA still collected a total of 25 weekly paired samples from Magela Creek upstream (MCUS) and MG009.

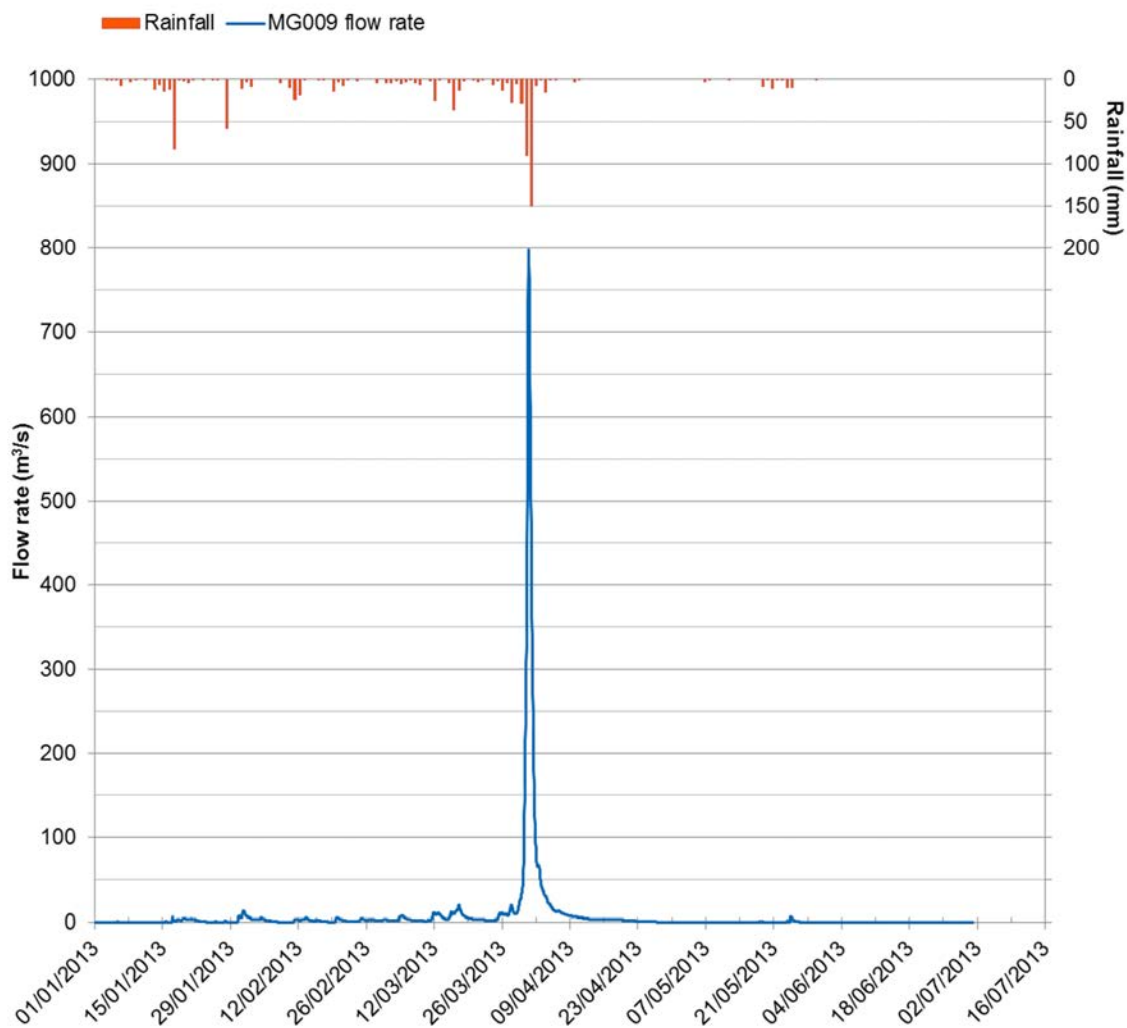


Figure 8-7: Flows in Magela Creek at MG009 in the 2012 – 2013 wet season

⁸ At the time of writing, data from the 2013 – 2014 wet season program was still being compiled and assessed.

Electrical conductivity (EC), pH (**Figure 8-8**) and turbidity values at both upstream and downstream sites exceeded either the focus or action trigger values (as they were at the time) on a number of occasions during the 2012 – 2013 wet season. These exceedances reflected either natural variations in creek conditions as a result of pulses associated with localised rainfall events or recession flow periods when shallow groundwater inflows exerted a greater influence on water chemistry. No exceedances of the then-current guideline values were recorded.

Within a broader context (**Figure 8-8**), pH results were consistent with historical values, ranging generally from pH 5.5 to 6.5, increasing in the latter stages of the wet season at both the upstream and downstream sites to values that approach pH 7.0. The low EC (generally <25 $\mu\text{S}/\text{cm}$) in the creek is also consistent with previous data and reflects well-leached soils in the catchment and a general dominance of surface run-off. Turbidity levels are similarly consistent with the historical range for Magela Creek, and are typical of relatively 'clean' waters.

Filtered uranium concentrations remained well below the compliance limit of 6 $\mu\text{g}/\text{L}$ and the management focus and action triggers.

Total ^{226}Ra activity in Magela Creek was relatively constant through the 2012 – 2013 wet season, with no difference in median wet season values between the upstream and downstream site (where the limit for this difference is 10 mBq/L). This finding is consistent with historical data, with the median difference between the two sites for all wet seasons since 2000 – 2001 being well less than 1 mBq/L , refer **Section 2.4.8**.

Although filtered Mn concentrations at MG009 were occasionally elevated during the 2012 – 2013 wet season, on both of these occasions the flow in the creek was <5 m^3/s and hence the trigger values do not apply in these low conditions. The elevated results reflect both natural variation during low stream flow conditions and the influence of groundwater, which decreases as the wet season progresses and increases at the end of the wet season.

Calcium and Mg concentrations followed a similar trend at both the upstream and downstream sites throughout the 2012 – 2013 wet season, with initial decreases in values and subsequent increases as the wet season progressed. However, Mg concentrations were consistently higher at MG009 indicating some mine influence, although no values exceed the action trigger value of 2.0 mg/L . These temporal trends are consistent with historical data. Sulfate concentrations were consistent with the Mg results in that they indicate some mine influence at MG009, but were within the ranges observed in historical data for these sites.

The generally low concentrations of these major ions are consistent with the low conductivities discussed above.

