Hydrobiology

Environmental Values Downstream of the Former Rum Jungle Mine site - Phase 2

Northern Territory - Department of Mines and Energy

April 2013

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EXECUTIVE SUMMARY

Hydrobiology was commissioned by the Northern Territory Government Department of Mines and Energy to undertake a study of the environmental values downstream of the former Rum Jungle Mine. The purpose of the study was to describe the receiving environment in terms of its key ecological and geomorphological attributes, identify environmental values (EVs) and set appropriate water quality objectives (WQOs) in accordance with the ANZECC/ARMCANZ (2000a) methodology. The Terms of Reference required this to be achieved in a two-stage process. The outcome of Stage 1 was the setting of EVs and WQOs (by river zone) with Stage 2 (this report) defining a monitoring plan.

A monitoring program is recommended that would provide support for the proposed EVs and WQOs, and enable the development of locally-derived water quality guidelines in accordance with relevant frameworks and guidelines. The monitoring program focuses on water quality, aquatic biota, aquatic and riparian tetrapoda (vertebrates other than fishes), channel processes, and riparian vegetation and aquatic macrophytes with bush food monitoring components across the biological subprograms.

To that end the recommended monitoring program encompasses:

- upstream (reference) sites;
- downstream sites within each river zone that has previously been shown to have had some aquatic and/or riparian ecosystem impacts; and
- sampling to a point downstream where impacts have, historically, not been detected nor would not reasonably be expected to occur into the future as rehabilitation progresses (River Zone 7).

The monitoring is focussed on both water and sediment quality objective compliance and assessment of ecosystem status. It is proposed that the routine monitoring is supported by targeted studies in the first instance and, overall, has been designed so that the DME Environmental Monitoring Unit can undertake the work with as little external support as possible.

Reporting and review is an important consideration with regard to the program in order to measure ecosystem response to progressive rehabilitation and, ideally, enable the extent of the program to be reduced in the future as ecosystem conditions improve post remediation. Results of the program should be reported directly to Traditional Owners.

Recommended further activities include a three-stage impact assessment which, at the time of writing, has been initiated.

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1 INTRODUCTION

1.1 Background

Hydrobiology was commissioned by the Northern Territory Government (Department of Mines and Energy) to undertake a study of the environmental values (EVs) downstream of the former Rum Jungle Mine site.

As described in the study Terms of Reference (ToR), the former Rum Jungle Mine site was mined in the 1950s-1970s then rehabilitated during the 1980s. Monitoring of landform stability and water quality within the mine area has continued since that time. The current project (under a National Partnership Agreement between the Northern Territory and Commonwealth Governments) has tasked the Department of Mines and Energy (DME) with developing an improved rehabilitation strategy for the site in recognition of the ongoing environmental impacts from this site due primarily to acid and metalliferous drainage (AMD). In order to achieve this, the DME intends to apply the ANZECC/ARMCANZ (2000a) water quality guidelines to:

- obtain a clear definition of environmental values, or uses;
- obtain a good understanding of links between human activity (including Indigenous uses) and environmental quality;
- set unambiguous management goals;
- identify appropriate water quality objectives (WQOs), or targets; and
- develop an effective management framework, including cooperative, regulatory, feedback and auditing mechanisms.

Therefore (per the ToR), the purpose of this study is to:

- identify and define the receiving environment including the relevant environmental values of the receiving environment in accordance with ANZECC methodology. This will include assessment of the aquatic ecosystems as well as fluvial sediments downstream of the mine site; and
- determine appropriate water quality guidelines.This is a two stage study. The second stage of the study (this report) required that the study team:

- outline a detailed monitoring program which will enable the development of locally-derived water quality guidelines for the receiving environment.
- recommend further activities necessary to address gaps in understanding the impacts on aquatic ecosystems downstream of the site, including possible surveys (i.e. aquatic surveys), project timelines and estimated costs.

1.2 Methodology

The monitoring program and survey needs were developed using the gaps analysis undertaken during Phase 1 of the study as a starting point. The assigning of EVs and WQOs to the nine river zones defined by Hydrobiology (2012) implied that at least one monitoring point be located in each zone although it was noted that previous studies did not identify any mine-related impacts in Zone 7 and, therefore, only targeted and necessary campaign monitoring for Zones 8 and 9 was considered likely to be necessary.

Also of relevance was knowledge of the current and historic datasets and monitoring locations in order that the monitoring plan proposed herein was complementary to the existing and historic data to the best extent possible.

In addition to consideration of data gaps and existing / historic monitoring sites and data sets, consideration was also given to:

- parameters to be monitored;
- frequency of monitoring;
- key objectives of each proposed monitoring element;
- special considerations associated with each monitoring element; and
- reporting.

The above information was collated and the monitoring plan was developed at a team workshop held on the 27th November 2012.

1.3 Summary of Gaps

During Phase 1 of this study, it became quickly apparent that, despite the accumulation of comprehensive environmental datasets and studies of the mine site, East Branch and Finniss Rivers (and surrounding watercourses), there remained a lack of understanding of impact processes and extent downstream of the mine area. This was due, largely, to (a) limited ongoing interpretation of the accumulating datasets in this regard and (b) a degree of misalignment of the monitoring activities with respect to the suitability of these data sets for downstream riverine impact assessment purposes, particularly the quality of those data and the choice of monitoring parameters, sampling locations and frequency of sampling downstream of the mine lease area.

The key data gaps (based on the Finniss River Proper, Finniss River East Branch and upstream reference sites) that were identified in Phase 1 and considered further in Phase 2 are presented in Table 1-1 below.

Table 1-1 Summary of data gaps

Data Type	Data Needs
Water quality	• General parameter reference data incl. TSS, pH, conductivity and general water characteristics such as major anions and cations • Filterable metals integrated over flow cycle downstream of the mine and in reference locations • Regular sampling in lower East Branch and Finniss River proper to Bad Crossing
Sediment quality	• Better spatial coverage of river sediments further downstream, particularly for the main Finniss River, but frequency can be relatively low (as sediments less variable within each year). • One-off floodplain coring to determine spatial / depth distribution of contaminants across floodplain.
Groundwater	• Better understanding of possible poor-quality groundwater inflows from fractured rock aquifer to the East Branch and downstream.
Geomorphology & Habitats	• Initial snapshot required. • Ongoing morphological and suspended sediment monitoring in strategic locations. • Standardised habitat assessment at strategic location.
Vegetation Surveys	• Seasonal or annual to include bush tucker plants.
Aquatic Biota	• Determine current impact status for at least fish, macroinvertebrates and diatoms using methods that are compatible with historical surveys. • Monitoring for future recovery for impacted groups and confirm unimpacted status for others (if any).
Tetrapods	• Initial snapshot focussing on turtles, frogs and other groups. • Monitoring for those groups potentially most sensitive and/or of highest traditional owner significance.
Bush Tucker	• Monitoring to ensure continued suitability for consumption • Radionuclides are key issues for human consumption of aquatic foods but assessment will need bioconcentration factors to be developed so the monitoring program will need water and sediment data for each site for comparison with the tissue data.

2 WATER QUALITY

2.1 Compliance Monitoring

Although Hydrobiology (2012) provided water quality objectives (WQO) for specified river reaches, it did not indicate how compliance with those WQO was to be assessed. This section addresses that issue.

2.1.1 Background – ANZECC/ARMCANZ and State/Territory requirements for assessment of water quality in temporary waters

Section 7.4.4.2 of the guidelines discusses how to compare monitoring data for toxicants with guideline trigger values (and hence the WQOs of Hydrobiology 2012). It stipulates (Section 7.4.4.2 - 2) that the 95th percentile of monitoring data should not exceed the trigger value, noting that this stringent requirement means that in most cases a single measurement above the trigger value would indicate action was required. In practical terms, for establishing data requirements for monitoring, that section refers to the previous section (Section 7.4.4.1 - 9 specifically) for how to assess compliance. That section more broadly covers assessment of compliance for physico-chemical stressors, including some of relevance to the WQOs developed for the Finniss River system by Hydrobiology (2012), specifically pH, suspended solids and conductivity, which involve comparison of the 80th percentile of the monitoring data from the test site with the median of data from the appropriate reference site.

