3.4 Surface water transport of uranium in the Gulungul Creek catchment

3.4.1 Background

Gulungul Creek lies to the west of Ranger mine and flows north to join Magela Creek, a tributary of the East Alligator River. Part of the mine's infrastructure, notably the tailings dam, lies within the Gulungul Creek catchment (Figure 3.6). Flow in the creek occurs mostly in the wet season, during which time it is made up of the main channel and numerous side channels and tributaries, three of which flow from areas possibly influenced by the Ranger mine.

In January 2004, samples taken for weekly routine monitoring recorded higher concentrations of uranium at Gulungul Creek downstream (GCDS) compared to Gulungul Creek upstream (GCUS). This difference in concentrations was greater than in previous years, and coincided with lower pH values, higher EC values and higher sulfate concentrations at the downstream site.

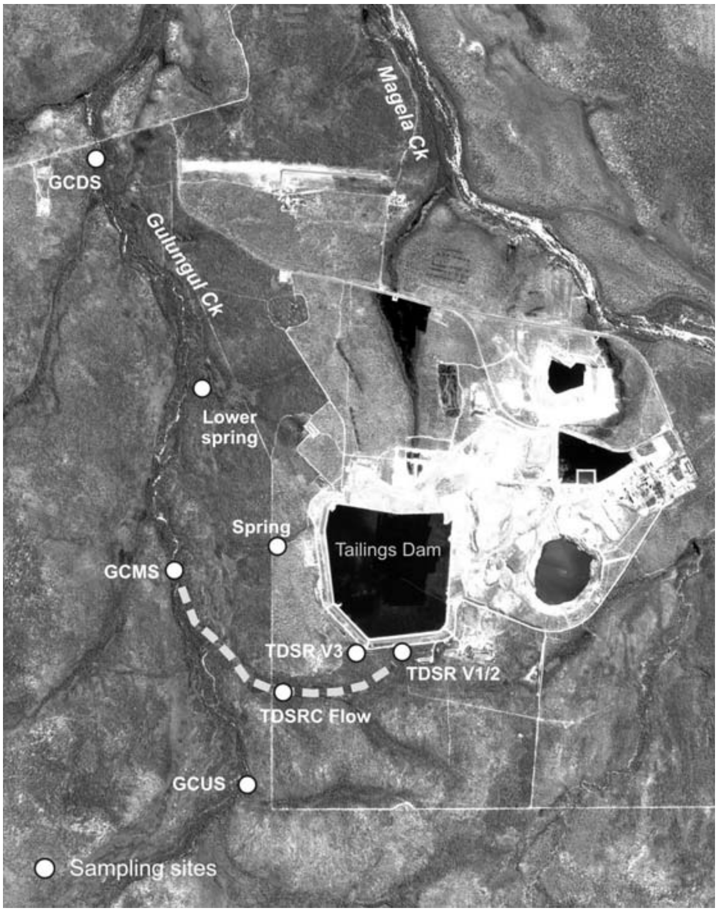

Figure 3.6 The Gulungul catchment and project sampling sites

Whilst the uranium concentrations were more than one order of magnitude less than the limit value of 6 µg/L established for 99% aquatic ecosystem protection, they were comparable to the focus trigger value for G8210009 in Magela Creek. An investigation was therefore initiated in the 2004–05 wet season to identify the source of the increase.

Samples of surface waters were collected during 2005 in (i) February, several days after a four day period of heavy rain that resulted in the flooding of the creek; (ii) in March, towards the middle of the wet season when the creek was reasonably full; and (iii) in May, towards the end of the wet season when water flow was much diminished and sampled tributaries had dried up.

Sites sampled were the upstream (GCUS), downstream (GCDS) and midstream (GCMS) sites and several locations in the vicinity of GCMS – downstream at 'GCMS–10 m', 'GCMS–50 m' and upstream at 'GCMS+50 m' and 'GCMS+150 m'. Additional samples were taken from V-notches (TDSRV 1–3) located upstream of the tailings dam southern road culvert (TDSRC), the overland flow from TDSRC (TDSRC flow), a spring tributary flow (Spring) and from a swampy area produced by another suspected spring (Lower Spring) (Figure 3.6).