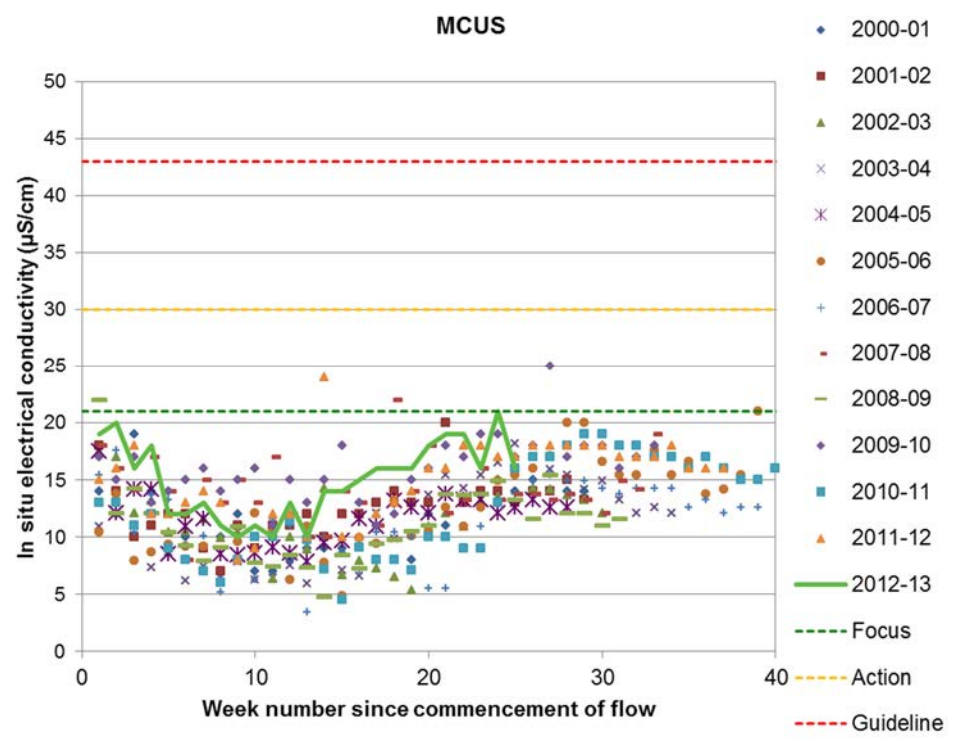
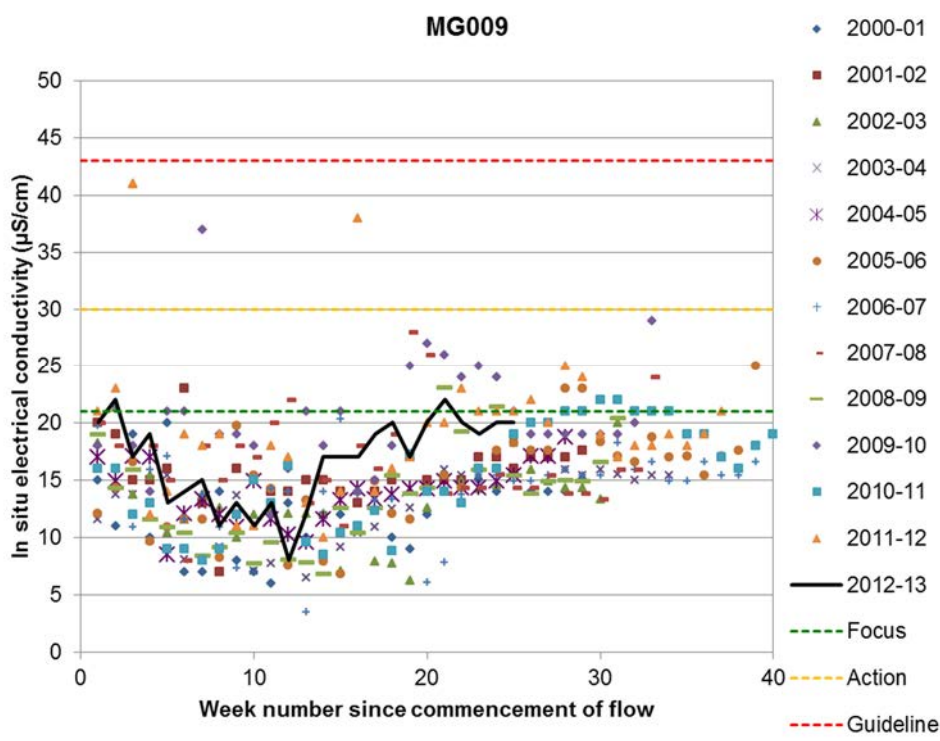
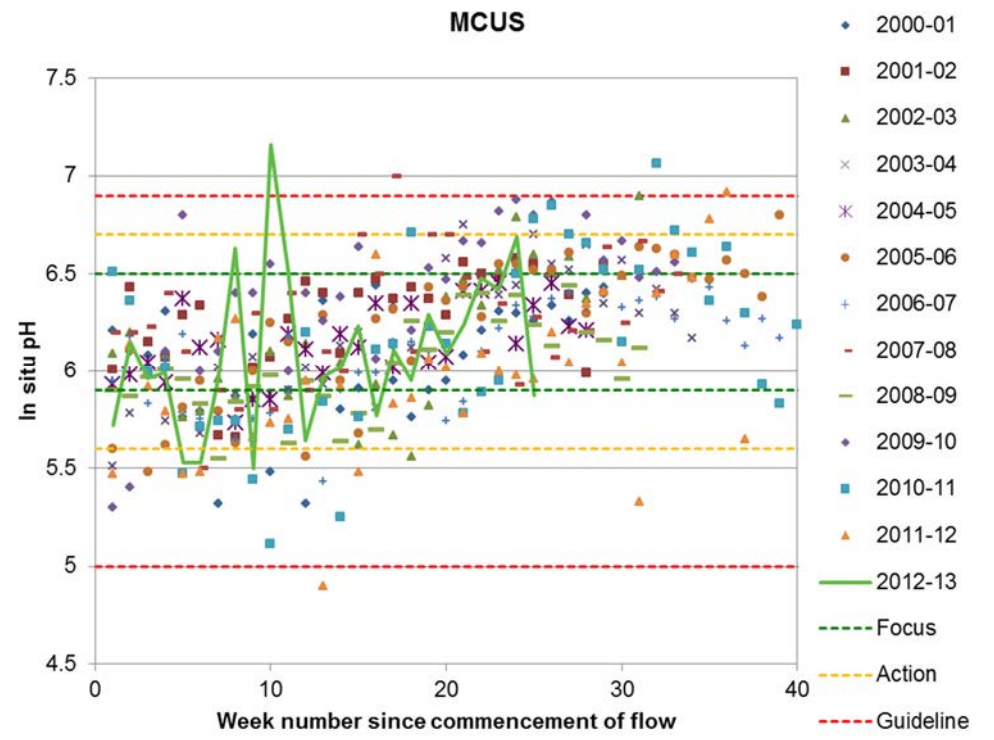
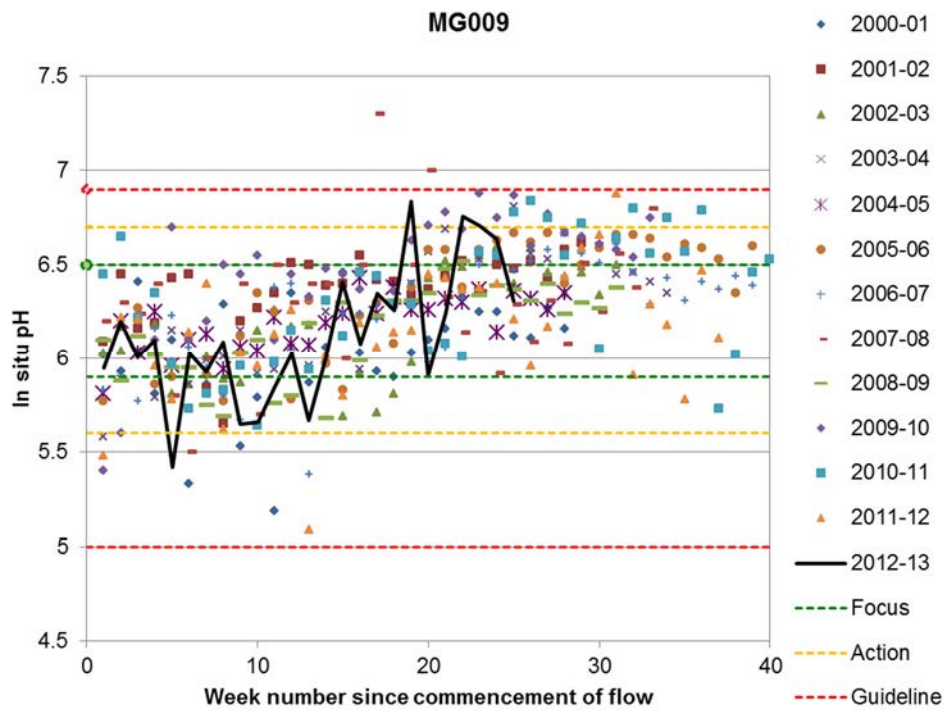


Figure 8-8: pH and EC in Magela Creek in the 2000 – 2013 wet season

Throughout the 2012 – 2013 wet season, ERA continued to operate eight real-time continuous monitoring stations within Magela Creek. Continuous EC measurements in Magela Creek did not exceed 42 $\mu\text{S}/\text{cm}$ at any point during the wet season and were consistently well below this value (which is the current limit). The maximum recorded EC was 26.7 $\mu\text{S}/\text{cm}$ in April 2013, where this was obtained following a significant rainfall event over the preceding days.