Section 7.4.4.1 sets the data requirements for the reference sites as being the last two years of contiguous monthly monitoring. Note that this does not take into account the intermittent nature of the reference site if that is the case, and there is no guidance in the document regarding how to deal with such systems for assessing compliance. It simply implies that two years of monitoring will result in 24 rolling months of sampling data, but for many reference sites in the Finniss system there will be less than 24 months of water availability during any such period.

There does not appear to have been any development of specific guidance on how to manage this issue in the Northern Territory since the publication of the guidelines, but there is some guidance provided by the Queensland Government in the Queensland Water Quality Guidelines (QDERM 2009) and the Queensland Monitoring Guidelines (QDERM 2010). The former states:

> "*The application of guidelines to ephemeral waters is undoubtedly problematical. The ANZECC 2000 Guidelines mention the lack of good data on these stream types but in general offer little advice on how to approach the issue. There is some existing research being undertaken to develop better indicators and methods for ephemeral waters (e.g. Review of Methods for Water Quality Assessment of Temporary Stream and Lake Systems – see the ACMER website: http://www.acmer.uq.edu.au/publications/reports.html).*"

QDERM (2009) also notes that "problems arise when guidelines derived in base flow periods are applied to high flow or nil flow periods because water quality in these times is naturally different" and devotes a section (5.2) to this issue. Nonetheless, the recommended approach for applying guideline values to non-flowing streams for toxicants (in both water and sediment) is to apply "normal" (or default ANZECC/ARMCANZ) guideline values, as it was considered that the effects on the biota under stagnant conditions would be similar to those during flowing conditions. Similarly, while noting that the impact of short-term spikes in toxicant concentrations during flood flows might differ from the impacts of similar concentrations over longer time periods, the recommended approach was to use the default guidelines in combination with biological monitoring to assess whether or not any spikes above the guidelines resulted in detrimental impacts.

QDERM (2010) notes that the "*initial flush of water after dry periods will be very likely to give a skewed assessment of water quality*" and recommends, in general, that sampling of water quality for assessment of impact to biota should occur four weeks after the flow event, and in regards to the use of automatic samplers the use of falling stage samplers would be preferable to the use of rising stage samplers to avoid sampling the rising limb of the flood pulse. However, it also notes that "*when flow diminishes, evapo-concentration of contaminants in surface waters can occur, thereby potentially heightening the effects of exposure on* components *of the ecosystem.*" While noting that there may be different processes of impact during periods of flow compared with the no-flow period in temporary streams, and noting also the utility of assessment of water quality via biological assessment and assessment of sediment quality, it gives no further guidance on the mechanisms to achieve assessment of water quality compliance for temporary streams other than reference to Smith *et al*. (2004) and Batley *et al.* (2003).

While the former of these references provides general discussions of the nature and timing of water quality impact processes over the hydrocycle, and indicates approaches that, at the time, showed merit for assessment of water quality, it does not discuss the mechanisms of assessing compliance with water quality objectives. The latter reference makes several salient points with respect to the applicability of the ANZECC/ARMCANZ (2000a) guidelines to temporary waters:

1. *Temporary systems tend to be highly variable in nature with flows (or inundation) unpredictable and short but intense. Toxicant concentrations may subsequently be highly variable over the hydrological cycle and fixed frequency sampling may miss events.*
2. *The toxicant trigger values from the Guidelines are derived from chronic exposure responses to single toxicants. The mechanisms for compensation for pulsed exposures are not well defined.*
3. *The Guidelines provide no description of how the assessment of water quality in temporary systems should be modified to account for the lack of surface waters for varying, and often extended, periods.*
4. *There are logistical difficulties associated with sampling in systems that can flood unpredictably and over enormous scales.*

5. *Remoteness of arid and semi-arid zone systems from major centres has hampered an understanding of these systems, including life cycles and life histories of resident biota and general ecological processes.*
6. *There is no clear guidance on which biological indicators will be useful to employ in temporary systems or how to measure these.*

However, it subsequently states:

> *"For toxicants and sediments and in the absence of site-specific trigger values, users should adopt the Guideline defaults. While the relevance of these guidelines to particular temporary systems may not have been assessed, other broad-ranging comparisons, including between temperate and tropical species sensitivity, have not revealed significant differences; in the absence of site-specific information, recourse to the default values is reasonable. It may be necessary to adjust values for background, particularly in the case of the first flush.*
>
> *Exceedence of Guideline trigger values should be assessed in the manner prescribed in the Guidelines, partitioning and comparing the data for physical and chemical stressors into or by respective seasons."*

Note that the specific reference to assessment of water quality during the first flush runs counter to the argument of QDERM (2010) of avoiding assessment of this event. This issue will be discussed further below in the specific context of the Finniss River system.

The key point from Batley *et al.* (2003) is that assessment should be partitioned into "seasons". While the authors don't state what is meant by that term, the context indicates that major hydrocycle stages is what was implied by the term. This is a sensible approach, particularly if site-specific hydrocycle stage reference data are available for comparison. However, the requirement of the guidelines for 24 months of contiguous sampling data to make such site-specific comparisons would appear to be a substantial impediment. Even if it is assumed that reference data could be accumulated over successive years for each hydrocycle stage, this would imply four to eight years of reference site data would be required to acquire sufficient reference and test site data for comparison, resulting in a default to direct comparison with the default trigger values for individual samples for that length of time. In other words, for sites without substantial multi-year reference site datasets, the ability to partition sampling into "seasons" would provide no practical improvement in accounting for hydrocycle variability of water quality.

The situation is somewhat more uncertain for toxicants that have hardness dependent trigger values because the trigger values will vary with hardness, which will vary at each site over the hydrocycle. In Section 3.4.3.2 (and in the formulation of the hardness algorithms in Table 3.4.3) the guidelines imply that hardness correction is made for each individual measurement, but there is no overt guidance on how to apply that principle to determine whether or not the 95th percentile of a dataset was compliant. The simplest approach that would be consistent with this principle would be to use hardness correction for every measurement and thereby determine whether or not 95% of the measurements were below their hardness corrected trigger values.

In the case of the Rum Jungle Mine, where many of the parameters of concern are derived from acid drainage, which itself will affect water hardness, care must be exercised in the application of the hardness correction algorithms. The use of hardness as a modifier has been the subject of some debate since the publication of the guidelines (e.g. Markich *et al.* 2005). The reason for this debate is essentially because hardness correction is a simplistic method of adjustment for metal bioavailability as affected by inorganic speciation in solution in fresh waters. The intent of the hardness correction algorithms of the guidelines is to adjust for the competitive binding of calcium and/or magnesium for cell membranes (or other ligands in solution) on the basis of changes to toxicity that have been observed in ecotoxicity testing (Markich *et al*. 2001). Hardness correction was used to account for this speciation and competition because, simply, it was a commonly measured parameter in ecotoxicity tests, and hence was amenable to *post hoc* statistical adjustment, whereas metal free-ion concentrations were not. Because the algorithms were based on available laboratory toxicity data, they suffered from two key limitations with respect to the influence of acid mine drainage on hardness and metal speciation. Firstly, they were largely limited to a data set that spanned the hardness range of 25 to 400 mg/L as $CaCO_3$ (Markich *et al.* 2001). Secondly, in most laboratory waters hardness is controlled by the concentrations of calcium and magnesium, with little contribution from other cations. In acid mine drainage waters hardness can readily exceed 400 mg/L and other cations can make substantial contributions to total hardness, particularly aluminium iron and manganese, and these ions will differ in binding affinities to biotic and other ligands from those of calcium and magnesium. Hence care must be exercised in the application of the hardness modification algorithms to such waters, as erroneous "corrected' trigger values can readily result, particularly for hardness values above 400 mg/L.