Trace concentrations of heavy metals and uranium were measured using the technique of Inductively Coupled Plasma Mass Spectrometry (ICPMS). Activity ratios of uranium isotopes were measured via alpha spectrometry to determine whether there was a difference in upstream and downstream activity ratios that may enable discrete contributing sources to be identified.

3.4.2 Results

Uranium concentrations

Figure 3.7 shows the routine weekly uranium monitoring results for GCUS and GCDS, the difference between downstream and upstream uranium concentrations and the catchment rainfall measured at Jabiru Airport during the 2003–04 and 2004–2005 wet seasons.

Differences between downstream and upstream uranium concentrations in Gulungul Creek during the first part of the 2004–05 wet season were less pronounced than in the previous wet season. Although there is no direct correlation between rainfall and uranium concentration over these wet seasons, it appears that the cumulative effect of heavy rain influences the difference in uranium concentration measured upstream and downstream of the mine. Rainfall was reasonable heavy and constant during December–January (582 mm in 25 days) leading up to the uranium increase at GCDS in the 2003–04 wet season. In the 2004–05 wet season, rainfall was lower and less frequent, apart from two large rain events in early January and February 2005.

Table 3.2 shows the spatial distribution and the percentage increases in uranium concentration along Gulungul Creek measured in 2005. The data indicate that during the peak wet season (February and March), much of the increase in uranium concentration between GCUS and GCDS had already occurred at GCMS. The disparity in uranium input over time indicates that uranium input into the creek may be dependent on specific hydrological conditions. This is supported by the 2005–06 wet season data which exhibit a similar uranium spike as the 2003–04 data and a similar rainfall pattern.

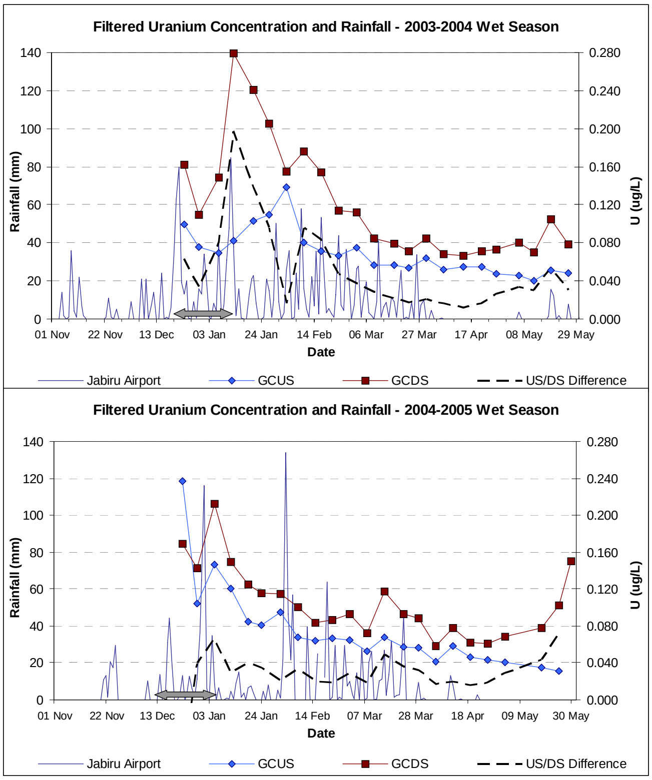

Figure 3.7 Uranium concentration and rainfall time series data in the Gulungul Creek catchment