As would be expected, water quality in waterbodies immediately next to the mine and upstream of the MG009 compliance point, e.g. Corridor Creek (which includes natural and constructed wetlands), reflects both inputs from the current operation and processes such as attenuation, dilution and concentration that occur within these waterbodies. For example, Ca, Mg and SO_4 concentrations at GCBR (refer **Figure 8-3**) all increased through the 2012 dry season due to evapo-concentration of mine-derived runoff at this site, and elevated pH values between pH 8.5 and 9.5 were recorded over a few weeks in July 2012 due to algal productivity at the same site.

The results from SSD's biological monitoring program also provide an insight into water quality in Magela Creek near the Ranger mine. These can be summarised as follows (**Appendix 11**):

- Larval black banded rainbow fish survival at sites upstream and downstream of the Ranger mine remained relatively constant over time and across all tests (1991 – 1992 to 2005 – 2006).
- The similarity between fish communities in Mudginberri Billabong (a directly exposed site downstream of Ranger mine in Magela Creek) and in Sandy Billabong (a control site in another catchment) showed no adverse effects on fish communities due to changes in water quality from mining, in the period 1994 – 2013.
- The similarity between macroinvertebrate communities in 'exposed' streams downstream of Ranger mine and control sites in different catchments showed no change in community structure from 1988 to 2013.
- The low and constant U concentrations in mussels from Mudginberri Billabong up to the last sample taken in October 2012 indicate the absence of any mining influence.

8.3.2.3 Independent Surface Water Working Group

In March 2012, ERA and the Gundjeihmi Aboriginal Corporation (GAC) agreed to establish an Independent Surface Water Working Group in response to concerns of the Mirarr Traditional Owners. These concerns were arranged into four categories that were related to surface waters flowing from the Ranger mine:

- surface water management and releases;
- existing monitoring practices, compliance framework and management responses in relation to surface waters;
- downstream monitoring to provide confidence that the environment is being protected; and
- the integrity and reporting of, and stakeholder access to, relevant data.

The working group consisted of representatives from ERA, GAC, SSD and the Northern Land Council (NLC), and had an independent chair and an independent science advisor.

After a 6-month program, it was found that (Hart & Taylor 2013):

- The current surface water management and regulatory systems in place at the Ranger mine are of a very high standard.
- An agreed action plan was needed to ensure that the surface water management system continued to be best leading practice.

One of the key messages that the Independent Surface Water Working Group's scientific advisor noted was that the combined efforts of ERA and SSD:

"... have ensured the outcome of no identifiable adverse environmental or human health outcomes on downstream receiving environments or populations."

and

"There is nothing in the reports that would suggest that previous or existing practices have or will cause significant environmental damage or adverse long-term accumulative impacts that could be construed as a significant risk to human or environmental health."

The findings of the Independent Surface Water Working Group therefore support both the contention that the available water quality and related data are sufficient to provide the basis for an impact assessment, and that the Ranger mine has had no significant impacts on Kakadu National Park. However, it was noted that some gaps still exist. For example, the Independent Surface Water Working Group recommended that a review be undertaken concerning: a) mine-derived metal loads and balances; b) the additional annual load limits; and c) additional water quality indicators (Hart & Taylor 2013). Similarly, it was recommended that sediment and bushtucker monitoring (e.g. heavy metals and radionuclides in fish and other freshwater biota) be re-instated (Hart & Taylor 2013). These findings are consistent with Bartolo *et al.* (2013), who noted that:

"While knowledge gaps exist in relation to a number of pathways and stressors (e.g. organic toxicants), based on current scientific knowledge, there is no evidence to suggest that any of these pathways are resulting in adverse ecological impacts on the off-site environment within the [Alligator Rivers Region] (i.e. outside of the [RPA]) during the operational mining phase at [Ranger mine]."

MTC Technical Working Group

ERA formally agreed to the recommendations of the Independent Surface Water Working Group in December 2012 (Hart & Taylor 2013a; p. 5). After considering the 60 recommendations from the four consultant reports and the Independent Science Advisor's report (Hart & Taylor 2013b), the Independent Surface Water Working Group made 15 key recommendations for action or change (Hart & Taylor 2013a).

In February 2013, the MTC agreed that a Technical Working Group be established to review the technical and regulatory aspects of relevant recommendations and as a forum for tracking progress against all recommendations. Since the establishment of the MTC Technical Working Group, approximately 70% of the recommendations and their associated subcomponents have been implemented with the balance of the remaining recommendations awaiting data or currently in progress. The status of all outcomes of the Independent Surface Water Working Group are reported through the MTC.

8.3.2.4 Impacts of Current Mining Operations on Surface Water

The EIS guidelines request a discussion concerning changes to surface water systems as a result of mining and mining-related activities. The preceding discussion addresses this requirement in terms of comparing current and historical water quality at upstream and downstream sites on Magela Creek, and the findings of SSD's biological monitoring program. SSD uses an integrated monitoring program that provides multiple lines of evidence, has been developed over nearly 30 years, and can be regarded as leading practice. The program includes biological monitoring (in situ toxicity monitoring and ecosystem level response with annual assessment of fish and macro-invertebrate communities) and physicochemical monitoring (surface water chemistry and continuous monitoring for pH, EC, turbidity and flow). Review of the outcomes from this integrated program leads to the following findings (**Appendix 11**):

- The biological monitoring results from 1988 to the present have shown that water quality downstream of Ranger mine has not adversely affected biological communities. The Supervising Scientist (2013) concluded: *"The measured responses of the snails during the 2012–13 wet season, combined with the results from monitoring of fish and macroinvertebrates conducted in the recessional flow period towards the end of the wet season, continue to confirm that the downstream aquatic environment remains protected from the effects of the mining of uranium at Ranger."*
- The Supervising Scientist (2013) concluded, as in previous Annual Reports, that: *"... the (water quality) results indicate that the aquatic environment in the creek (Magela and Gulungul) has remained protected from mining activities."*

The 30 years of multiple lines of evidence show that, during the operational phase, water quality variables from Ranger mine that are considered to be of potential environmental importance (including Mg, U, Mn and ²²⁶Ra) have not adversely affected the water quality, or the abundance, diversity and quality of aquatic organisms, downstream of the mine site (**Appendix 11**).

These findings are also consistent with those of the Independent Surface Water Working Group, as discussed above.

8.4 APPROACH TO WATER MANAGEMENT

8.4.1 Ranger Mine

Management of surface water on site, as detailed in **Section 2.6.5** and **Section 2.6.6**, involves classification of surface water based on water quality, with these classes including process water, pond water and managed release water.

The process water management system addresses water that has passed through the uranium extraction circuit (or otherwise come into contact with that circuit), as well as rainfall that has fallen onto catchments such as the tailings dam and Pit 1. The main features of the system include:

- Storage in the tailings dam, which is designed for storage of both tailings and process water and is used to maximise passive evaporation of process water. Pit 1 has historically been used to store process water and was included as a process water catchment, but is now being rehabilitated.
- Treatment by a brine concentrator, with brines reporting to the tailings dam.

The existing pond water management system addresses rainfall on active mine site catchments (e.g. those containing mineralised rock stockpiles or parts of the processing plant for which runoff is not directed to the process water circuit) and requires specific management. The main features of the system include:

- Storage in RP2, RP3, RP6 and Pit 3 (with passive evaporation), with recycling for dust suppression, cooling water in the power station, fire control and processing.
- Treatment via three plants that use ultrafiltration/microfiltration and reverse osmosis to produce permeates which are suitable for either land application using irrigation (in the dry season) or discharge to the downstream environment (in the wet season).
- Brines from these treatment plants typically report to the tailings dam, although they may also be discharged to RP2 depending on operational requirements, the season and water levels in the pond.

Managed release water is derived from rainfall that falls on designated catchments within the mine footprint. The higher quality of this release water is such that it does not need to be included in the pond water or process water management systems.

Release water streams include, but are not limited to, RP1, the Ranger 3 Deeps access road culverts, Djalkmarra pump station 12, Djalkmarra release point and Georgetown Creek 2. This water is closely monitored as part of statutory and operational monitoring to ensure that water quality objectives are met in Magela Creek.

Management of these various classes of water is an integral component of ERA's health, safety and environment management system, and encompasses all aspects of water capture, storage, supply, distribution, use and disposal at Ranger mine. ERA employs tools such as a release plan calculator and an operational water balance model (OPSIM), combined with routine monitoring results and meteorological records, to meet the objectives of the water management system. Water is directed to a range of locations on site depending on factors such as operational requirements, water quality/extent of treatment (e.g. pond water), and flows/quality in Magela Creek (for release waters) (refer **Chapter 2, Figure 2-32**).