2.1.2 Recommended Approaches for Rum Jungle

On the basis of the combined assessment of the references discussed above that there is no evidence that the general sensitivity or tolerance of temporary stream biota to toxicants differs substantially from those of perennial stream biota, for the recessional flow phase and most of the wet season flow phase in the East Branch, and for most of the year for the main Finniss River, the mechanism of assessment of compliance with the designated WQOs for each river zone should be consistent with the default ANZECC/ARMCANZ approach. That is, where the WQO is based on the aquatic ecosystem protection environmental value (see Hydrobiology 2012) the default trigger values should apply and 95% of monitoring data, seasonally stratified if appropriate or desirable, should be below that trigger value or WQO. If a monthly sampling frequency is assumed, then it will take 20 to 24 months (accumulated across years for these parts of the hydrocycle) to be able to calculate a 95%ile, but until that occurred, individual exceedances of the WQOs should be investigated.

It may be prudent, especially given the seasonal flows of the East Branch, and the near-perennial but still seasonally variable flows of the main Finniss River, to consider sampling more frequently than monthly to more rapidly acquire datasets that can be seasonally stratified but still constitute a sufficient basis for assessment of compliance. This would be a particularly useful strategy for development of a sufficient reference site dataset for derivation of site-specific WQOs for parameters such as pH, EC and TSS. However, there would be an increased annual cost associated with such a decision, and it would need to be considered in that context.

As fish kills associated with the first flush have historically been a feature of downstream impacts associated with the Rum Jungle Mine, it would not be advisable to avoid consideration of that phase of the hydrocycle as recommended by QDERM (2010). However, natural fish kills caused by the first flush in stream systems have been well documented in the Northern Territory (e.g. Griffin *et al.* 1998), so the aquatic ecosystems of the area have to be able to tolerate such events. Therefore, it is arguably overly protective to apply the default, chronic toxicity based trigger values from the guidelines for this phase of the hydrocycle.

ANZECC/ARMCANZ does not provide specific guidance on pulsed events such as this, but other jurisdictions do. A well-established pulsed event criterion has been established by the United States Environmental Protection Agency (USEPA 2012), which sets a Criterion Maximum Concentration (CMC) for toxicants that is "*an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect*". This concept is appropriate for consideration of the first flush in the Finniss River system and it is recommended that it be considered for use for assessment of compliance for samples from the first flush. The potential utility of this compared with use of the ANZECC/ARMCANZ derived WQOs of Hydrobiology (2012) is illustrated in Table 2-1. In general the CMC is substantially higher than the WQO except for cadmium in Zones 2 and 3 and zinc in Zone 2. Where the WQO is higher than the CMC, or there is no CMC, the continued use of the WQO for assessment of water quality in the first flush is recommended.

Table 2-1 USEPA CMC values (µg/L) for parameters of concern for the Finniss River System in comparison with Hydrobiology (2012) recommended WQOs for river Zones 1-7. WQO values above the CMC are highlighted in red. NA denotes no CMC available.

Parameter	CMC	WQO by Zone				
		1	2	3	4	5-7
Aluminium	750	55	236	150	50	55
Cadmium	1.8[1]	0.54	**4.3**	**2.2**	1.1	0.54
Cobalt	NA	2.8	Reduction[2]	Reduction[2]	2.8	2.8
Copper	12.2[1,3]	3.4	8	6.25	4.5	3.4
Iron	NA	300	Reduction[2]	Reduction[2]	300	300
Manganese	NA	140	759	443	228	140
Nickel	428[1]	27.5	55	42.5	32.5	27.5
Lead	57.6[1]	13.6	51.6	37.6	22.4	13.6
Zinc	107[1]	20	**142.5**	77.5	37.5	20
Uranium	NA	18.9	96	62	32.9	18.9

[1] Hardness modified criterion with value for 90 mg/L hardness as $CaCO_3$

[2] As only a low reliability trigger value was defined by ANZECC/ARMCANZ (2000) for this parameter, Hydrobiology (2013) set a water quality objective of a reduction of its concentration for this zone.

[3] Criterion based on a biotic ligand model (see http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/copper/2007_index.cfm) but values in table are provided based on hardness correction parameters of Appendix B of USEPA (2012)

For the dry or no-flow phase of the hydrocycle, for most river Zones, where refugial water holes will be important for provision of environmental values through the dry and for aquatic ecosystem recolonisation when flow resumes, continued use of the default WQOs is appropriate. For Zone 2 (East Branch within the mine site to Old Tailings Creek) where management of water quality impacts from the mine site will occur post remediation via some sort of management system, it is nonetheless likely that some continuance of acid mine drainage inputs is likely to persist for an extended period and evapoconcentration of solutes in small, isolated water bodies in that context is likely to result in exceedance of the default WQOs for some time. Therefore, it would likely be overly protective to apply the aquatic ecosystem protection derived WQOs for all dry phase waters at all times.

In this Zone it is recommended that individual water sample exceedances of the WQOs during the dry phase not be considered to indicate non-compliance provided that the following conditions are maintained:

- The subsequent first-flush concentrations of contaminants remain compliant with the appropriate WQOs for that event described above;

- The subsequent wet season and recessional flow phase monitoring data remain in compliance; and
- Biological monitoring continues to demonstrate that the aquatic ecosystem environmental values for each Zone are maintained during the wet season and recessional flow phases.

If the approach recommended in this section is adopted, a method of assessing compliance will result that provides for protection of the environmental values identified by Hydrobiology (2012), but is not overly protective for short term pulses of reduced water quality or for geographically isolated dry season water bodies in the mine area. It takes into account the seasonal nature of the receiving ecosystems and the practical limitations of achieving compliance with chronic aquatic ecosystem WQOs in a rehabilitated mine landscape in the seasonal tropics.

2.2 Reference site baseline and ongoing monitoring

There currently exists an extremely limited reference site water quality dataset (see Hydrobiology 2012). For some parameters reference site data are crucial to setting WQOs, particularly pH, conductivity and suspended solids. For most other parameters reference site data are needed to inform assessment of compliance and trends at the sites downstream of the mine area. It is essential that increased effort be put into collecting reference site data as soon as practical.

ANZECC/ARMCANZ provides guidance on the selection of reference sites, and QDERM (2009) provides an extended framework for this. In most of Australia, and particularly in the seasonal tropics, the requirements for selection of reference sites will tend to favour headwater and upland locations that are less likely to have development and substantial agriculture in their upstream catchments. This tendency can be problematic for lowland test site comparisons. Nonetheless, this process of identifying reference sites should be used to assess the suitability of sites to be classed as reference locations for the Finniss River system. In the interim, sites that have historically been used as reference sites for the Rum Jungle Mine should continue to be used. These include the main Finniss River upstream of the Rum Jungle, Rum Jungle South, and Mount Burton mines (FR6, FRUSMB), the East Branch upstream of the mine area (EB8, EBUSDOH) and Fitch Creek (FC@LB). Pseudo-reference sites that have been used in the past and may retain some value include sites downstream of measurable impact in the past, particularly the main Finniss River at and downstream of Bad Crossing (FR1 and FR0).

ANZECC/ARMCANZ recommends monthly monitoring of reference sites for two contiguous years to develop a reference dataset for comparison purposes. As that would constitute a considerable period of delay before any comparisons could be made, it is recommended that more frequent monitoring be considered for at least the first year. For some parameters, this could be achieved by automatic samplers – either instream instrumentation or discrete autosamplers. At least fortnightly (or twice-monthly) sampling for the first year should be considered, as that would provide more than double the number of measurements in the first year and facilitate some ability to assess 80th and 95th percentile values for test sites after that first year.

2.2.1 Sampling requirements

The aim of the water quality monitoring program should be to assess compliance with the WQOs established for each river Zone (Hydrobiology 2012). ANZECC/ARMCANZ recommends that this be accomplished by monthly monitoring and a rolling 24 month period, potentially seasonally stratified, be used for that assessment (see Section 2.1). To that end monthly monitoring would be sufficient, but more frequent monitoring would provide additional insights and should be considered.