TABLE 3.2 PERCENT INCREASE IN FILTERED URANIUM CONCENTRATION IN GULUNGUL CREEK IN 2005

Site	Dist (m)	Filtered U (µg/L)			Increase from GCUS to GCDS (%)			Increase above GCUS (%)		
		08/02	18/03	10/05	08/02	18/03	10/05	08/02	18/03	10/05
GCUS	0	0.068	0.060	0.045	0	0	0	0	0	0
GCMS +150 m	1950	ns	ns	0.052	–	–	21	–	–	17
GCMS +50 m	2050	0.087	0.093	0.053	58	74	23	28	56	19
GCMS -10 m	2215	ns	0.105	0.054	–	100	26	–	76	22
GCMS -50 m	2255	ns	ns	0.055	–	–	27	–	–	23
GCDS	6520	0.101	0.105	0.082	100	100	100	48	76	85

ns: not sampled

Uranium isotope activity ratios ($^{234}U/^{238}U$) measured in Gulungul Creek samples from 2004 and 2005 suggest input at GCMS of uranium that has an activity ratio of close to one. This ratio is similar to the ratios measured in the flow from the tailings dam southern road culvert (TDSRC) that enters Gulungul Creek in the vicinity of GCMS and reflects a ratio typical for a mine-related source.

Soil as a possible source

Soil samples were collected in the 2005 dry season along the tributary indicated by the dashed line in Figure 3.6. Uranium concentrations in the soils were found to decrease by almost by three orders of magnitude from the tributary source close to the tailings dam, to where it enters Gulungul Creek, indicating substantial attenuation. Leaching tests show that much of the uranium is able to be readily leached from the dry soils into water.

The previously identified large areas of black soils in the Gulungul catchment thus act as both a sink and a source of contaminants from one season to the next. During the initial phase of the following wet season the metals leached out of the black soils in the vicinity of GCMS are flushed down into Gulungul Creek causing a small spike in concentrations of uranium and a decrease in uranium isotope activity ratios in the vicinity of GCMS. The height of the concentration spike seen at GCMS depends on the ratio of flows in the tributary and Gulungul Creek at the time that this flush occurs.

3.4.3 Future work

A watching brief will be kept on the early wet season concentrations of uranium in Gulungul Creek. The 2006–07 wet season will be of especial interest given the major works currently underway to raise the height of the tailings dam wall. Previous experience has shown that the rock used to armour the walls and to toe load the base of the walls contains leachable uranium.

3.5 Development of a spectral library for minesite rehabilitation assessment

3.5.1 Background

An important component of mine site monitoring and rehabilitation assessment includes an analysis of revegetation success. Traditionally, field-based measurements have been used and data collected that can be used to compare vegetation communities between rehabilitated and reference sites. The disadvantage of these field-based assessments are that they are labour intensive and they sample only a small proportion of the area affected by mining (at field point locations, along transects or within quadrants). The qualitative nature of many methods may also cause problems with consistency when used by different assessors.

Remote sensing techniques are routinely applied for landscape-scale applications. By contrast, minesites are typically characterised by relatively small areal extents, and variability and short range variation in surface cover as a result of the disturbed environment. For these reasons, minesite monitoring and rehabilitation assessment require high spatial and/or spectral and radiometric resolutions.

While very high spatial resolution satellite data have been used contextually to identify temporal changes in minesite vegetation cover, individual species identification has been limited by the resolution of broad multispectral bands. Currently, hyperspectral data with suitable resolving power are limited to airborne platforms. Knowledge of the reflectance characteristics of vegetation species over time is required to develop an understanding of the most appropriate spatial, spectral and temporal scales for revegetation assessment. The Supervising Scientist Division aims to understand the spectral response of vegetation species which are important for mine site rehabilitation assessment, including introduced weeds and natives, in order to make recommendations for monitoring method(s) most appropriate for a given application.

The following pragmatic questions provided the basis for the design of this research project. What are the fortnightly spectral responses of ground cover vegetative species? Can ground-cover vegetative species be distinguished using ground-based reflectance spectra, and if so, what spectral resolution is required? At what vegetative stage is maximum separability detected and is there a phenological time when species are confounding? What are the implications for hyperspectral imaging through-out the year?