The release plan calculator is based on a mass balance equation model where "background" water flow (which is not influenced by the mine) is mixed with a series of "mine influenced" streams. This allows water quality at MG009 to be predicted, and is used to determine if conditions are favourable for release with respect to meeting water quality objectives in

Magela Creek at this site. Relevant flow data is obtained from sources including gauging station MG001 located on Magela Creek upstream of the Ranger mine (refer **Figure 8-3**) and various locations within the RPA. Water quality data used for the release plan calculator is similarly obtained from sites in Magela Creek (MG009; MCUS) (refer **Figure 8-3**) and various sites within the RPA. Water transfers around the site are continuously monitored through mechanisms such as pumping rates and in-line flow meters.

The release plan calculator has been used by ERA since the 2009 – 2010 wet season and has demonstrated a good relationship between predicted and actual EC values at MG009. A review of the release plan calculator's performance is provided in ERA's annual wet season reports.

Once the decision is made to release water from the site based on the release plan calculator, the calculator is then used during the period of the release to determine the flow rate in Magela Creek at which release from the specific location will cease. Releases are also stopped or reduced based on the results of the real time monitoring station at MG009. Consideration of both flow data and water quality data means that seasonal variations are inherently accounted for in the mine's existing water management practices.

8.4.2 Project Requirements

Water management requirements associated with the Project will be accommodated by Ranger mine's current water management system. Points to note are:

- Runoff from the office, hardstand and backfilled portal areas associated with the Project will be directed to the existing storm water drainage and hence to RP2, thereby becoming part of the pond water inventory.
- Ore from the proposed underground mine will be processed through the same circuit as ore for the open pit (and will replace the equivalent tonnage of stockpile feed to the processing plant), hence generating process water in exactly the same manner. No net change in mill throughput or tailings will occur as a result of the Project.
- Waste rock and low-grade ore generated by underground mining will be used for mine backfill or otherwise managed using current waste rock management procedures.
- Project mine water from the underground mine will be incorporated into the pond water management system and will be managed in accordance with its specific water quality characteristics. As noted above, excess pond water is currently managed primarily by evaporation or treatment through one of the three water treatment plants. Project mine water volumes have been estimated using the groundwater model referred to previously, and the capacity of the current water management system to accommodate this additional water has been modelled using OPSIM (and is discussed in **Section 8.5**).

8.5 ASSESSMENT OF RISKS

8.5.1 Risk Register

The environmental risk assessment (refer **Chapter 5**) identified a total of 80 risks. The initial identification of risks was aided by applying a 'risk breakdown structure' derived from the

major identified risks in the EIS guidelines and augmented by previous and current operational risk registers. Potential impacts to sensitive receptors (e.g. world heritage values of Kakadu National Park, Mount Brockman) were considered when evaluating and rating each risk scenario. Where multiple potential impacts are associated with a risk scenario, the impact with the highest risk rating defines the risk management class. Risk ratings reflect the implementation of appropriate mitigation measures (existing controls and new treatments).

Of the total of 80 risks referred to above, 24 are associated with groundwater and/or surface water. Of these, five risks were identified as having a current (inherent) Class III (high) risk rating and one had a Class IV (critical) rating (**Table 8-5**). A comparison of the current and residual risk profile shows that these have been reduced to three Class I (low) and three Class II (moderate) risks. No residual Class IV risks are associated with groundwater or surface water.

The level of certainty associated with the overall risk ranking, based on the quality of data and information available, and the effectiveness of the treatments in mitigating the risk has also been included in **Table 8-5**.

Risk TF2-12 has both a current (inherent) and residual Class III rating. This risk concerns human health but is addressed in this chapter because the controls relate to the Project's water management system. Risks TB5-01, TE3-01 and TE3-02 are inherently associated with rehabilitation and closure activities and are therefore discussed in detail in Chapter 13. However, the potential downstream water impacts associated with these risks are discussed in this chapter.

All remaining risks had either an inherent or residual Class I or Class II risk rating. These are discussed where they are of particular interest to stakeholders and/or additional treatments were identified.

A description of the risk assessment method is provided in **Chapter 5**. Additional discussion of the risks associated with the Project is provided in **Appendix 5**.

Table 8-5: Current Class III and Class IV water risks, including certainty level associated with the residual risk rating

Threat identification and title	Possible causes	Potential impacts	Current risk ranking ¹ (with existing controls)	Residual ranking ¹	Certainty level ²
TA7-01: An unsustainable drawdown of potable water aquifer (Magela or Brockman) may occur.	Leaks in the current network. Future demand from other operational needs.	Insufficient potable water supply for workers on site. Reduced water availability for plants that access the aquifer. Reduced aquifer discharge to local watercourses.	III	II	C3
TB5-01: Solutes from tailings paste backfill may transport through host rock and affect groundwater quality and Magela Creek.	Paste contains tailings and Category 2 waste that may leach solutes (including radionuclides) in the long term. Permeability characteristics of host rock may influence transport.	Solute delivered to surface water systems in unacceptable concentrations. Groundwater in the weathered zone becomes contaminated.	III	I	C3
TB6-01: Quantity of groundwater inflow to underground workings may be greater than water management capacity.	Blast impact on rock permeability. Unknown major structure(s). Intersection with historic exploration drill hole. Lack of pumping capacity.	Dewatering volumes exceed current pond water storage capacity. Pond water diverted to process water impacting on ability to meet closure schedule (compliance consequence).	III	II	C2
TB6-02: Underground water may need to be treated as process water.	Leakage of water from tailings and brine filled Pit 3. Seepage of water from paste fill. Unknown highly contaminated groundwater source.	Increasing process water inventory or changes of inventory of other water classes. Water treatment requirements alter closure schedule.	III	II	C2
TE3-01: Vent shafts may	Intersecting Pit 3	Additional solute loading to	IV	I	C3

Threat identification and title	Possible causes	Potential impacts	Current risk ranking ¹ (with existing controls)	Residual ranking ¹	Certainty level ²
provide pathway for solute transport to Magela Creek post closure.	depressurisation holes provides a pathway for Pit 3 tailings solutes to Magela Creek. Higher permeability pathway for solutes to Magela Creek from underground mine tailings storage areas.	Magela Creek (over 10,000 years).			
TE3-02: Decline may provide a conduit for solute transport from Pit 3 sources to Magela Creek.	Open void spaces underground. High permeable material used to backfill decline.	Reputational compliance. Solute egress to Magela Creek.	III	I	C3
TF2-12: Underground workers may be exposed to <i>Legionella</i> bacteria.	<i>Legionella</i> occurs in pond water. Inadequate dosing of water. Misting of water for dust control.	Legionnaires disease.	III	III	C2

1 – Risk ranking: Class IV – Critical; Class III – High; Class II – Moderate; Class I – Low.

2 – Certainty level: C1 – Low; C2 – Moderate; C3 – High. (refer Chapter 5)

8.5.2 Potential Impacts

8.5.2.1 Aquifer Drawdown

The potential for an unsustainable drawdown of the current potable water aquifer (TA7-01) has a current risk rating of Class III. Should this occur due to factors such as leaks or future operational demands, the impacts could include a lack of potable water for Ranger mine personnel, reduced water availability for vegetation, and reduced groundwater discharge to local watercourses such as Magela Creek.

Brockman and Magela borefields

Potable water for Ranger mine is obtained largely from the Brockman borefield (see **Section 2.6**), primarily from bore 84_3. Groundwater levels in this bore show a characteristic pattern, fluctuating in response to seasonal rainfall and varying up to 10 m between the wet season maximum and the dry season minimum (**Figure 8-9**). As also shown in this figure, groundwater levels in the bore show negligible response to the pumping regime, indicating that current operational practices and extraction rates are hydrogeologically sustainable.