In particular, for assessment of contaminant loads exiting the mine site there has been use of automated sampling to achieve greater sample frequencies for some parameters, and event-based sampling to detect pulses of contaminants. This approach has considerable potential to assist monitoring for protection of environmental values, but to aid flexibility in allocation of funds to both monitoring and other investigations it should be regarded as supplementary to the main monitoring effort rather than an integral, mandatory component. Particular benefit would be gained by the continued use of automated instrumentation at gauging stations for parameters such as pH, conductivity and turbidity, especially if similar instrumentation was also established at one or more reference sites. Event-based autosampler collection of water samples for other parameters would also be beneficial, particularly if filterable metals could be added to the list of measurements currently carried out for the gauging stations with such devices fitted. This would require the use of refrigerated samplers to maintain sample integrity for sufficient periods to enable sample collection and delivery to the laboratory within acceptable hold times. Consideration of this is highly recommended. As for the probe-measurements, it would be especially beneficial if event-based sampling could also be established at one or more reference sites.

The wet season is a critical time for mobilisation of contaminants and also for movement of aquatic organisms. However, it is also a period when access to stream sampling sites is most difficult. Year-round access is possible to most of the sites within the mine area, but is less feasible to other sites. We have been advised (C. Edwards, NTDME, pers. comm.) that access to sites around the East Branch confluence with the main Finniss River should be possible through the wet season, and we strongly recommend that this be established this wet season. Some reference sites above mine influence should also be accessible through the wet season, and these samples would also be critical for assessment of mine influence on water quality.

It must be acknowledged that some sites more remote from the mine area will simply not be accessible throughout the wet season, and the monitoring and assessment program must accommodate this fact. With careful planning, sufficient accessible sites should be able to be incorporated into the monitoring program to enable wet season representation for each Zone.

The other period when sampling at some sites will be impossible is during the dry season, when flow will cease and water holes will dry up in the East Branch every year, and at least in some years for the main Finniss River sites. A minimum of five samples per site per year is required to enable determination of an 80%ile in that year for that site, and it is recommended that this be achieved even though a rolling two year period may be used for assessing compliance. Year-on-year tracking of trends is also advisable, and so this minimum number of "monthly" samples is recommended. This may require some adjustment of the sampling frequency at some sites and in some years.

Maintenance of appropriate sampling and analysis quality is essential for a monitoring program. General advice is available for how to achieve this from a number of sources (e.g. ANZECC/ARMCANZ 2000b, DRET 2007, QDERM 2010). It is important that a laboratory and analysis methods be selected that are able to achieve levels of resolution that are below the water quality objectives for each parameter for each Zone. Note that this is a particular challenge for some parameters for the High Conservation value Zones 8 and 9. Measurements that do not have appropriate levels of resolution are essentially worthless for monitoring. Quality control of the sampling and sample handling is also a critical component to ensure assessments are made on the basis of valid measurements and not sample contamination, particularly where low level measurements are required in mineralised landscapes. Quality control samples, such as field and trip blanks, sample spikes and sample splits and duplicates should constitute at least 10-15% of the samples analysed in each batch. Care must also be taken to ensure that sample analysis occurs within recommended sample hold times.

The parameter lists in Table 7-2 include parameters that have set WQOs (pH, EC, TSS, metals, radionuclides and radioactivity) for which compliance should be monitored, and also additional parameters that will assist with assessing speciation and bioavailability of the main contaminants. For the parameters other than the contaminants of potential concern, it is possible that relationships and trends could be established that would enable reduced frequencies of analysis. Review and reporting of the monitoring data should take this into account, and where possible recommend reduced analysis frequency of these parameters to optimise the monitoring program costs.

3 AQUATIC BIOTA

The design of the future monitoring program for the aquatic ecosystems downstream of the Rum Jungle Mine has been developed in the context of the following issues:

- The historical environmental investigations that have set benchmarks of detriment from:
  a) unabated contaminant loadings during the 1970's; and
  b) reduced post-remedial contaminants in the 1990's;

  and in relation to the existence of considerable databases of information regarding annual contaminant loading and water concentrations through the annual hydrocycle;

- The benefit of including more measures of environmental quality than previous investigations, where the focus was mainly on fish diversity and abundances, macro-crustacean occurrences and benthic macroinvertebrates (e.g. aquatic algae);
- The potential for further ecological recovery following from remedial efforts in the 80s and subsequent to studies undertaken in the 90s, due to ecological time dependencies and lag effects (e.g. further recovery of the geographical distributions of freshwater bivalves in the Finniss and East Branch);
- The societal requirements for the adoption of sampling methods that are less potentially lethal to fishes, for example, particularly in the context of an ongoing monitoring program, but that still permit valid statistical comparisons of contemporary monitoring data with the historical databases, in order to:
  a) chart the degree of ecological recovery, following any further remedial activities at Rum Jungle; and
  b) discern any longer-term trends that may also be due to other factors (e.g. climate change impacts on flow regimes);
- The need to provide greater information on the contemporary concentrations of metals and radionuclides in bush tucker and assessment of their ongoing acceptability for human consumption, based on national and international criteria and guidelines;
- The need for the incorporation of sampling designs, frequencies and statistical analytical methods which have adequate statistical power to demonstrate ecological change when it has occurred, in line with their availability and the enhanced level of scrutiny of the results by the environmental science community and other stakeholders in modern times - this requirement would be commensurate with the level of economic investment notionally required for further remedial improvements at the Rum Jungle Mine site and its receiving waters, and the need to unequivocally demonstrate to stakeholders the anticipated ecological improvements, when they have occurred;
- This level of scrutiny would also be extended to the initial phases of remediation, when there could feasibly be initially enhanced loads of contaminants to the receiving waters before their longer-term diminution; and

- The need for explicit protocols for the methodologies to facilitate assessment of monitoring data and the timely reporting to stakeholders, particularly in relation to anomalous outcomes.

The need to both facilitate backwards compatibility with historic sampling and develop an ongoing monitoring will require a period of transition in sampling methods. In the first year or two, the historic destructive fish sampling methods (primarily gill netting) should be used in combination with less-destructive methods, such as electrofishing or trap netting. As relationships between methods are developed, the destructive sampling methods should be phased out. Similarly, for macroinvertebrate sampling, backwards compatibility with historic sampling is required, and as the most comprehensive historic dataset for this group is that of Edwards (2002), it is recommended that the sampling methodology of this study be used. The method used by Edwards (2002) was quantitative, collected sufficient specimens per sample to enable robust statistical analysis, and was equally suited to flowing and standing waters.

It is also recommended that as far as possible that the sampling sites used in the historic studies be used for the monitoring program to facilitate comparison with the historic datasets. As the historic sampling site set included sites in all the river Zones defined by Hydrobiology (2012) except for the two most-downstream zones, which are downstream of the identified limit of historic aquatic ecosystem impact, and they include sites close to existing water flow and quality monitoring sites, continued use of those sites is compatible with the monitoring program objectives. With the expectation of improvement to the aquatic ecosystems of the East Branch of the Finniss River, it is important that the site selection not only includes sites in each of the East Branch Zones from downstream of the mine area, but also reference sites in the upstream zone and sites within the mine area Zone (2).

It is recommended that the monitoring program should include measurement of a range of trophic levels, and so in addition to continuation of the historic use of fishes, decapod crustaceans, and macroinvertebrates to assess aquatic ecosystem condition, primary producer groups should be included. Monitoring of aquatic macrophytes is discussed in Section 4. Additionally, it is recommended that benthic micro-algae be included in the monitoring. Standard methods exist for this group, including those of the national River Audit (John 2000a, 2000b).

Although there are advantages to seasonal sampling for aquatic biota, in the environs of the Finniss River system this can be difficult to achieve in practice. Sampling during the recessional flow phase is recognised as an appropriate season for assessment of ecosystem status in the seasonal tropics, and is used by the Supervising Scientist Division for monitoring at other mines in the Northern Territory (Humphrey and Pidgeon 2001). The advantage of this phase of the hydrocycle is that flows tend to be more predictable than during the wet season, and hence most biota assemblages are more stable, but there is less stochastic variability in assemblage composition between sites than occurs after flow connectivity ceases (see Faith *et al*. 1995, Batley *et al.* 2003 and Smith *et al.* 2004 for further discussion of this). Ideally, sampling should occur as early in the recessional flow phase as access allows.

With these requirements in mind, the recommended monitoring program is outlined in Table 7-2.

