Copper and Zinc in Surface Water — Rehabilitation Standard for the Ranger uranium mine

Water and sediment theme

# Preface

The Supervising Scientist developed this Rehabilitation Standard to describe the requirements to protect aquatic ecosystems outside of the Ranger Project Area in the Alligator Rivers Region of the Northern Territory from the effects of copper and zinc in surface water. Standards for other metals including magnesium, manganese and uranium, are published separately.

This document is part of a series of Rehabilitation Standards for the Ranger uranium mine. It may be updated as additional relevant knowledge becomes available.

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/ss-rehabilitation-standards](http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards). Cited [Date].

# General elements

## Scope

1.1 The Rehabilitation Standards for the Ranger uranium mine have been developed in accordance with section 5c of the *Environment Protection (Alligator Rivers Region) Act 1978* and are advisory only.

1.2 The Environmental requirements of the Commonwealth of Australia for the operation of the Ranger uranium mine (Environmental Requirements) (Australian Government 1999) specify the environmental objectives for the rehabilitation of the Ranger uranium mine.

. The Supervising Scientist's Rehabilitation Standards quantify the rehabilitation objectives and recommend specific values based on the best available science that will ensure a high level of environmental protection. These values can be used to assess the achievement of, or progress towards, the rehabilitation objectives, some of which may not be reached for a significant time period.

1.4 Until it can be determined that the rehabilitation objectives have or will be reached, there will be an ongoing need to ensure environmental protection during and after rehabilitation, through continued water quality monitoring, including the comparison of water quality data with relevant water quality limits.

## Objective

. There is currently no agreed acceptable level of effect to the environment surrounding the Ranger Project Area. In the absence of agreement, the Rehabilitation Standards for copper and zinc in surface water aim to protect the biodiversity and health of aquatic ecosystems outside of the Ranger Project Area. This includes ecosystems upstream of the mine, given that poor water quality within the Ranger Project Area could form a barrier to the movement of aquatic organisms. If an acceptable level of effect is agreed, this standard will be updated accordingly.

## Application

1.6 This Rehabilitation Standard should be applied in Magela and Gulungul creeks at the boundary of the Ranger Project Area, downstream from the Ranger uranium mine.

1.7 Given the potentially long time-frame before the peak delivery of contaminants to surface water, this Rehabilitation Standard will most likely be used to assess predicted copper and zinc concentrations from modelled scenarios. Ongoing surface water and groundwater monitoring will be required after rehabilitation to continue to ensure the environment is being protected and validate and assess confidence in the models.

# Relevant requirements

## Environmental Requirements

2.1 The primary environmental objectives in the Environmental Requirements require that surface waters or groundwater arising from the Ranger uranium mine do not result in any detrimental change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area, including during or following rehabilitation. This Rehabilitation Standard is relevant to the Environmental Requirements listed in Box 1.

## Aspirations of traditional owners

2.2 The Mirarr Traditional Owners desire that operations at the Ranger uranium mine should not result in anychange to the natural water quality of surface waters outside of the Ranger Project Area (Iles 2004). Specifically, as stated in Garde (2013):

…the waters contained within all riparian corridors, (i.e. rivers and billabongs), must be of a quality that is commensurate with non-affected riverine systems and health standards. The principle of ‘as low as reasonably achievable’ should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and level of contamination must be as low as technically possible.

**Box 1: Ranger Environmental Requirements relevant to the Other Metals Rehabilitation Standard**

**1 Environmental protection**

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

(a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list

(b) maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park)

(d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

1.2 In particular, the company must ensure that operations at Ranger do not result in:

(a) damage to the attributes for which Kakadu National Park was inscribed on the World Heritage list

(b) damage to the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park)

(d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region.

**3 Water quality**

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

# Recommended values for metals in tailings and brine

3.1 A tiered risk assessment of all metals in tailings and brine identified copper and zinc as the two key Contaminants of Potential Concern (COPCs, see section 4). Other key COPCs in the tailings and brine, uranium, manganese and ammonia, had existing site-specific guideline values.