To answer these research questions, the research design needed to ensure that the spectral response is not confounded by extraneous factors such as localised changes in atmospheric conditions. With a well designed approach to collecting field spectral measurements and metadata, extraneous factors can be accounted for, accurate processing of spectra can be performed and the first calibrated and validated database of spectra relevant to the mine environment in the Top End can be developed.

3.5.2 Method

Sites with homogenous dense vegetation cover that were unlikely to be regularly disturbed from threats such as fire, development or mowing were located and replicate plots established with support from Commonwealth and Northern Territory Government agencies and private industry. Priority species of plants and weeds were identified with stakeholders.

Dense and homogenous stands of plants selected include pasture species such as Para grass (*Urochloa mutica*), Guinea grass (*Urochloa maxima*), Jarrah grass (*Digitaria milanjiana*), Tully grass (*Urochloa humidicola*), Joint Vetch (*Aeschynomene americana)* and Stylo species (*Stylosanthes* spp*.).* Introduced weeds include Snakeweeds (*Stachytarpheta* spp.), Hyptis (*Hyptis sauveolens*), Mission grasses (*Pennisetum* spp.), wild passionfruit (*Passiflora foetida*), Calopo (*Calopogonium mucunoide*), Gamba grass (*Andropogon gayanus*), Couch grass (*Cynodon dactylon*), Rhodes grass (*Chloris sp.)*, Gambia Pea (*Crotalaria goreensis*), Sicklepod (*Senna obtusfolia*), and native grasses (*Heteropogan* spp. *Sorghum stipodeum, Panicum mindanese* and *Schizachyrium fragile*). Reflectance characteristics of weed and native ground covers over the visible to shortwave infrared (350–2500 nm) are being measured fortnightly from permanent plots around the greater Darwin region using a FieldSpec-FR Analytical Spectrometer.

3.5.3 Results

Standards for the collection, documentation and storage of spectral data and metadata have been developed and implemented. These standards enable a consistent and repeatable method that minimises the influence of extraneous factors in spectral measurement. Figure 3.8 shows the metadata recorded with each spectral measurement. In addition to obtaining meaningful spectra at the time of data collection, concurrently documenting the optical, local environmental, scalar and physical variables will aid in quantifying changes through time at each site.

The temporal measurements of ground-based spectra will provide information on separability likeliness, and plant mixtures and vegetation-soil mixtures will be able to be modelled. This information is useful not only to the local mine environment, but also for weed management in the broader Kakadu National Park, assessing introduced 'weedy' pastures in nearby Arnhem Land, and any remote sensing feasibility study involving weed and native covers.