4 RIPARIAN VEGETATION AND AQUATIC MACROPHYTES

Baseline vegetation data for the Finniss River riparian zone, both upstream and downstream of the East Branch confluence, and along the East Branch itself, are essentially absent from the published literature. Aquatic macrophyte survey data for the Finniss River and its tributaries and billabongs are also nonexistent. For the unpublished Area 55 NOI (Coffey Environments 2009), only a single site on the main branch of the Finniss River, and two sites located on the flood levee above the East Branch confluence, may have recorded riparian plant assemblages. Monitoring of the impacts of heavy metals on the riparian flora and aquatic macrophytes in the receiving environment has likewise never been initiated. The vegetation monitoring plan outlined below attempts to rectify these deficiencies by establishing a baseline prior to remedial works at the Rum Jungle Mine site, and generating a knowledge-base for the assessment of trends during and following the rehabilitation process.

Concerns over possible toxicity of native plant foods or 'bush tucker' collected from the Finniss River riparian zone have been expressed by traditional owners and other indigenous groups during stakeholder consultation meetings. The requirement for some analysis of heavy metals and other toxins that may be sequestered in fruits, tubers and other edible plant material was subsequently identified as a public health and safety concern. Consequently, a recommendation for heavy metal assays of representative bush foods from the riparian zone has been included in the plan.

4.1 Objectives

The Objectives of vegetation monitoring are as follows:

- Establish baseline riparian vegetation data for the Finniss River and the East Branch, both above and below the Rum Jungle Mine site, including the presence of rare and threatened native plant species in the survey area.
- Establish permanent vegetation monitoring sites within the riparian zone of the Finniss River and the East Branch, both above and below the Rum Jungle Mine site.
- Identify a methodology for determining short and long term trends in riparian vegetation condition during and following rehabilitation of the mine site.
- Report on the spread or control of woody weeds and other invasive species along the Finniss River and the East Branch over time.
- Survey the presence and abundance of aquatic macrophytes in the fluvial environment, and record changes in abundance over time.
- Record the presence and abundance of culturally significant plants or "bush tucker", and monitor trends in abundance over time.
- Assay representative “bush tucker” samples from the riparian zone to determine levels of heavy metals and radionuclides, and to record trends in bioaccumulation over time, that may be associated with the mine rehabilitation.
- Develop a strategy for reporting of monitoring program results to stakeholders.

4.2 Methodology

The proposed riparian vegetation monitoring plan combines the two primary methodologies developed for vegetation survey and monitoring in the Australian tropics and routinely deployed in the Top End. The field survey techniques and data standards for vegetation analysis in the Northern Territory were developed during the Conservation Commission of the NT (now DNRM) project to map the Northern Territory vegetation from satellite imagery (Wilson *et al*. 1990), and the Tropical Rapid Appraisal of Riparian Condition (TRARC) (Dixon *et al.* 2006) was developed by the Tropical Savannas CRC and participating agencies to facilitate assessment of the riparian zone using simple indicators of condition. The latter also provides a series of useful indices that may be used to identify short and long term trends in vegetation condition both during and following the proposed rehabilitation.

4.3 Sites

In line with those accepted standards, the proposed monitoring plan will consist of a series of permanently located vegetation monitoring sites within the riparian zone immediately adjacent to the river channel. Each site will consist of a 100 m long stretch of the river within which a pair of vegetation plots will be centrally located one on each side of the main river channel. Sites will be chosen to reflect the dominant vegetation in each reach of the river and vegetation plots should be located appropriately therein without preconceived bias.

All sites will be surveyed using precision GPS and vegetation monitoring plots permanently marked with star pickets. Vegetation monitoring plots will be 20 m × 20 m square, initially marked out by fibreglass tape. Plots may be narrower than 20 m in areas where the river levee and consequent riparian zone is restricted by terrain. Each site will be photographed for future reference.

Three monitoring sites will be located on the Finniss River upstream of the East Branch confluence (nominally FR6, Finniss Valley Crossing, FR5), three sites immediately downstream of the confluence (nominally FR4, FR3, and FL3 a sites examined by Hydrobiology (2012) upstream of FR2), three sites in the mid-section of the receiving environment (nominally FL6, FL2, FL1, Hydrobiology (2012) survey sites between FR2 and Florence Ck), and three sites further downstream towards Bad Crossing (nominally both Florence Ck, below Florence Ck and FR1). On the East branch, three sites will be located upstream of the mine-site (nominally between EBUSDOH to EB8 and upstream of EB8) and three sites downstream towards the confluence (nominally EB5, EEB3, GS8150097).

Additional single sites should be located on Hanna Spring, Mount Burton Spring, and the lower section of Florence Creek.

There may be some merit in locating a series of monitoring sites on the Finniss River floodplain downstream of Bad Crossing, but anecdotal evidence suggests that the impact on riparian vegetation of historical tailings releases during mine operations did not extend beyond that point. If this was seen to be worthwhile, then sites should be located immediately upstream, immediately downstream, and at the point of entry of the Finniss River channel onto the floodplain.

4.4 Frequency

Monitoring sites should be visited twice each year, firstly at the end of the wet season when vegetation growth is at a maximum, and secondly in the mid dry season prior to the flush of new growth associated with the build-up in humidity ahead of the next wet season. It is recognized that access to some sites for the late wet season visit may be restricted by a prolonged or wetter than average wet season.

4.5 Attribute Data

Terrain data recorded at each site should include landform pattern, slope and aspect; base geology, surface soil, percent rock outcrop and surface gravel. Recent fire history should also be recorded.

For the 100 m length of the site, TRARC values should be recorded for large trees, logs, high-impact weeds, canopy continuity, exposed tree roots, and any slumping, gullying or undercutting of tree roots. The complete TRARC proforma and associated score-sheets are available online (Land & Water Australia 2006).

Specific vegetation plot data should include the overall vegetation structure, the dominant growth form and projected foliage cover for each of the 3 main layers (canopy, mid-story, and ground), the percentage cover and average height of each growth form present, and a complete floristic list of species present in each layer. Species dominance for the canopy layer should be determined by basal wedge, for the other layers by projected foliage cover.

The location of woody plant within the 20×20 m vegetation plots should be recorded on a 1 m grid, and each plant attributed according to projected canopy area, diameter at breast height (DBH) and general health status. A hemispherical canopy photograph should be acquired at the centre point of each vegetation plot for empirical canopy closure comparison.

The detection of rare or threatened species should be given priority, and the relative abundance of any invasive weed species should also be recorded.

The presence and abundance of nominated 'bush-tucker' species and other plants of indigenous cultural significance should be afforded special attention.

4.6 Aquatic Macrophytes

The presence and abundance of aquatic macrophyte species should be recorded for a 100 m length of the main river channel at each monitoring site, including immediately adjacent overflow channels and billabongs where present. The location and extent of established weed-beds, if any, should be mapped using GPS.

4.7 Heavy Metal Assay

Collection of sample bush foods for heavy metal analysis may be undertaken when in season, and in cases where harvest is non-destructive or collection of fruit or seeds is unlikely to impact on the regeneration of that species within the monitoring site.

Should aquatic macrophytes be found in abundance at any site, tissue samples may be collected for heavy metal analysis.

4.8 Condition Indices

Trends in vegetation condition at each site should be monitored using a series of condition indices developed from a set of specific indicators. The majority of these indicators are included in or modified from the TRARC methodology (Dixon *et al.* 2006). TRARC combines the indicator values into four main indices, and further into a single index as an expression of 'pressure' on the riparian environment, but this may not be appropriate for the Rum Jungle situation and simple Analysis of Variance may provide a better assessment of variation over time. The specific indicators are listed below:

- canopy cover (percentage cover of trees in the canopy layer);
- canopy continuity (percentage of longitudinal bank covered with canopy trees);
- mid-layer cover (percentage cover of trees in the mid-layer);
- ground cover (percentage of cover of ground-layer vegetation);
- organic litter (percentage cover of leaves and fallen branches <10 cm diameter);
- fallen logs (abundance of logs >10 cm diameter);
- canopy health (appearance of canopy health on a score of 1 – 5);
- dominant tree regeneration (abundance of juveniles 0.3 – 3 m);
- other tree regeneration (abundance of juveniles 0.3 – 3 m);
- woody weeds (proportion of weed versus native canopy cover); and
- other weeds (percentage cover of weeds in the ground layer).