3.2 The guideline values reported in this Standard are site-specific (copper) and site-adapted (zinc), hence they were derived based on local conditions. A site-specific guideline value refers to a guideline value that has been specifically developed using local species and accounts for relevant chemical, physical and/or ecological conditions that occur at a site of interest. A site-adapted guideline value refers to a guideline value that has been adapted, based on existing knowledge, to make it more relevant to the chemical and physical conditions at a site of interest. To protect the aquatic ecosystems outside the Ranger Project Area in accordance with the rehabilitation objectives, predicted water quality at the boundary of the Ranger Project area, reported as 72-hour moving averages, should not exceed the recommended values for the parameters shown in Table 1.

**Table 1 Rehabilitation standard for copper and zinc in surface water**

| **Parameter** | **Location** | **Rehabilitation standard** |
| --- | --- | --- |
| Dissolved a copper | In Magela and Gulungul creeks at the boundary of the Ranger Project Area, downstream of the Ranger uranium mine | 0.5 µg/L (72-h moving average) |
| Dissolved zinc | In Magela and Gulungul creeks at the boundary of the Ranger Project Area, downstream of the Ranger uranium mine | 1.5 µg/L (72-h moving average) |

a Dissolved = <0.45 µm filtered

# Scientific basis

## Guidelines and standards used to develop the recommended values

4.1 This Rehabilitation Standard is based on site-specific and site-adapted guideline values which have been derived for local conditions, as recommended in the *Australian and New Zealand guidelines for fresh and marine water quality* (ANZG 2018). Additional details for the two contaminants are provided in the Appendix.

4.2 Given the ecological importance of the region surrounding the Ranger uranium mine, the rehabilitation standards for copper and zinc are based on guideline values that provide the highest level of protection, i.e. at least 99% of species, as recommended in the national water quality guidelines (ANZG 2018).

## Scientific evidence summary

4.3 A mixture of contaminants will be present at high concentrations in the Ranger uranium mine tailings and the concentrated brine that will be disposed of into the Pit 3 void. These contaminants could potentially enter creeks through groundwater egress after rehabilitation. Uranium, manganese and ammonia were elevated in operational discharge waters and so site-specific guideline values had previously been derived for these COPCs. However, other tailings- and brine-related contaminants were at relatively low concentrations in actively discharged release waters during the operational phase of mining and, therefore, they were previously assessed as low-risk (Turner & Jones 2010). Hence, limited site-specific toxicity data had been collected.

4.4 Given the potential for tailings- and brine-related metals to enter creeks during the post-decommissioning phase, a hazard assessment was undertaken to identify which contaminants might pose the greatest risk after rehabilitation (Iles & Humphrey 2014). Eight metals were identified, and Rehabilitation Standards were derived for each of these using national Default Guideline Values (ANZG 2018) or background concentrations present in the creeks during mine operations. These Standards were published in the Metals in Surface Water Rehabilitation Standard (version 1), now superseded following further tiers of assessment, described below.

4.5 Further assessment of the eight trace metals indicated that six were unlikely to be a risk if other site-specific guideline values were met. In particular, the assessment indicated that copper (Cu) and zinc (Zn) may still present a risk even if the guideline value for magnesium, the key limiting COPC, was achieved. Copper was also identified as a key contaminant in process water during the toxicity assessments of whole waters from the mine-site, thereby warranting a greater level of consideration (Trenfield et al. submitted). Consequently, a site-specific and site-adapted guideline value were derived for Cu and Zn respectively.