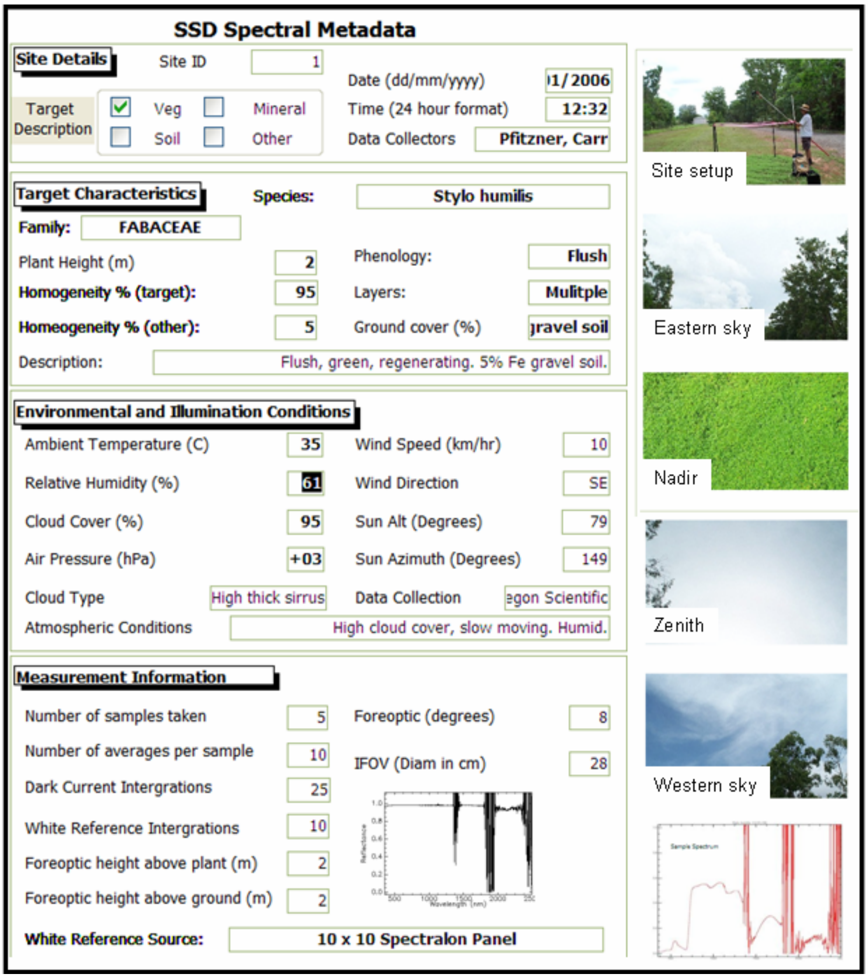

Figure 3.8 SSD's Spectral Database concept – spectral data and metadata records

The acquisition of this high resolution spectral library is proceeding concurrently with the new generation of hyperspectral sensors being implemented on satellite platforms, such as the Compact High Resolution Imaging Spectrometer (CHRIS) flown on the European Space Agency's Project for On-Board Autonomy (Proba) satellite and the German Space Agency's proposed Environmental Mapping and Analysis Programme (EnMAP). The library will provide a strong quantitative basis for translating the remotely sensed data from these platforms to practically useful information for assessing vegetation distribution both on minesites and at a broader regional scale in the northern tropics.

3.6 Monitoring fine suspended sediment movement within the Gulungul Creek catchment

As part of the data set required to assess the success of rehabilitation of the Ranger mine, the baseline loads of suspended sediment in the catchment of Magela Creek need to be quantified. The first stage of this work involves the measurement of suspended sediment loads in Gulungul Creek, a small left bank tributary of Magela Creek (Figure 3.6). Given the location of Gulungul Creek and the potential for erosion and transport of sediment into Magela Creek, the suspended sediment transport characteristics in Gulungul Creek are being investigated before the start of rehabilitation works at the mine site. Of particular importance is the silt/clay fraction (mud) component of suspended sediment, as nutrients and contaminants, including heavy metals and radionuclides, are primarily transported in association with fine suspended particulate matter.

Streamflow and mud concentration data are currently monitored at two gauging stations within the Gulungul Creek catchment – one upstream and one downstream of the Ranger mine (Figure 3.6). Mud transport is monitored at the stations using field-calibrated turbidimeters. Mud loads were determined for eleven runoff events at the stations upstream and downstream of Ranger during the 2005–06 wet season. These upstream and downstream event load data were compared using an event-based Before-After-Control-Impact, paired difference design (BACIP). This comparison of event mud loads observed upstream and downstream of the mine under non-mine impacted conditions will be used to provide the basis for future impact assessment during operations and following closure.

The mean ratio of event mud load measured downstream to event mud load measured upstream along Gulungul Creek for the one-year monitoring period is approximately 1.8 (Figure 3.9). Events that lie greater than two standard deviations above the mean ratio (ie, > +2 SD) indicate that the event mud load observed downstream of the mine is significantly elevated above that observed upstream (compared to other events), which may indicate a possible mine-related impact. During 2005–06 no events were considered to be 'outliers', although there were three successive events above the +1 SD line (Figure 3.9) that occurred during a ten-day period in February 2006. This behaviour indicated that event mud load measured downstream was relatively high compared to the event load measured upstream during this period. It is recommended that event load data are collected for at least two more years within the Gulungul Creek catchment to provide a larger database from which to establish the pre-closure baseline using BACIP analysis before rehabilitation commences at Ranger.