Hemispherical canopy photography, if undertaken, provides an empirical measurement of canopy cover expressed as a percentage. This figure can be used as an alternative to the estimate normally made visually by the practitioner. The limitations of this methodology are the requirement for precise location of the tripod each time, and the fact that all vegetation layers are represented in a single figure. Any plant regeneration in close proximity to the camera lens will be disproportionately represented in the cover percentage.

The baseline vegetation plot data from the initial survey should also be compiled using a database to permit cross-reference of species composition and biodiversity indices with the DNRM database as required.

Trends in aquatic macrophyte colonisation should be assessed on the basis of presence/absence, and if abundant, on total area of macrophyte-bed within the 100 m stretch of river at each monitoring site.

5 TETRAPODA (VERTEBRATES OTHER THAN FISHES)

5.1 Background

Studies on the aquatic and terrestrial tetrapods downstream of the former Rum Jungle Mine appear to be almost non-existent. Despite a large number of database records of wildlife occurrences, there does not appear to have ever been any studies of the distribution and abundance of this group downstream. Consultation with traditional owners highlighted the cultural importance of the aquatic reptiles that are present in the riparian areas of the Finniss River in particular.

5.2 Objectives

Due to a lack of knowledge the objectives of this monitoring are presented:

- Detailed terrestrial vertebrate fauna monitoring downstream of the former Rum Jungle Mine.
- Detailed monitoring of the culturally significant aquatic reptiles downstream of the former Rum Jungle Mine to gain an understanding of species abundance and secondly to determine distribution in relation to the former Rum Jungle Mine

Reporting on this monitoring be produced for distribution to traditional owners in the area.

5.3 Terrestrial Vertebrate Monitoring

In order to commence a more detailed monitoring program for the terrestrial vertebrates it is recommended that a Level 2 Fauna Survey following the methodology outlined in NRETAS (2011) be undertaken initially. This survey should have a minimum of eight sampling sites, (four upstream and four downstream of the confluence) and should be conducted in the wet and dry season (Table 5-1) in order to identify seasonal changes in the fauna structure. These sampling sites should be placed adjacent to the vegetation monitoring sites. Secondly, this survey should focus on determining which threatened species are present in the area as these may require targeted monitoring if important populations are found. These surveys should also target the following groups with respect to changes in abundance and species composition during the proposed rehabilitation:

- Aquatic Birds
- Frogs

These surveys should provide opportunities for traditional owner involvement.

Table 5-1 Frequency of recommended surveys and monitoring for vertebrates downstream of the former Rum Jungle Mine site.

Survey	Zones	Frequency
Terrestrial Vertebrates	5, 6	A three night trapping program conducted in the wet and dry seasons
Culturally Significant Reptiles	5,6	A two week freshwater turtle trapping survey combined with Merten's Water Monitor and Crocodile counts.

5.4 Culturally Significant Reptile Survey and Monitoring

As highlighted through the consultation with tradition owner groups there should be an ongoing monitoring program on the culturally significant reptiles as discussed below.

5.4.1 Freshwater Turtles

These should be monitored using a mark recapture program at sites to be determined as the extent of these species downstream of the mine site is unknown at present. The proponents should systematically trap for freshwater turtles and individually mark them enabling population structure, and number to be determined. These surveys should be conducted in the dry season as freshwater turtles are easier to trap at this time (Table 5-1).

5.4.2 Merten's Water Monitor

This species which was noted to live in the area based on traditional knowledge is listed as "Vulnerable" under the *Territory Parks and Wildlife Conservation Act (2006)*. As this species is shy and not easily captured it should be monitored using the boat survey technique outlined by Doody *et al.* (2009). It should also be noted that this species has been highly affected by the introduced cane toad in other areas of the top end (Griffiths & McKay 2005; Doody *et al.* 2009), thus numbers may be low at the proposed study sites. This program can be run concurrently with the freshwater turtle work (Table 5-1).

5.4.3 Freshwater and Saltwater Crocodiles

These species were noted to be significant totem animals that were also used for ceremonial purposes. These two species are easily assessed by nocturnal spotlight counts using the methods described in Bayliss (1988). This program can be run concurrently with the freshwater turtle work (Table 5-1).

As noted above these surveys should provide opportunities for traditional owner involvement.

6 CHANNEL PROCESSES

The term 'Channel Processes' refers to the morphology and evolution of the channel and inner floodplain which are controlled by the characteristics of flow, sediment transport, erosion and deposition.

6.1 Objectives

The key objectives of monitoring channel processes are to:

- Assess values and changes to values over time of aquatic habitats and other morphological features;
- Quantify (as far as possible) the erosion, transport and fate of suspended sediments and particulate-bound contaminants;

6.2 Surface Flows

Although changes to the topography, vegetation cover and surface characteristics of the mine area have and will influence runoff and downstream flow characteristics, we do not consider that these changes are likely to be significant with respect to the effect of these changes on flow and sediment processes. Nevertheless, ongoing monitoring of flow at operational gauging stations GS8150200 and GS8150097 (Zones 2 and 3 respectively) will provide critical data for sediment and contaminant flux estimates.

The accuracy and therefore usefulness of flow data rely heavily on the accuracy of the stage – discharge relations at each station, which can vary over time as channel morphology changes, and require regular gaugings at a range of flows to maintain accuracy. This is not an uncommon problem in hydrometric monitoring. A preliminary review of gauge records for the aforementioned stations suggested that the frequency and range of gaugings is insufficient to allow accurate flux estimates and this issue was highlighted by Moliere *et al*. (2007). Aside from the accuracy of the stations' rating tables, the quality and the coverage of the logged water level data (converted to flow by using the rating tables) has not been assessed.

Ideally, station visits for maintenance, downloading and (if possible) gauging should be undertaken on a monthly basis.

6.3 Sediment Transport

Sediment in transport is commonly divided into two components, suspended load (sediment transported mostly suspended in the flow) and bedload (coarser material that moves along the bed of the channel).

Bedload transport along the East Branch and Finniss River proper can be thought of as a 'jerky conveyor belt', with episodic erosion, transport and deposition of (predominantly) sand occurring in response to flow events. Finer sediments in suspension are transported more rapidly through the system, both in a downstream direction and laterally across the floodplain.

6.3.1 Suspended sediments

Suspended sediment and particulate-bound contaminant loads are calculated as the product of flow and TSS concentration at a particular site. Typically, loads are calculated and reported on an annual basis.

As a minimum, defensible load estimation requires good quality and continuous flow data and regular (fortnightly during the wet as access allows or more frequently with use of automated samplers) TSS data, ideally covering a range of flows at both operating gauging stations. In turbulent and well-mixed flow conditions it would be reasonable to retrieve the TSS sample from the side of the river.

6.4 Sediment Quality

Sediment quality downstream of the mine site is an important potential impacting process for the aquatic and riparian ecosystems downstream. Sediment-associated contaminants will be transported as both suspended load and bed load, but suspended sediment quality is difficult to assess unless the suspended solids concentrations are high. While the potential use of suspended sediment quality assessment during high flows in the wet season should be considered, when suspended solids concentrations will be at their peak, a more practical monitoring method would be to collect sediment quality samples during the dry season when access is possible at more sites. Collection of recently deposited sediments, i.e. from sediments deposited in the preceding wet season, will provide a good snapshot of the sediment quality that was mobilised in the wet, and if the finer size fractions are analysed, should also be representative of the quality of sediments that were transported as suspended load. To be consistent with previous sediment quality assessments for the river system downstream of the mine, at least the less than 63 μm size fraction should be analysed for metal and radionuclide concentrations.

Although a campaign of floodplain sediment sampling and assessment if recommended to be part of the impact assessment, it is not considered necessary for this to be included in the monitoring program, except for inclusion of bed sediment sampling from representative floodplain billabongs. Floodplain sediment quality should be assessed further if riparian flora and/or fauna assessments indicate poor or declining status that might be caused by poor sediment quality, or if there was an indication of declining sediment quality in the adjacent stream bed sediments. The main habitat monitored should be stream bed deposits in depositional areas following each wet season.