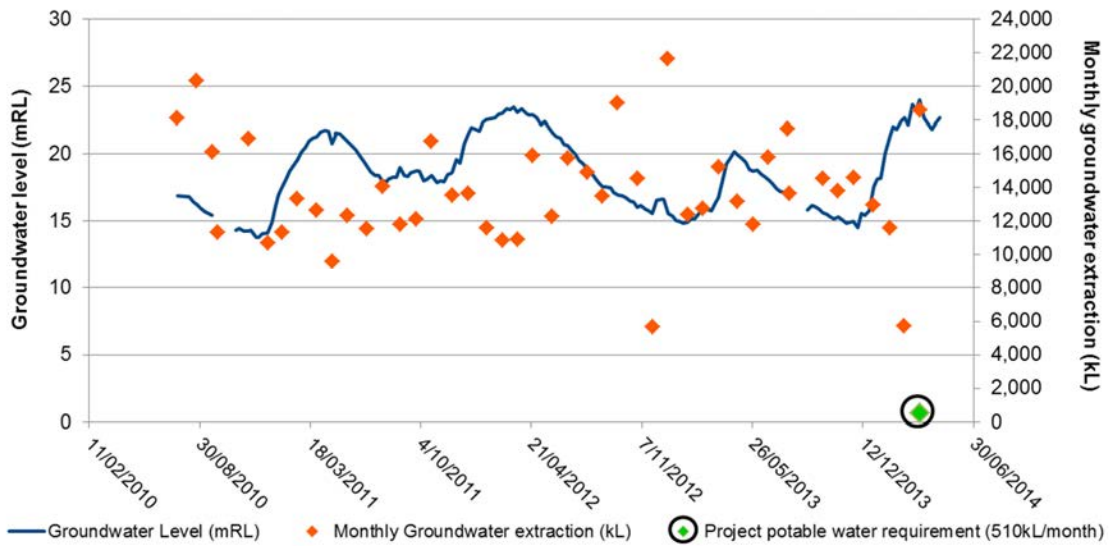


Figure 8-9: Monthly extraction volumes and groundwater levels in Brockman Bore 84_3

If the Project's entire forecast average monthly demand (510 kL) were to be sourced from this bore, the additional groundwater extraction volume represents 3.8% above the long-term average monthly abstraction (13.5 ML).

The Magela borefield is located in the north of the RPA and primarily serves the potable supply requirements of Jabiru East. As can be seen in **Figure 8-10**, monthly groundwater extraction rates from the primary bore (78_10) generally range between 4.0 and 9.0 ML. When no pumping occurs, groundwater levels display a natural seasonal range of about 5 m.

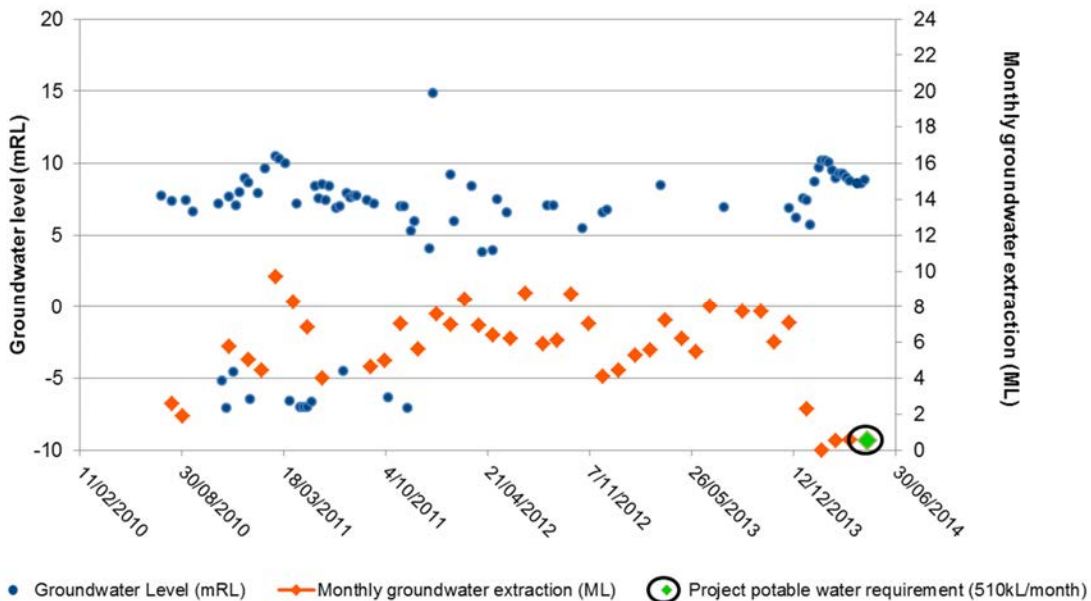


Figure 8-10: Monthly extraction volumes and groundwater levels in Magela Bore 78_10

Using a long-term average monthly abstraction rate of approximately 6.4 ML, 510 kL represents an additional abstraction of 8%.

Based on the long term average monthly groundwater extraction rates and groundwater level records from the Brockman and Magela borefields, the potable water supply assessment for the Project therefore represents a small additional demand (3.7% or 8%, respectively). Both borefields show historically sustainable yield characteristics and associated groundwater levels, hence the small additional Project-related demand is expected to result in no significant potential impacts on either groundwater source or local water resources, resulting in a residual risk ranking of Class II. No additional treatments are proposed, although groundwater drawdown will continue to be monitored. Given that the risk rating is based on historical data from the borefields, a high degree of certainty (C3) is associated with this assessment.

Local aquifer drawdown

A related issue concerns potential impacts associated with groundwater drawdown around the underground mine, where the consequent depression in groundwater levels can affect vegetation (and hence fauna habitat) and groundwater discharge to surface waterbodies such as Magela Creek. From a more regional perspective, an associated risk relates to whether such drawdown can affect the Brockman or Magela borefields. After mine closure, the issue becomes one of rebound and the length of time required for groundwater levels to return (or nearly return) to those that would exist in the absence of mining.

The assessment focused on predicting (i) changes in groundwater contours, (ii) reduction in the rate of groundwater discharging to Magela Creek that could be attributable to the underground mine, and (iii) the amount of time necessary following completion of mining for groundwater levels to recover to values that approach no-mining conditions (which were defined as drawdown that is less than 5% of its maximum).

The hydrogeological model (refer **Section 8.2.3.2** and **Appendix 10**) conservatively predicts that maximum changes in shallow groundwater during mining will:

- occur only within a very small area close to the entrance to the decline; and
- will be less than 12 m when mining is completed at the end of 2020.

The restricted distance over which the drawdown will occur is such that no measureable impacts will be evident in groundwater levels at or near Magela Creek, with the 1 cm (0.01 m) drawdown contour in the shallow groundwater system predicted to extend no closer than 400 m from the creek (**Figure 8-11**). The consequent change in groundwater discharge to the creek is negligible, decreasing by less than 0.03% (0.01 L/min) of the baseline rate (35 L/min) that occurs in the no-mining conditions.



Figure 8-11: Groundwater drawdown at the end of 2020

Given the limited nature of the predicted groundwater drawdown, measureable impacts to groundwater levels at or near the Magela and Brockman borefields are very unlikely since the borefields are located more than 2 km from the 0.01 m drawdown envelope.

A further potential impact that was assessed concerns recovery of groundwater levels on cessation of underground mining. The model indicated that this will occur quickly, with drawdown in the shallow groundwater system decreasing to 0.1 m, roughly 1% of the maximum drawdown, within 8 years after closure of the Project. This will further decrease to 0.03 m within 16 years after closure.

8.5.2.2 Changes in Magela Creek Water Quality due to Solutes

The risk associated with solutes (including radionuclides) being transported from tailings paste backfill through host rock and affecting both groundwater quality in the weathered zone and water quality in Magela Creek (TB5-01) was also a current Class III risk.