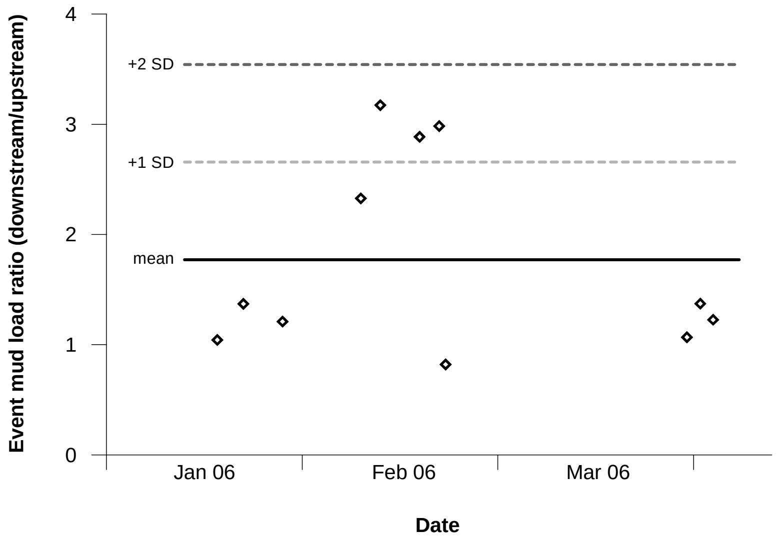

Figure 3.9 Control chart showing temporal variation of the ratio of event mud loads measured downstream to that upstream along Gulungul Creek during 2005–06 (indicated as ◇). The mean ratio and associated standard deviations are also shown.

3.7 Developing water quality closure criteria for Ranger billabongs using macroinvertebrate community data

The approach to deriving water quality criteria from local biological response data outlined in the Australian and New Zealand Water Quality Guidelines (2000) is being applied to the derivation of water quality closure criteria for waterbodies such as Georgetown Billabong, located immediately adjacent to the mine site (Maps 2 & 3). Specifically, if the post-closure condition in Georgetown Billabong is to be consistent with similar undisturbed (reference) billabong environments of Kakadu, then the range of water quality data from the billabong over time that supports such an ecological condition in Georgetown Billabong (as measured by suitable surrogate, biological indicators) may be used for this purpose.

For shallow lowland billabongs such as Georgetown Billabong, distinctive wet season and dry season water quality regimes can be recognised. This is a consequence of flushing of the billabongs during the wet season, followed by contraction in surface area and substantial evaporative concentration of solutes during the six months of the subsequent dry season. If water quality closure criteria were derived from the annual-average water quality record, then the resultant values would be too conservative for the dry season and too lenient for the wet season. For this reason, two sets of water quality criteria are required – one for the wet season and one for the dry season.

Data derived from macroinvertebrates are regarded as most useful for setting water quality criteria because of the enhanced sensitivity of this group of organisms to water quality generally. Hence monitoring of macroinvertebrate communities is being used to develop closure criteria for relevant water quality indicators in the local Ranger billabongs.

Sampling for macroinvertebrates in most of the Ranger and relevant reference water bodies has been conducted previously in 1995 and 1996 and provides a basis for time series comparison. For the 1995 and 1996 surveys, the macroinvertebrate communities of Georgetown Billabong resembled those of reference waterbodies in the Alligator Rivers Region.

Given the changes that have occurred on the mine site since 1996 – in particular the increased wet season loads of solutes entering Georgetown Billabong – a contemporary survey was needed to determine if the macroinvertebrate communities in the billabong were still comparable to reference waterbodies in the region. Accordingly, macroinvertebrates were sampled in May 2006 from Coonjimba, Georgetown and Gulungul Billabongs and Ranger Retention Pond 1 and Retention Pond 2 (mine-water exposed sites) and Baralil, Corndorl, Wirnmuyurr, Malabanjbanjdju, Anbangbang, Buba and Sandy Billabongs and Jabiru Lake (reference sites, not exposed to Ranger mine waters). See Maps 2 and 3 for locations of these waterbodies.