6.5 Channel Morphology and Habitat

Monitoring of changes to channel morphology includes width, depth, lateral migration and transient depositional features such as bars and benches (which evolve via erosion and deposition of bedload). For the case of the East Branch, there is evidence of widening and sand deposition, particularly near the junction of the Finniss River proper.

We recommend that channel morphology be monitored in three ways:

- Repeat photos from fixed photo points. Photographs are useful for a qualitative assessment of landscape change and can be easily undertaken seasonally (post-wet and mid-dry). We recommend at least one photo point in Zones 1 to 7.
- Cross-Sections. These are a quantitative assessment of width and depth change over time. For practical purposes, it is recommended that these be done at strategic locations of interest (e.g. the lower East Branch) and other sites that can be easily traversed (e.g. upper East Branch and upstream reference sites) and at gauging station sites. Cross sections at gauging stations would normally be surveyed when a flow gauging is done at those sites that are operating. However, gauging cross sections are normally sited at locations where minimal change is expected (in order to maintain a stable flow-discharge rating) and therefore may not be particularly representative of reach-scale morphological change. Cross sections may be undertaken annually or bi-annually.
- Habitat Assessment. Habitat assessments typically involve recording detail of habitat characteristics and values on an annual or bi-annual basis. Methods vary regionally in Australia, but include State of the Rivers (Anderson 1993a, 1993b) or the Index of Stream Condition (e.g. www.water.vic.gov.au) and the AusRivAS methodology (e.g. QDERM 2010).

7 SUMMARY OF MONITORING PROGRAM

A tabulation of the recommended monitoring program is presented in Table 7-1 and Table 7-2 below.

Table 7-1 Parameter sets for monitoring table

Set	Set name	Parameters
A	WQ Field	pH (field), EC (field), Turbidity (field)
B	WQ General	anions and cations including Ca, Mg, HCO_3, SO_4
C	WQ Additional	DOC, TOC, measured Hardness
D	WQ Metals	(filtered and total) - Al, Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn, U
E	WQ Radionuclides	210-Po, 210-Pb, 226-Ra, 228-Ra
F	WQ Radioactivity	Gross Beta, Gross Alpha
G	SQ metals	Al, Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn, U, Th
H	SQ Radionuclides	210-Po, 210-Pb, 226-Ra, 228-Ra
I	Biota metals	Al, Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn, U, Th
J	Biota Radionuclides	210-Po, 210-Pb, 226-Ra, 228-Ra
K	Biota Fish	Fish and Decapod abundance and diversity
L	Biota Macro	Macroinvertebrate community
M	Biota Diatoms	Diatom assemblage from depositional sediments
N1	Biota Tet	Aquatic vertebrates other than fish
N2	Biota Tet	Riparian vertebrates
O	Rip Veg	Riparian Vegetation
P (PP, HG, XS, TSS)	Channel Processes	Photo point, Habitat / Geomorphology assessment sheet, Cross Section, Total suspended solids

Table 7-2 Summary of monitoring program

Zone	Sites	Program Component	Parameter Sets	Frequency	Considerations	Objective	Reporting
		W.Qual	A,B,D	M/F	Need 20 measurements	Reference data	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
1	EB8/EBUSDOH	Water, Sediments, Biota	E-N1	A (recession flow)		Reference and distribution data	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	Reference	Biannual
		Channel processes	P (PP,HG,XS)	B	end Wet, mid Dry	Reference	Ann
		W.Qual	A,B,D	M/F	Need 20 measurements	Reference data	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
1	FC@LB	Water, Sediments, Biota	E-N1	A (recession flow)		Reference and distribution data	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	Reference	Biannual
		Channel processes	P (PP,HG,XS)	B	end Wet, mid Dry	Reference	Ann
		W.Qual	A,B,D	M		Monitor upper lease area	Ann/Seas
2	GS815_DYS	W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-M	A (recession flow)		ecosystem status	Ann
		W.Qual	A,B,D	M		Monitor lower lease area	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
2	GS8150200/EB6	Water, Sediments, Biota	E-M	A (recession flow)		ecosystem status	Ann
		Channel processes	P (PP,HG,XS,TSS)	B (TSS F/M)	end Wet, mid Dry, TSS campaign	Monitor lower lease area, Sediment Transport	Ann
2	EB5	Biota	I-M	A (recession flow)		ecosystem status	Ann
		W.Qual	A,B,D	M		Monitor lower lease area	Ann/Seas
2	TC@LB	W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-M	A (recession flow)		ecosystem status	Ann
		W.Qual	A,B,D	M		Compliance	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
3	GS8150327/EB4	Water, Sediments, Biota	E-M	A (recession flow)		ecosystem status	Ann
		Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Ann
		Channel processes	P (PP,HG,XS)	B	end Wet, mid Dry	morphological status	Ann
3	GS8150097	W.Qual	A,B,D	M		Compliance	Ann/Seas

Zone	Sites	Program Component	Parameter Sets	Frequency	Considerations	Objective	Reporting
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-M	A (recession flow)		ecosystem status	Ann
		Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Ann
		Channel processes	P (PP,HG,XS,TSS)	B (TSS F/M)	end Wet, mid Dry, TSS campaign	Morphological status, Sediment Transport	Ann
3	EB3	Biota	I-M	A (recession flow)		ecosystem status	Ann
		Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Ann
4	EB2	Biota	I-M	A (recession flow)		ecosystem status	Ann
		Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Ann
4	EB1	W.Qual	A,B,D	M		Compliance	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-N1	A (recession flow)		ecosystem status	Ann
		Riparian Vegetation	N2, O	B	end Wet, mid Dry	ecosystem status	Ann
		Channel processes	P (PP,HG,XS)	B	end Wet, mid Dry	morphological status/sand slug monitoring	Ann
5	FR6/FRUSMB/ Finniss Valley Crossing	W.Qual	A,B,D	M/F	Need 20 measurements	Reference data	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-N1	A (recession flow)		Reference and distribution data	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	Reference	Biannual
		Channel processes	P (PP,HG)	B	end Wet, mid Dry	Reference	Ann
5	FR5/FRDSMB	W.Qual	A,B,D	M/F	Need 20 measurements	Reference data	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-N1	A (recession flow)		Reference and distribution data	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	Reference	Biannual
		Channel processes	P (PP,HG)	B	end Wet, mid Dry	Reference	Ann
5	FRUSEB	W.Qual	A,B,D	M/F	Need 20 measurements	Reference data	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments	E-H	A (recession flow)		Reference and distribution data	Ann
		Channel processes	P (PP,HG)	B	end Wet, mid Dry	Reference	Ann
6	FR4/GS8150204	W.Qual	A,B,D	M/F	Need 20 measurements	Compliance	Ann/Seas

Zone	Sites	Program Component	Parameter Sets	Frequency	Considerations	Objective	Reporting
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-N1	A (recession flow)		ecosystem status	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	ecosystem status	Biannual
		Channel processes	P (PP,HG,XS)	B	end Wet, mid Dry	morphological status/sand slug monitoring	Ann
6	FR3	Biota	I-M	A (recession flow)		ecosystem status	Ann
		Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Biannual
6	FL3	Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Biannual
6	FL1	Riparian Vegetation	O	B	end Wet, mid Dry	ecosystem status	Biannual
6	FR2-Florence	Biota	I-N1	A (recession flow)		ecosystem status	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	ecosystem status	Biannual
7	FR1-Florence	W.Qual	A,B,D	M/F	Need 20 measurements	Compliance	Ann/Seas
		W.Qual	C	M/Q	Need to characterise	Important for metal speciation	Ann
		Water, Sediments, Biota	E-N1	A (recession flow)		ecosystem status	Ann
		Riparian Biota	N2, O	B	end Wet, mid Dry	ecosystem status	Biannual
		Channel processes	P (PP,HG)	A		morphological status	Ann
7	FR0	Biota	I-N1	A (recession flow)		ecosystem status	Ann
8	SOCS	Biota	Aquatic Birds Only	B	end Wet, mid Dry	ecosystem status	Biannual

A=Annually, B=Biannually, M=Monthly, Q=Quarterly, F=Fortnightly

8 REPORTING AND REVIEW

8.1 Traditional Owners

The Traditional Owners and other indigenous and non-indigenous users of the receiving environment should be regularly consulted and updated on the results of the monitoring and as much as is possible for each monitoring component should be included in the sample collection and analysis. In particular, any measureable improvement of environmental values of each monitoring component following mine-site rehabilitation should be conveyed to users of the river and its resources. Public health concerns relating to the potential heavy metal bioaccumulation by nominated bush tuckers from the aquatic and riparian environments should be addressed as a matter of priority. Ideally, a dedicated report should be provided to the traditional owners.