The hydrogeological modelling undertaken as described in **Section 8.2.3.2** and **Chapter 13** encompassed a 10,000 year period after mine closure. Project-related sources used in the modelling include cemented tailings paste aggregate fill for backfilling the stopes and cemented waste rock fill for backfilling the vents and decline, with the paste being designed to be low permeability and having a low moisture content. The paste will also be de-slimes, dewatered and washed to remove contaminants, and will contain cement as a binding agent. As described in **Section 13.4.1**, the modelling predicts that changes in Mg loads reporting to Magela Creek due to the Project will be negligible. More specifically, the predicted long term annual groundwater Mg load (3 kg) will be 0.0015% and 0.002% of the mean annual (2005 - 2012) mine-derived Mg load and background Mg loads, respectively (refer **Appendix 11**). Solutes leached from tailings in backfilled stopes will be only a very minor component of these very small loads and will remain well below ground level (and Magela Creek) due to the depth of the stopes and the low hydraulic conductivity of the surrounding rock. A similar assessment for U, Mn, ²²⁶Ra, TAN, nitrate, phosphate (total-P) and ²¹⁰Po shows that the predicted annual loads from all Project sources will be between 0.04% and 0.00000041% of the mean annual mine-derived loads. When compared with the additional annual load limits, the predicted annual loads will be between four and eight orders of magnitude lower.

Given these very low additional loads, corresponding changes to concentrations at MG009 are expected to be negligible. The predicted concentrations of selected key variables are shown in **Table 8-6**, based on both a worst case and an average scenario. As is evident from this table, these concentrations will be between two and four orders of magnitude less than the corresponding trigger values. Comparison with baseline values in Magela Creek also shows that the predicted increments will not be measurable above the background concentrations in the creek (**Appendix 11**).

Table 8-6: Predicted Project-associated concentrations in Magela Creek after closure compared with water quality objectives (trigger values)

Variable	Predicted concentrations in Magela Creek from Project sources		Trigger values			
	Scenario 1 ¹	Scenario 2 ²	Focus	Action	Guideline	Limit
Mg (mg/L)	0.036	8.1×10^{-6}	1.0	2.0	N/A	3.0 (\geq 72 hour limit)
U (μ g/L)	5.3×10^{-3}	1.2×10^{-6}	0.3	0.9	N/A	6.0
²²⁶ Ra (mBq/L)	5.1×10^{-2}	1.2×10^{-5}	N/A	N/A	N/A	10 (wet season median difference)
Mn (μ g/L)	2.66×10^{-2}	6.1×10^{-6}	35	45	N/A	75
TAN (mg/L)	8×10^{-5}	1.9×10^{-8}	0.1	0.3	0.7	N/A

¹ Scenario 1 (worst case) = based on annual load discharged to Magela Creek in 24 hours with low creek flow of 1 m³/s.

² Scenario 2 (average case) = based on annual load discharged to Magela Creek over an average wet season flow.

Based on these findings and the results from the monitoring programs discussed previously that show no detrimental environmental impact⁹ during the operational phase of the Ranger mine, it is apparent that transport of these solutes from the Project after mine closure will not have any environmental impact on the aquatic environment. The environmental values of Magela Creek and, by inference, the world heritage values associated with Kakadu National Park, will therefore not be compromised. This assessment also results in the risk rating decreasing from an inherent Class III risk to a residual Class I risk. A high level of certainty (C3) is associated with this assessment given that it is based on the findings from sophisticated, world-class solute egress models.

Two related risks concern the vent shafts and the decline potentially providing pathways for solutes to reach Magela Creek (TE3-01 and TE3-02) after closure. The source of these solutes includes both the underground mine and material (tailings and brine) scheduled to be placed in Pit 3 as part of the closure process (and backfilling of this pit is currently in progress). The first of these had an inherent risk rating of Class IV, while the inherent risk rating for the second risk was Class III.

A Bow Tie analysis was undertaken to better understand the risks and the proposed mitigation measures due to the potential significance of these risks (refer **Section 13.4**). The mitigation measures will minimise the extent to which solutes will be transported to Magela Creek by these pathways and will affect water quality within the creek. The modelling referred to above takes into account these potential solute pathways and the proposed

⁹ Defined in the Environmental Requirements as "any impact ... which causes or is likely to cause a change to biodiversity, or impairment of ecosystem health".

mitigation measures, adopting a conservative approach as discussed in **Chapter 13** and further detailed in **Appendix 9**. Project-derived changes to water quality in Magela Creek will therefore be negligible. Both risks are reduced to Class I ratings when the additional treatments are taken into account, as discussed in **Chapter 13** and **Appendix 6**. As with risk TB5-01, a high level of certainty (C3) is associated with this assessment for both risks.

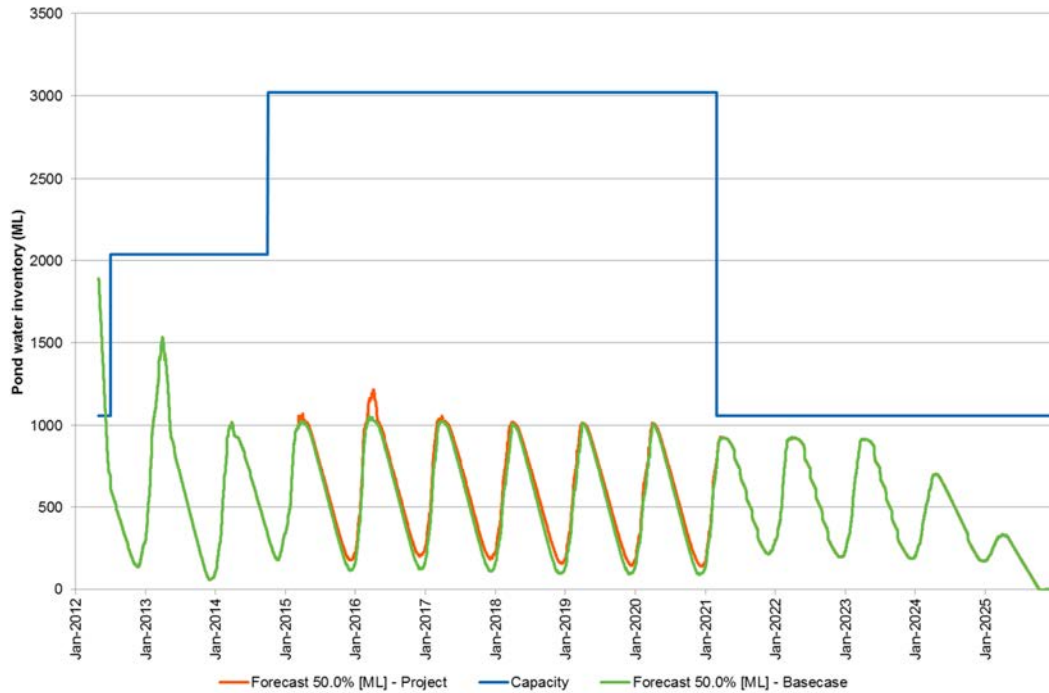
8.5.2.3 Management of Groundwater Inflow

The remaining two risks with an inherent Class III risk rating relate to management of groundwater inflows. The first of these involves dewatering requirements for the underground mine exceeding the current pond water storage capacity (TB6-01), with a consequent direct discharge to the environment. This excessive groundwater inflow could result from factors such as increased rock permeability from blasting, mine development intersecting previously unknown water-bearing structures or historic exploration drill holes, or insufficient pumping capacity within the mine. A related consequence is that pond water would then be diverted to the process water circuit, thereby affecting the ability of ERA to meet Ranger mine's current closure schedule since removal of process water from the site (by treatment) is one of the key items that determine this schedule.

Treatments to address these risks take into account both underground mining itself and management of water inflows into the mine. Concerning underground mining, the mining method chosen will involve stopes that are relatively small, with consequent small blasts that are unlikely to materially affect rock permeability. Should high flow areas still be encountered, the mining schedule can be modified to mitigate inflows. These measures will complement existing controls such as the known locations of drill holes (thereby providing assurance that both current and future drill holes are grouted) and having contingency provisions in the pumping system.

In relation to water management, underground mine dewatering facilities (including appropriate mitigation measures) are described in **Section 3.5.4**. Mine water will be classed and treated as pond water, and will report to RP2 for eventual treatment through the existing pond water treatment plants. This will result in an increase in pond water inventory, and the OPSIM water balance model¹⁰ was therefore used to compare the pond water inventory due to the Project with that in the absence of the Project. As shown in **Figure 8-12**, this increase can be managed within the existing pond water storage and treatment infrastructure, with the pond water treatment plant operations increasing to accommodate the increased volumes from the underground mine. The ability to manage seasonal variations in pond water inventory, as shown by the fluctuating values in this figure, is also evident.