At the time of writing this report, the samples collected in May 2006 were being sorted and the organisms identified and counted. Interim water quality criteria will be derived in December 2006 based on the findings from the three sets of macroinvertebrate and associated water quality monitoring data from Georgetown Billabong in 1995, 1996 and 2006.

Post-closure water quality criteria for Georgetown Billabong – consistent with maintaining the billabong in a condition similar to undisturbed reference waterbodies in Kakadu – will be based on the range of water quality data measured in the billabong over the preceding wet (‘wet season criteria’) and dry (‘dry season criteria’) seasons for each of the three years of macroinvertebrate data. Wet season criteria will be produced from summary statistics of the water quality measured over the period January to May and dry season criteria produced from the worst water quality observed in the preceding dry season, typically for the months September to December.

Macroinvertebrate and associated water quality data gathered from sampling in future years will be used to further revise the criteria current at the time of the new sampling. This adaptive approach to revising criteria to accommodate new findings is consistent with the Australian Water Quality Guidelines (2000) and the stakeholder agreed strategy to periodically update water quality compliance trigger values at G8210009 in Magela Creek.

3.8 Continuous monitoring of water quality

For environmental protection and improved wastewater management associated with the Ranger mine site, there is a recognised requirement to track and quantify the movement of solutes originating from point and diffuse sources through the receiving Magela and Gulungul Creek systems. Continuous in situ measurement of key water quality variables using dataloggers placed at strategic locations on and off-site can meet these needs, particularly when linked to localised and catchment-wide rainfall and stream discharge data. Continuous monitoring can also complement the Supervising Scientist’s routine water chemistry programme, based on weekly grab samples, by capturing possible ‘events’ and exceedances undetected in the routine sampling programme (an advantage also shared by biological monitoring).

To this end and to meet these needs, as part of the 2005–06 wet season water chemistry monitoring programme in situ water quality data (including electrical conductivity [EC], pH and turbidity) were collected at 15–20 minutes intervals using a network of ***eriss*** and ERA dataloggers deployed at key sites in Magela Creek and Ranger mine site tributaries (RP1 and Corridor Creek). Three loggers were deployed in Magela Creek – one located approximately 0.5 km downstream of the Magela upstream control site (but still upstream of mine surface-water influence) and another two located approximately 0.5 km downstream of the Magela downstream compliance point (G8210009), on either side of the western-most channel (see Map 2). Corresponding stream flow data were collected from upstream and downstream gauging stations on Magela Creek (by ERA and NRETA respectively) and from RP1 and Corridor Creek on the mine site (by ERA), enabling integration of both on-site and off-site flow and water quality data. See Map 2 for locations of the upstream and downstream SSD monitoring locations in Magela Creek and the locations of RP1 and Corridor Creek.

The quality-control, spot check measurements made at the Magela Creek sites were very similar to the continuous measured values on both sampling occasions, at approximately 10 µS/cm for the upstream site and 15 µS/cm for the downstream site (Figure 3.10).