8.2 Data Reporting

The results of routine monitoring should be stored in a dedicated database after the usual QA/QC checks and quality-coding where appropriate.

In order to ensure ongoing review of the data and early detection of trends etc., data summaries and interpretation should be prepared on a regular basis. We recommend an Annual report is produced, that provides a summary of that year's data (including summary statistics and graphs) for each monitoring component, but also incorporates data from previous years in the analysis for the purposes of trend detection and to avoid 'data binning'. The report should be subject to peer review and distributed to stakeholders as appropriate.

8.3 Monitoring Program Review

Review and revision of the monitoring program is an integral part of the monitoring cycle (DRET 2009) but is one that is often overlooked or poorly implemented. In the case of the monitoring program recommended herein, review and revision is an essential component for two main reasons:

- Many of the recommended monitoring components have not been implemented in the past or have not been conducted in recent years, and so the design of the monitoring program is necessarily initially designed to be somewhat expansive to ensure these information gaps are filled; and
- It is envisaged that the planned mine site rehabilitation will improve environmental quality downstream over time, and hence require less linear extent of monitoring downstream as improvement occurs, and is confirmed to be stable.

Therefore, the annual reporting of the monitoring should include a review of the monitoring program, and as information accumulates and fills the data gaps, and as some components are demonstrated to have reached reference condition and maintained that condition for an appropriate period of time at sites downstream of the mine area, monitoring could and should be reduced for those components and for those sites. There may be a need to undertake some sampling of those components and those sites following extreme events, such as El Niño droughts or La Niña floods, to confirm maintenance of reference condition, but it should be expected that the monitoring program should reduce in extent over time.

9 FURTHER ACTIVITIES TO ADDRESS GAPS AND UNDERSTAND IMPACTS

At the time of writing, an impact assessment has already been considered and commissioned, with work expected to start in December 2012. For completeness, the commissioned scope for that study is summarised below.

The impact assessment should be undertaken in a three-stage study as follows:

- Stage 1. Desktop Data Analysis.
- Stage 2. Wet Season Water and Sediment Quality Snapshot.
- Stage 3. Flora, Fauna and Bush Foods Surveys.

9.1.1 Stage 1 - Desktop Data Analysis

A Desktop Data Analysis is to be conducted in order to identify and then fill critical gaps that will allow a preliminary impact assessment to be undertaken. Subsequently, a snapshot field sampling program may be undertaken during the wet season (as access allows, and probably restricted to the East Branch and sites in the Finniss River near the junction with the East Branch) and during flow recession (by mid-April to late-May). It is expected that the snapshot sampling will be undertaken by the DME's Environmental Monitoring Unit (EMU).

The purpose of the Desktop Data Analysis will be to analyse and evaluate the routine surface water monitoring data for the Mine Area, East Branch and Finniss River (near the confluence), and appropriate reference locations, to assess data quality, patterns, trends and critical deficiencies. Data from the DME databases (e.g. Hydstra for hydrological and meteorological data, and DEEP for water quality data) will be used. The Desktop Data Analysis will be achieved by:

a. Interpretation of surface water data (we understand that there are no sediment quality data available in the DME database);
    - Determine quality of data and assess whether they are fit for impact assessment purposes;
    - Compare against relevant WQOs. This is to be done for sites on the East Branch (mostly) and Finniss River (as data allow).

b. Identify data gaps and develop a sampling plan to address gaps critical for the impact assessment. Sites are expected to include the East Branch upstream and downstream of the mine, and the Finniss River upstream of the confluence to Bad Crossing (to be used [with caution] as a reference site).

c. Review of hydrographic records with particular reference to (a) data gaps (b) quality codes (c) stability of stage-discharge relations and (d) mass balance / continuity checks using (for example) double mass curve analysis. This will be undertaken for relevant current and historic gauging stations on the East Branch and Finniss River.

d. Analysis of river imagery. The purpose of this task will be to review readily (and cheaply) available remote imagery (photographs, satellites) to gain a greater level of understanding of the morphologic features of the fluvial system including (for example), evidence of stream migration, mapping of depositional features, and evidence of widening.

e. Search of floristic and faunal records using the online Biodiversity Information Facility (GBIF) / Atlas of Living Australia (ALA) portal search. A broad search was undertaken as part of the initial EVs assessment of Hydrobiology (2012), but a more detailed search will be undertaken for the impact assessment using a tighter and better defined search grid that will identify species present with a greater level of restriction to the riparian zone, but potentially with some loss of older, poorly geographically referenced records.

9.1.2 Stage 2 - Data Collection – 2012-13 Wet Season

It is expected that the Desktop Data Analysis will inform a sampling program for the 2012-13 wet season. This is expected to include:

a) Water quality snapshot. This will be undertaken at both reference and impact sites on the East Branch and Finniss Rivers. It is expected that actual field data collection will be undertaken by EMU.

b) Sediment quality snapshot. This will be undertaken post-wet and will involve collection of sediments from river bars and banks (not floodplain) by EMU.

c) Interpretation of results in combination with the existing data/information base.

For the case of Rum Jungle, filtered results (in addition to totals) for water quality samples are most relevant for ecosystem impact assessment (i.e. assessment of the duration and frequency of organisms' exposure to metals concentration) but it is noted that the current regime of water sample collection from auto-samplers does not allow for samples to be analysed for filtered metals within permitted sample holding times.

9.1.3 Stage 3 – Aquatic, and Terrestrial Snapshot

Stage 3 of the Impact Assessment is proposed to involve a broader survey of receiving ecosystem components as follows:

a) Fish, aquatic ecology, aquatic foods – snapshot survey;

b) Vegetation and 'bush tucker' – snapshot survey;

c) Fauna (including turtle tissues) – snapshot survey;

d) Floodplain contamination study. This would involve floodplain cores / test pits to assess the extent of floodplain contamination, to assess risk to the terrestrial ecosystems and the risks that contamination could be released to the aquatic riverine system via processes of erosion, thereby increasing contaminant load.

10 DISCUSSIONS AND CONCLUSIONS

Despite the accumulation of comprehensive environmental datasets and studies of the Mine Site, East Branch and Finniss River (and surrounding watercourses) over recent decades, there is a lack of understanding of impact processes and extent downstream of the mine area.

A monitoring program is recommended to support the proposed EVs and WQOs, and enable the development of locally-derived water quality guidelines. The monitoring program focuses on water quality, aquatic biota, tetrapoda (vertebrates other than fishes), channel processes, and riparian vegetation and aquatic macrophytes. To that end a routine monitoring program is proposed that encompasses both upstream (reference) and downstream sites within each river zone that has previously shown to have had some aquatic and/or riparian ecosystem impacts and to a point downstream where impacts have, historically, not been detected nor would not reasonably be expected to occur into the future as rehabilitation progresses (River Zone 7). The monitoring is focussed on both WQO compliance and assessment of ecosystem status.

The routine monitoring has, as far as possible, been designed to be achievable by the Environmental Monitoring Unit with minimal requirement for external assistance, or at least with decreasing external expert assistance over time. However, in Zones 8 and 9 where routine monitoring is not required, one-off or campaign studies have been recommended in order to characterise specific ecosystem components of relevance, and it is expected that these studies would be undertaken by external service providers.

An important consideration of the routine monitoring program will be data management interpretation and reporting to ensure that the program delivers the necessary information for environmental management needs. We also recommend regular reporting of key outcomes to Traditional Owners and other stakeholder groups, and regular review and revision of the monitoring program itself.

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