### Copper (Cu)

4.6 A national default guideline value has been published for Cu, i.e. 1.0 µg/L (ANZG 2018). However, this value was derived for fresh waters of moderate hardness and is not recommended for application to the soft surface waters surrounding the Ranger mine. Initially, in the absence of site-specific toxicity data, a reference condition approach was used to generate the previous rehabilitation standard of 0.2 µg/L (median of combined upstream and downstream Magela Creek data for the 2002–2018 period, *n* = 714). Subsequently, SSB has completed site-specific toxicity testing and generated a site-specific guideline values for Cu in Magela Creek water using toxicity estimates for seven local species (Table A1). The site-specific guideline value of 0.5 µg/L is considered ‘moderate reliability’ under the criteria recommended by Warne et al. (2018).

### Zinc (Zn)

4.7 A national default guideline value has been published for Zn, i.e. 2.4 µg/L (ANZG 2018). However, given the preference for guideline values derived for local conditions (section 4.1), site-specific and site-adapted toxicity data were generated for Zn. Site-specific toxicity estimates were acquired from testing of seven local species in Magela Creek water (Table A2). These estimates were combined with 22 published toxicity estimates that were adjusted to the local water quality conditions using a published model (CCME 2018, Table A2). This approach used a “preferred” dataset size (≥15 species) and resulted in a significantly improved fit and reliability of the Species Sensitivity Distribution over that relying only on site-specific toxicity estimates. It was deemed appropriate because Zn research has been conducted internationally to determine the relationships between biological effects and key toxicity modifying factors (i.e. pH, hardness and DOC). This collective site-adapted dataset was used to derive a guideline value of 1.5 µg/L, considered to be of ‘moderate-reliability”. The use of the CCME algorithm, which has not been validated in low-hardness waters, reduces the reliability of the guideline value. Once a model becomes available that has been validated in low hardness waters, it should be used to revise the guideline value and improve its reliability. The guideline value is classified as ‘site-adapted’ rather than ‘site-specific’ due to the incorporation of a large proportion of adjusted, non-site-specific data (van Dam et al 2019).

# Future knowledge needs

5.1 Rehabilitation planning can only be based on the best available information at a given time, but this should not preclude the continual improvement of the knowledge base and its subsequent application where possible.

5.2 The Supervising Scientist, through its Key Knowledge Needs, has identified the knowledge required to ensure appropriate management of the key risks to the environment from the rehabilitation of the Ranger uranium mine. The knowledge needs for contaminants are shown in Table 3.

**Table 3 Key Knowledge Needs for contaminants (including copper and zinc)**

|  |  |  |
| --- | --- | --- |
| **ER Link** | **Key Knowledge Need** | **Questions** |
| Biodiversity and human health | WS7. Determining the impact of chemical contaminants on aquatic biodiversity and ecosystem health | WS7D. How do acidification events impact upon, or influence the toxicity of contaminants to, aquatic biota? |

# References

ANZG 2018. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia.  Available at [www.waterquality.gov.au/anz-guidelines](http://www.waterquality.gov.au/anz-guidelines)

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# Appendix: Evidence and further details for copper and zinc toxicity

### Copper

There is comprehensive literature reporting the toxicity of copper (Cu) and the key environmental modifying factors that affect its toxicity, especially water hardness, pH and DOC (De Schamphelaere & Janssen 2004, Brix et al. 2017). Applying the results of these studies to the water quality of the creeks surrounding the Ranger mine (low hardness, pH and DOC) indicates higher Cu bioavailability and, hence, higher toxicity in these local waters compared to most freshwater systems (De Schamphelaere & Janssen 2004, Brix et al. 2017), although algal species appear to be less sensitive to Cu at low pH (Wilde et al. 2006). Researchers have developed models that adjust water quality guideline values for varied water quality conditions, and some are used by regulatory authorities (USEPA 2007). However, these models are not validated for the water quality conditions of Magela and Gulungul creeks. Copper also adsorbs particularly strongly to suspended sediment (Bradl 2004), accounting for the high total background concentrations of Cu relative to dissolved concentrations, suggesting that Cu leaving the mine site via surface waters may be associated with suspended sediments. For the data available for Magela Creek, the median concentration of Cu values is 0.2 µg/L (<0.45 µm filtered fraction), with 5th and 95th percentiles of 0.1 and 0.5 µg/L, respectively (data from combined upstream and downstream data from SSB samples over the 2002–2018 period, *n* = 714).