¹⁰ Outputs from OPSIM are displayed as confidence traces, which provide the output for each individual day of the forecast simulation at a defined confidence level. As recommended by the developer of the model, the forecast was based on the 50% confidence trace.



Note: Increased capacity from mid-2014 to 2021 reflects implementation of contingency measures if required

Figure 8-12: OPSIM forecast pond water storage

The treatment of this pond water will result in additional process water volumes due to pond water brines reporting to the tailings dam. The OPSIM model was therefore also used to predict changes in free process water inventories that would result from the Project (**Figure 8-13**). As is evident from the modelling outputs, the incremental impact associated with the Project is not significant; existing process water storage and treatment infrastructure can successfully accommodate this additional water. These additional process water volumes will not adversely affect Ranger mine's closure strategy or closure date.

In the unlikely event that high inflows to the underground mine still occur, or that extreme rainfall events occur, ERA's current water management system contains several levels of contingency. These supplement the existing primary control measures and, depending on the particular scenario, include actions such as re-directing water transfers between the retention ponds, directing pond water to the appropriate treatment plants or, if water quality is appropriate, releasing water to the downstream system.

These measures result in the inherent Class III risk becoming a residual Class II risk, with a moderate (C2) certainty being associated with this classification.

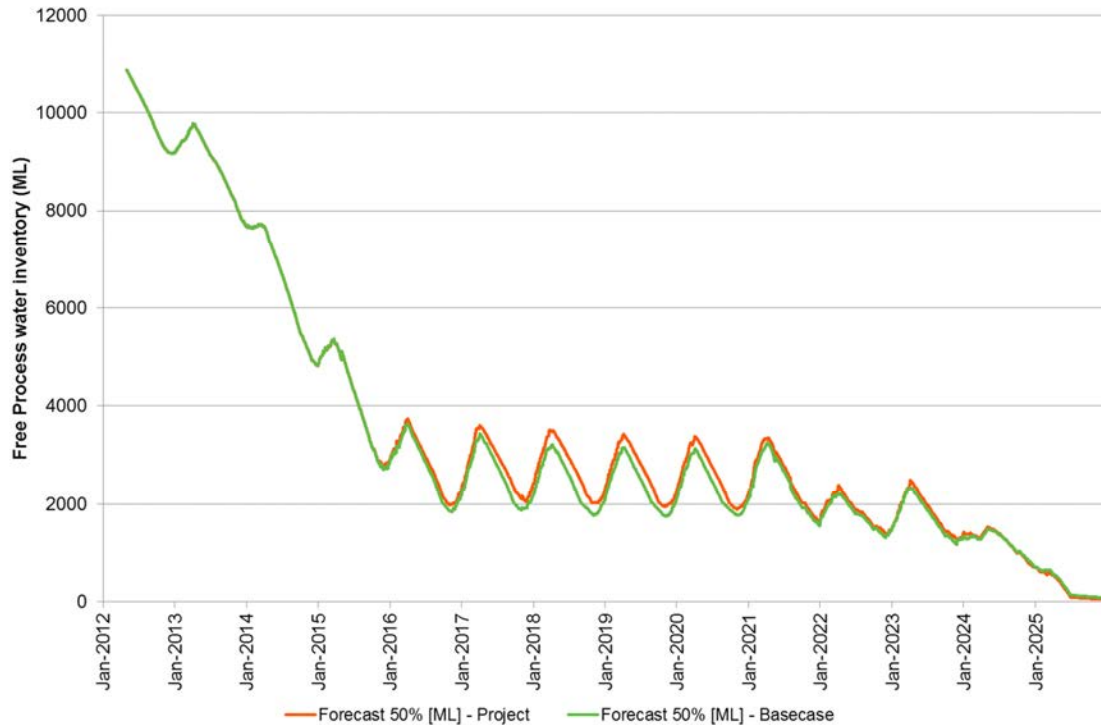


Figure 8-13: OPSIM forecast process water storage

A related risk concerns the generation of poor quality water in the underground mine due to factors such as leakage of water from the material used to backfill Pit 3 (specifically tailings and brine), contamination from paste fill in the underground mine, or an unknown highly contaminated groundwater source (TB6-02). This could increase the volume of process water or change the volumes of other classes of water, thereby affecting water treatment requirements or the closure schedule. This risk is addressed through a combination of existing controls and additional treatments. Existing controls focus on the current robust nature of the water management system at Ranger mine. Additional treatments specific to the Project include: retaining a minimum working distance (pillar) between Pit 3 and the underground mine; having a process for the tailings backfill in the underground mine that includes tailings washing and dewatering (that lowers contaminants concentration in the backfill), cement binding in the backfill (that reduces the amount of leaching from the paste backfill), and implementing protocols for water management when undertaking paste backfill. As with the previous risk, these measures result in a residual Class II risk with a moderate (C2) certainty level.

8.5.2.4 Legionnaires Disease

A risks that was identified as Class III in relation to the health of workers in the underground mine concerns the possibility of these workers being exposed to Legionella bacteria contained within the pond water circuit and contracting Legionnaires disease (TF2-12). ERA currently has a standard that addresses this risk in a broader context and includes monitoring and testing requirements. An additional treatment that will be specific to the Project is that all water will be chlorinated prior to being sent underground. However, the high consequence associated with this risk means that the residual risk rating remains Class III despite the low

likelihood. Although this risk was assigned a moderate (C2) certainty level as a result of the risk assessment (as shown in **Table 8.5**), this is a standard health and safety risk in underground mining and could well have a higher level of certainty (C3) associated with it.

8.5.2.5 Other Risks

Although only having an inherent risk rating of Class I or Class II, a number of other risks are likely to be of interest to stakeholders and hence warrant brief discussion.

Groundwater contamination

Groundwater contamination may occur during various stages of project development (e.g. operations, closure and post-closure) by mechanisms such as hydrocarbon spills from underground mining equipment (TB1-01), excessive foaming in leach tanks (TC1-01), and hydrocarbon-contaminated waste in excess of handling capacity (TD5-02). These will be addressed by existing controls such as: primary, secondary and tertiary containment practices; process controls; management plans; standards; and standard operating procedures. Existing controls will be supplemented where necessary by specific treatments such as minimising hydrocarbon storage underground, implementing traffic management rules to minimise collisions, using fast fill systems and quick connect nozzles with backflow prevention, and minimising the amount of carbonate material that is leached. All of these risks have both inherent and residual risk rankings of Class I or Class II.

Different ore, tailings and waste rock

A number of additional risks concern ore and tailings and, although they have inherent and residual risk rankings of Class I or Class II, are discussed due to their potential interest to stakeholders. The first of these is focused on solute modelling results for tailings being placed into Pit 3. If the tailings geochemistry differs from what is expected, then the modelled solute generation may also differ (TD2-01). Similarly, other risks are concerned with matters such as acid generation from waste rock (TB6-04) or more general concerns such as the amount of waste rock being greater than expected (TD1-01) or more geochemically adverse waste being generated than expected (TD1-02).

Existing controls include the proposed blending of ore from the Project and existing stockpiles; the output of tailings from processing the blended ore is then scheduled to be transferred to Pit 3, along with existing tailings from the tailings dam¹¹. In particular, there is also a high degree of confidence concerning the nature of the ore and the tailings. For example, the mineralogy of the leach residues for both historical processing plant data and the drill core composite leach tests from the Project is presented in **Section 3.4.1, Figure 3-14**. No significant difference in mineral abundance is apparent, with similar minerals being present in comparable abundances. This finding is consistent with the behaviour of ore when it is processed to remove the contained uranium, with the amount and rate of uranium extraction from both the typical historical Ranger mine ore and samples from the Ranger 3 Deeps deposit being similar.

Given this information and the fact that the ore from the underground mine will be mixed in nearly equal proportion with existing stockpile material, the risk associated with tailings management will not be significantly affected by the Project.

¹¹ Placement of tailings in Pit 3 is subject to final regulatory approval via the MTC process.