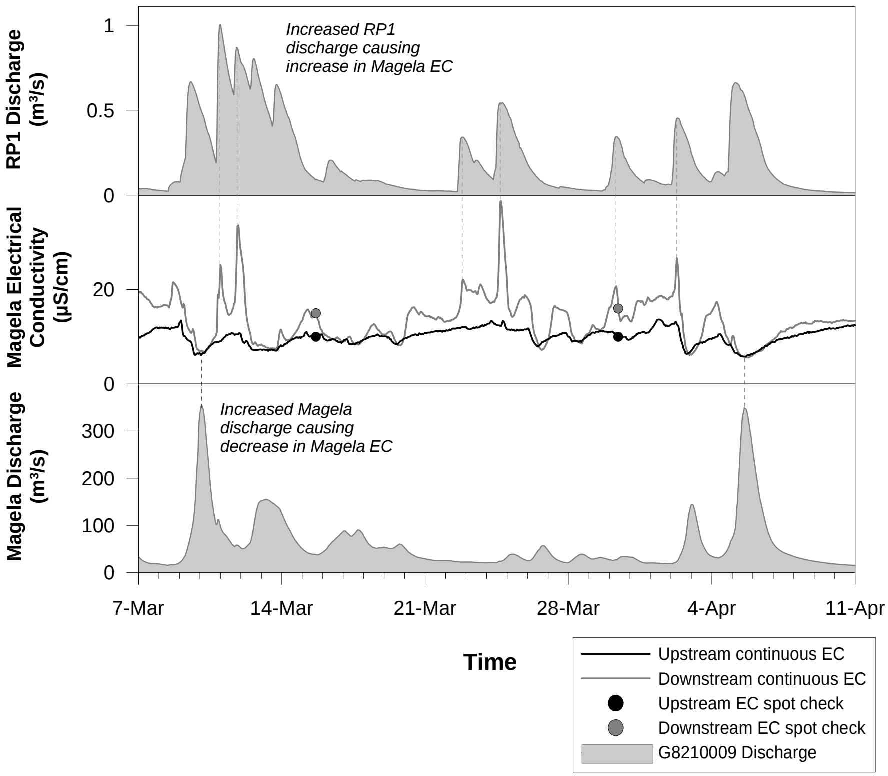

Figure 3.10 Continuous electrical conductivity (EC) at both the upstream and downstream sites on Magela Creek and quality-control spot checks measured using a calibrated portable field meter over mid-wet season months in 2006. The stream discharge measured at G8210009 and RP1 spillway is also shown.

However, the continuous data traces show that the difference between upstream and downstream EC values can be much larger than indicated by spot check data. This demonstrates how lower-frequency, grab sampling methods, as used for the current routine water quality monitoring programme, do not capture the full dynamic range of water quality behaviour.

Continuous, time-series water quality data offer a more complete description of the overall quality characteristics of a waterbody by capturing natural fluctuations in quality that are missed by weekly grab sampling, such as effects caused by variation in flow. Further, assurance and evidence that such short-term variations are having no detrimental effects are obtained from the results of the creekside monitoring programme (each test integrates exposure over a time period of one week).

Although the continuous monitoring data collected during 2005–06 have only undergone preliminary analysis thus far, the interaction between inputs of RP1 water and variable dilution by flow in Magela Creek can be clearly seen (Figure 3.10).

Figure 3.10 shows that EC downstream of the mine is generally higher and much more variable compared with upstream values. Figure 3.10 shows that a number of peaks in downstream EC correspond to increased discharge from RP1, likely due to localised rainfall over the mine site. Water quality measured during some of these events provides evidence that elevated EC observed at the downstream site is attributed to elevated magnesium and sulfate concentrations (and to a lesser extent calcium concentrations) present in discharged mine wastewaters, particularly from RP1. Overall, however, the EC measured at the downstream site remains relatively low and the results of biological (creekside) monitoring and magnesium and sulfate toxicity tests indicate no adverse ecological effects arising from these transiently elevated solute concentrations.

The continuous monitoring data collected during the first year of deployment (2005–06) will be rigorously evaluated during 2006–07 in a whole-of-mine catchment context. Data analysis will include:

- calculation of solute loads to quantify and compare differences upstream and downstream of the mine and to investigate relative contributions from point (RP1 and GC2) and diffuse (Magela Land Application Area) sources;
- interpretation of observed spatial and temporal variation; and
- identification of short-term trends.

The data collected by the continuous loggers will also aid interpretation of results from SSD's biological monitoring programs. Following analysis and interpretation, the continuous monitoring programme will be reviewed and refined, as required, for the second year of deployment.