Early local toxicity data generated for Cu in synthetic creek water (Franklin et al. 2000, 2002, Markich & Camilleri 1997, Riethmuller et al. 2000, Williams et al. 1991) were not applicable as the test water lacked DOC, and so represented relatively high bioavailable Cu, with associated enhanced Cu toxicity (Al-Reasi et al. 2012).

More recently (over the dry season of 2020), additional chronic toxicity data were generated for Cu using six local species in Magela Creek water (collected from Bowerbird Billabong, Table A1), following the methods set out in Trenfield et al. (2020). Exposure conditions were characteristic of the slightly acidic, extremely soft, sandy streams of this region: pH 6.1 ± 0.5, electrical conductivity 19 ± 6 µS/cm, water temperature 26-30°C (species-specific), dissolved organic carbon 2.2 ± 1 mg/L, hardness 3 ± 1 mg/L (CaCO3), and alkalinity 3.5 ± 2 mg/L (CaCO3).

Toxicity data for a seventh species, a local mussel, *Velesunio angasi* (Kleinhenz 2019), were also included in the derivation of the GV, with exposure conditions falling within the ranges specified above. The original toxicity data for *V. angasi* were reported as an acute lethal 50% effect concentration (LC50) value of 6.6 µg/L. This value was converted to a chronic 10% effect concentration (EC10 = 1.7 µg/L, Table A1), using an acute to chronic conversion ratio (ACR of 4.0). This ACR was derived following the guidelines set out in Warne et al. (2018) and Batley et al (2014), by calculating the geomean of all ACRs available for Cu and mussels (March et al. 2007, Wang et al. 2007). A Species Sensitivity Distribution was produced by fitting a log normal distribution to the data listed in Table A1 (ShinyApp tool, Dalgarno 2018). The concentration of Cu calculated to protect 99% of species (and the associated 95% confidence limits) was 0.5 µg/L (0.2-1.6).

**Table A1 Toxicity data for copper using local species in Magela Creek water**

|  |  |
| --- | --- |
| **Species** | **EC10 Cu (µg/L)** |
| *Chlorella* sp. | 1.6 |
| *Lemna aequinoctialis* | 5.5 |
| *Hydra viridissima* | 2.3 |
| *Moinodaphnia macleayi* | 1.0 |
| *Amerianna cumingi* | 3.7 |
| *Mogurnda mogurnda* | 8.2 |
| *Velesunio angasia* | 1.7 |

a Copper data reported by Kleinhenz (2019)

### Zinc

There is comprehensive global literature reporting the toxicity of zinc (Zn) and the key environmental modifying factors that affect toxicity, especially water hardness and pH (Bradley & Sprague 1985, Wilde et al. 2006), DOC and humic substances (De Schamphelaere et al. 2005, Koukal et al. 2003), and suspended sediment (Bradl 2004). Applying the results of these studies to the water quality of the creeks surrounding the Ranger mine (low hardness, pH and DOC) suggests Zn toxicity would be accentuated in these local waters. For the data available for Magela Creek, the median concentration of Zn is 0.25 µg/L (<0.45 µm filtered fraction), with 5th and 95th percentiles of 0.25 and 1.5 µg/L, respectively (data from combined upstream and downstream data from SSB samples over the 2002–2018 period, *n* = 540).

Only very limited local toxicity data had been generated for Zn, i.e. exposure of hydra to Zn in synthetic creek water (Wilde et al. 2006). These data were generated in test waters that lacked DOC, thereby representing conditions for high Zn bioavailability and, hence, higher Zn toxicity (De Schamphelaere et. al. 2005).