From a geological perspective, the Ranger 3 Deeps orebody is the continuation of the Pit 3 deposit. Mineralisation in the orebody occurs primarily within brecciated chlorite schists of the Upper Mine Sequence, which contains 80% of the uranium resource (refer **Section 3.3**). The remainder occurs in the Lower Mine Sequence carbonates, hosted by bedding parallel brecciated schist horizons. A similar abundance of chlorite and carbonate minerals in the Pit 1 and Pit 3 orebodies has resulted in waste rock runoff having a near-neutral pH over 30 years of operation. In addition to the waste rock from the underground mine being expected to generate similar runoff, the waste rock tonnages generated by underground mining will be very small, being an estimated 0.54 Mt of non-mineralised grade 1 waste rock and 0.56 Mt of low grade 2s and 3s material (compared with an estimated 90 Mt of grade 1 waste rock that will remain at the completion of current operations without the Project).

Application of existing relationships between sulfur concentrations in these materials and uranium grade indicate that 1s waste rock can be classified as a very low acid rock drainage risk, with grade 2 and grade 3 waste material having a slightly higher risk. This material will be managed according to current management systems (refer **Chapter 2, Section 2.6.2** and **Section 2.6.3**) and may be stockpiled or reused in general operations. Where necessary, and notwithstanding the low risk, current management procedures will be modified and applied as required during underground mining. Relevant measures include sampling programs during mining, identification of high risk acid rock drainage potential material (if present), and short-term storage of this material in a specific stockpile on the surface. Ranger mine's water management system can readily manage the drainage from such a short-term, temporary storage facility. Management of waste rock on mine closure, including 2s and 3s material, is addressed in **Section 13.3.4**.

A related risk involves the potential misclassification of material (e.g. ore as waste) (TD3-01), with consequent increased radiation exposure from the final landform after mine closure and increased solutes to Magela Creek from the final landform runoff. Again, existing controls include the known characteristics of the orebody and grade control systems. Additional treatments include ensuring that mine planning and grade control are integral to the mine design,¹² and using a surface discriminator to ensure that the appropriate material reports to the waste stockpiles.

Additional surface water impacts

Hydrocarbon spillage during surface activities (TA1-03), using the new diesel tank and distribution system (TA6-01), or underground mining equipment (TB1-01) are not likely to be problematic from a surface water quality perspective due to existing standards and protocols, and additional treatments. Examples of the latter include secondary containment and hazard assessment, minimising hydrocarbon storage underground, traffic management rules to minimise collisions, and including an oil-water separator in the underground water management system if required. In addition, the location of the Project's small footprint is well away from Magela Creek. A similar rationale applies to the risks posed by runoff from surface infrastructure and stockpiles (TA1-05), with most Project infrastructure being located within the current water management system and only non-mineralised material being used for construction. For those Project components located to the east of the mine access road, conventional soil erosion control measures will be considered and implemented as required,

¹² Both of these controls also enhance economic performance.

thereby minimising impacts on soil stability. Impacts on surface water due to concrete spills (TB3-01) or using shotcrete (TB3-02) similarly pose a low risk due to existing controls and additional treatments such as concrete transfers occurring within the disturbed mine area at an engineered (bunded) transfer point and water management ponds being dosed with acid (which is consistent with existing practice).

A scenario that was also considered in the risk assessment includes Pit 3 walls becoming destabilised by the underground mine and Magela Creek flowing into the pit (TB2-02). Mine design and assessment of other mitigation measures indicates that a major failure of the pit walls is not a credible scenario. The possibility of this occurring will not be exacerbated by the Project, given the small size of the underground blasts, use of approved drill and blast plans, and having a minimum pillar between Pit 3 and the underground mine.

The preceding discussion indicates that the Project is highly unlikely to cause incremental changes in water quality in Magela Creek at MG009 and further downstream. Water quality is a surrogate for measuring direct impacts on aquatic flora and fauna. In this case, the low residual risk (Class I or Class II) associated with water quality impacts from the Project similarly indicates that the Project poses a low risk to aquatic flora and fauna from a water quality perspective.

The health of aquatic ecosystems depends on other factors such as flow regime, habitat, sediment quality and riparian vegetation (see **Section 8.2.2**). With respect to the potential for the Project to cause material changes in the hydrology of Magela Creek, the average annual volume of water that is likely to be generated by groundwater flowing into the underground over the life of the underground mine is 1.6 Mm³, as determined by modelling undertaken by INTERA (and described in **Appendix 9**). The mean annual discharge in Magela Creek is 382 Mm³ (see **Section 8.3.2**). Even if all of the inflowing water to the underground mine were to be added to Magela Creek via the surface water management system, this would represent a Project-derived increment of <0.5%. Given additional inflows to the creek from tributaries further downstream, this percentage would be lower if the Magela Creek floodplain were to be considered. Additional amelioration of possible changes to the creek's hydrology due to water from the underground mine is provided by the requirement that discharges from Ranger mine's water management system accord with the current operating practices, which take into account flows (as well as water quality) in Magela Creek.

The potential for groundwater moving from the underground mine after closure affecting Magela Creek's hydrology has also been considered. While it could be argued that such groundwater discharge already occurs and the main consideration should focus on changes in quality of this discharge (as discussed elsewhere), the groundwater modelling presented in **Appendix 9** allows a more quantitative approach to be undertaken. As described in that report, outflows from the backfilled (i.e. after closure) stopes, decline and vents are predicted to 0.001 m³/d, 0.094 m³/d and 0.090 m³/d, respectively. This is a total of 0.185 m³/d, or 67.5 m³/y. Given the mean annual discharge at MG009 referred to above of 382 Mm³, the contribution from the underground mine post closure is <0.00002% of the creek's annual flow. The risk is therefore negligible.

Another risk to consider in terms of Project-related impacts on the hydrology of Magela Creek concerns losses from the creek into the underground workings due to surface subsidence or formation of a conduit between the creek and the mine (TB6-03). This is a

residual Class II risk due to a number of factors, such as the mining method substantially reducing the likelihood that surface subsidence will occur due to the small stopes and their location well below the base of the weathered rock, and the fact that the stope voids will be backfilled. Even if a conduit were to occur through which significant volumes of water could flow to the underground workings, the small total volume of the underground void (3 Mm³ in the absence of backfilling) relative to the average annual flow in Magela Creek (382 Mm³) shows that the associated risk is negligible.

Changes to the hydrology of Magela Creek due to the Project therefore do not pose a significant environmental risk.

8.6 SUMMARY

The assessment of risks to environmental values associated with groundwater and surface water reflects mitigation measures that are based on ERA's experience and existing environmental controls and systems, and have been demonstrated to be feasible and successfully implemented. The features of the Project and the existing Ranger mine that minimise water-related risks include:

- Demonstrated capability for the existing water management system at Ranger mine to manage water from various sources and of varying quality, thereby meeting both the water quality objectives for Magela Creek and the additional annual load limits under which the Ranger mine operates. This ensures a high level of protection for the downstream ecosystem and the environmental values associated with Kakadu National Park.
- The capacity for the water management system to accommodate mine water from the underground mine in both normal and high rainfall conditions (including several levels of redundancy).
- The current existence of other process controls, management plans, standards, and standard operating procedures with proven effectiveness.
- On closure, the predicted negligible Project-associated loads of solutes derived from the underground mine over a 10,000 year time frame due to factors such as the very low permeability of the host rock and the proposed use of low permeability, low moisture content paste as underground mine backfill.

No new discharges of water to the downstream environment are associated with the Project. Inherent (current) and residual risks to groundwater and surface water relate primarily to:

- Additional drawdown of both the Magela or Brockman borefields, and the shallow groundwater surrounding the underground mine.
- Contamination of aquifers from underground mining and related activities.
- Management of mine water from the underground mine.
- Solute loads from the underground mine that will report to Magela Creek after mine closure via movement through the surrounding rock or more direct pathways such as through the backfilled decline or vent raises.

A number of potential impacts are associated with the above. However, the consequent residual risks are all low level (Class I or Class II), the exception being the risk of underground workers of contracting Legionnaire's disease, which is both an inherent and residual Class III risk. No residual IV risks related to groundwater and surface water have been identified.

ERA has been effectively managing water at Ranger mine through a range of meteorological conditions, including extreme rainfall events for over 30 years. During this period the Supervising Scientist has confirmed there is no detrimental environmental impact to Magela Creek and the downstream receiving environment. The OPSIM water management model has shown that water generated by the Project can be fully integrated into the current water management system, thus ensuring that the environment will remain protected.

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