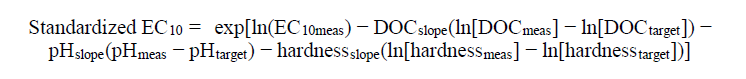
More recently (over the dry season of 2020), chronic toxicity data were generated for Zn and local species in MCW (collected from Bowerbird Billabong) following the methods set out in Trenfield et al. (2020). The initial approach to derive a site-specific GV was based on data generated for six local species (species 1-6 listed in Table A2). A Species Sensitivity Distribution (SSD) was produced by fitting a log-normal distribution to the data (refer to Supervising Scientist Branch Technical Advice #030). The concentration of Zn calculated to protect 99% of species (and the associated 95% confidence limits) was 6.5 µg/L Zn (2-10.5 µg/L). However, the resulting SSD model-fit was poor, and the site-specific GV considered to be of low reliability based on the national classification system outlined in Warne et al. (2018).

**Table A2 Chronic EC10 (µg/L Zn) values derived for seven local species and 22 additional species exposed to zinc**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **#** | **Local species** | **Chronic Endpoint** | **Zn (µg/L)** | **Converted EC10** | **Reference** |
| 1 | *Chlorella* sp. | EC10 | 286 |  | This study |
| 2 | *Lemna aequinoctialis* | EC10 | 320 |  | This study |
| 3 | *Hydra viridissima* | EC10 | 53 |  | This study |
| 4 | *Moinodaphnia macleayi* | EC10 | 40 |  | This study |
| 5 | *Amerianna cumingi* | EC10 | 27 |  | This study |
| 6 | *Mogurnda mogurnda* | EC10 | 29 |  | This study |
| 7 | *Velesunio angasi* | LC50a | 52 | 21 | This study |
|  | **Additional species** |  | **Original EC** | **Corrected EC10b** |  |
| 8 | *Bufos boreas* | NOEC | 172 | 52 | Davies & Brinkman (1999) |
| 9 | *Acipenser transmontanus* | LC20 | 102 | 23 | Vardy et al. (2011) |
| 10 | *Cottus bairdi* | NOEC | 37 | 13 | Besser et al. (2007) |
| 11 | *Oncorhynchus clarkii* | NOEC | 294 | 86 | Brinkman & Hansen (2004) |
| 12 | *Oncorhynchus mykiss* | EC10 | 130 | 37 | Mebane et al. (2008) |
| 13 | *Pimephales promelas* | NOEC | 129 | 36 | Norberg-King (1989) |
| 14 | *Prosopium williamsoni* | IC20 | 422 | 63 | Brinkman & Vieira (2008) |
| 15 | *Salmo trutta* | NOEC | 76 | 28 | Kallqvist et al. (2003) |
| 16 | *Salvelinus fontinalis* | NOEC | 190 | 92 | Davies et al. (2002) |
| 17 | *Hyalella azteca* | NOEC | 42 | 14 | Borgmann et al. (1993) |
| 18 | *Paratya australiensis* | LC50c | 100 | 11 | Bacher & O'Brien (1990) |
| 19 | *Hydropsyche betteni* | NOEC | 5400 | 244 | Balch et al. (2000) |
| 20 | *Ceriodaphnia dubia* | NOEC | 13 | 3 | Cooper et al. (2009) |
| 21 | *Ceriodaphnia reticulata* | NOEC | 90 | 7 | Carlson et al. (1986) |
| 22 | *Daphnia magna* | EC10 | 80 | 4 | Heijerick et al. (2003) |
| 23 | *Dreissena polymorpha* | NOEC | 517 | 63 | Kraak et al. (1994) |
| 24 | *Echyridella menziesii* | EC20 | 168 | 120 | Clearwater et al. (2014) |
| 25 | *Lampsilis siliquoidea* | IC10 | 55 | 37 | Wang et al. (2010) |
| 26 | *Physa gyrina* | NOEC | 570 | 205 | Nebeker et al. (1986) |
| 27 | *Potamopyrgus jenkinsi* | NOEC | 61 | 4 | Dorgelo et al. (1995) |
| 28 | *Lymnaea stagnalis* | EC10 | 508 | 65 | De Schamphelaere et al. (2010) |
| 29 | *Pseudokirchneriella subcapitata* | EC10 | 139 | 14 | De Schamphelaere et al. (2005) |

a This acute value was converted to a chronic value using an ACR (2.5) specific to mussels published by Wang et al. (2010).

b Original ECs have been corrected to a hardness of 5 mg/L CaCO3, pH 6.4 and dissolved organic carbon of 1.5 mg/L using the relationship for *Oncorhynkuss mykiss* (rainbow trout) with zinc toxicity reported by CCME (2018):



c This is a chronic LC50. It was first corrected as specified above (corrected to an LC50 = 30 µg/L) and then converted to an EC10 by dividing the LC50 by 5 (following procedure outlined in ANZG (2018))

Following current best-practice and to improve on the initial site-specific SSD model, toxicity estimates for both local species and additional non-local species were combined for guideline value derivation (Table A2). The toxicity estimates derived from non-local species were adjusted to local water quality conditions using a published model (CCME 2018). This approach was deemed the most appropriate because of the strong international research basis for Zn underpinning the relationships between biological effects and key toxicity modifying factors (i.e. pH, hardness and DOC). This “site-adapted” Guideline Value approach (van Dam et al. 2019) significantly improved the fit and reliability of the Species Sensitivity Distribution (Supervising Scientist Branch 2020).

Data for an additional 22 non-local species (Table A2) were sourced from the literature and quality-checked using the guidance of Warne et al. (2018). The selection of toxicity estimates also followed the advice of Warne et al. (2018), i.e. where there were multiple candidate values for a species, the lowest value has been used rather than a geomean of the values. The values were not combined and averaged due to the differences in endpoint and exposure duration across the studies. However, Warne et al., (2018) recommended that NOECs be excluded if more accurate toxicity estimates for ≥8 species from ≥5 taxonomic groups are available. This advice was not followed and NOECs were included in the dataset as they constituted 45% the available toxicity estimates and their inclusion also met the “preferred” dataset size of ≥15 data points. Their inclusion improved the modelling and fitting of the SSD. The lowest value was adjusted to the water quality conditions of Magela and Gulungul Creeks, i.e. ~5 mg/L hardness, pH 6.4 and 1.5 mg/L DOC (Table A2), prior to inclusion in the derivation using a Multiple Linear Regression model from CCME (2018). An acute toxicity estimate generated for larvae of a local mussel, *Velesunio angasi*, using methods reported in Tybell (2019), was also included. The acute effect concentration (LC50) was converted to a chronic toxicity estimate (EC10) using an ACR of 2.5 (Wang et al. 2010), for inclusion in the derivation of the GV.

A Species Sensitivity Distribution was produced, using the toxicity estimates from the collective 29 species, by fitting a model-average distribution to the data (Supervising Scientist Branch 2020). The concentration of zinc calculated to protect 99% of species (and the associated 95% confidence limits) was 1.5 µg/L Zn (0.7 – 4.1 µg/L). Based on the preferred sample size ≥15, the use of chronic data, and the adequacy of the fit of the data to the SSD model, this GV would be classified “very high reliability” using the criteria of Warne et al. (2018). However, the modelling relied on 13 NOECs and 75% of the toxicity estimates were adjusted with a model that has not been validated in soft waters. Hence, this guideline value should be only be considered “moderate” reliability. While original data for one of the 29 species were acute, this value was converted with high confidence using a mussel-specific ACR. This single data-point also had little overall influence on the GV. The GV is classified as ‘site-adapted’ rather than ‘site-specific’ due to the incorporation of a large proportion of adjusted, non-site-specific data (van Dam et al 2019).

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