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Water quality in Magela Creek upstream and downstream of Ranger

A summary of performance for 2000-2001 and derived triggers and limits for 2001-2002

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supervising scientist

Water quality in Magela Creek upstream and downstream of Ranger: A summary of performance for 2000–2001 and derived triggers and limits for 2001–2002

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1 Introduction

In June 2001, the Ranger Minesite Technical Committee approved the interpretative provisions and compliance framework for water quality triggers in Magela Creek downstream of Ranger Uranium Mine (see Appendix) as they relate to Section 3.3 of the Environmental Requirements (ERs) of the Commonwealth of Australia. The associated documentation was then presented to the Alligator Rivers Region Advisory Committee in August 2001. Consequently, these same processes and procedures contained in the ERs which determine the level of compliance with water quality objectives will now be applied for the first time during the 2001–02 wet season at Ranger. The opportunity has been taken, however, as a 'dry run' to assess performance during 2000–2001 using the triggers and limits which were approved by the MTC in November 2000 following submission of a draft document (later published as Klessa 2001) but not to determine compliance in any official capacity.

The Supervising Scientist reviews, and currently updates, the triggers and limits annually. This report provides this review, building upon previous studies (Klessa 2000, 2001). Significantly, the review incorporates for the first time chemistry monitoring data collected upstream and downstream of Ranger by the Supervising Scientist as a preliminary program in response to Recommendation 14 of the 'Leak Report' (Supervising Scientist 2000).

2 Methods

2.1.1 Data sources

Existing data (Klessa 2000, 2001) were supplemented by monitoring data from the Ranger water quality database, the NT DME and ***eriss*** (Table 2.1).

Table 2.1 Details of new data

Data sources	Sites	Time span and frequency	Analytes
ERA	GS 821028 and GS 821009	29/11/00–23/6/01; weekly	pH, EC, turbidity, Ca, Cl, Cu, K, Mg, Mn, Na, NH_4, NO_3, Pb, ^{226}Ra, SO_4, U and Zn
NT DME	GS 821009	2/12/00–9/5/01; monthly	pH, EC, Al, Ca, Cl, K, Mg, Mn, NO_3, SO_4, and U
eriss	GS 821028 and GS 821009	27/11/00–25/6/01; weekly	Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, SO_4, U and Zn

2.2 Data analysis

Unfiltered numeric data were used throughout as the starting point to reanalyzing frequency distributions for upstream data. Also, the same assumptions and procedures covering data handling and filtering as detailed in Klessa (2000) were followed when establishing the distributional characteristics of baseline data for the period 1979–2001 and checking whether the data conformed with normality. With the exception of ^{226}Ra, only the data for the dissolved concentrations of species were statistically analysed. pH and EC data measured *in situ* were excluded because of the possibility of analytical differences with equivalent laboratory samples which have been used to form the database.

Given the inclusion of data from ***eriss*** which span a similar period and are derived from a similar frequency of sampling to ERA (Table 2.1), one-way analysis of variance (ANOVA) was conducted on unfiltered data using paired upstream and downstream comparisons. Whilst the basic assumptions of ANOVA are that treatment and environmental effects are additive and that experimental errors are random, independent and are normally distributed (about zero mean with common variance) (Steel & Torrie 1980), no attempt was made to check the normality of the data used in the exercise. However, this does not necessarily negate the conclusions which might be drawn from ANOVA testing. ANOVA is relatively insensitive to non-normally distributed data but in applying it here, the conclusions which have been reached are approximate rather than exact.

3 Results and Discussion

3.1 General

Data for 2000–01 are summarised in Tables 3.1 and 3.2 for upstream and downstream of the mine respectively. In general, the inclusion of these data led to a lowering of medians and means in the baseline for 1979–2001 (Table 3.1) and was most apparent for turbidity, copper, magnesium, manganese, radium-226, sodium, zinc, and especially uranium. This was due principally to two factors. Firstly, as a consequence of ERA outsourcing samples for analyses, there were immediate improvements in metal detection limits by ICPMS compared to former in-house methods. In the case of uranium this has resulted in almost a two order of magnitude decrease in the detection limit (from 0.1 µg/L). Secondly, the baseline data was bolstered by the addition of ***eriss*** data for the first time which provides relatively low detection limits[1] from ion chromatography and ICPMS. A third reason, that of a higher than average rainfall, may also have made it more likely that compared to the average more high flow conditions were encountered during sampling.

Downstream of Ranger (Table 3.2), similar trends to those described for upstream were seen which undoubtedly stemmed from the same quality control issues described above. Interestingly, an historic high sulphate concentration of 46.9 mg/L was monitored on 29 November 2000 by ***eriss*** at the start of the wet season as first flush.

3.2 Upstream-downstream and mining company-*eriss* data comparisons

Results from one-way ANOVA are given in Tables 3.3–3.5. These are summarised as follows:

- separate comparisons of ***eriss*** (Table 3.3) and mining company (Table 3.5) upstream and downstream data showed higher mean Mg^{2+} and SO_4^{2-}concentrations downstream of Ranger.
- ***eriss*** data showed a lower average Al but higher U and Mn concentrations downstream compared to upstream of the mine (Table 3.3).
- a comparison of ***eriss*** and mining company data indicated that whilst a lower U mean was measured upstream by the former, the opposite was the case downstream (Table 3.4).

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[1] Detection limits are as follows(bracketed): Ca, Mg, K, SO_4 (0.1 mg/L); Fe (20 µg/L); Zn (0.5 µg/L); Al, Cr (0.1 µg/L); Cu, Mn, Ni, Pb (0.05 µg/L); Cd (0.02 µg/L); U (0.005 µg/L)

Table 3.1 Summary of median, range and mean values at GS 821028 (unfiltered). Shaded rows show key variables

	n			Median			Minimum			Maximum			Mean		
Analyte	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01
pH	410	439	29	6.20	6.20	6.08	4.20	4.20	5.32	7.00	7.00	6.44	6.16	6.15	6.03
EC	538	566	28	16	15	12	5	5	7	75	75	19	17	17	11
Turbidity	396	425	29	4.9	4.5	3.0	0.5	0.5	0.5	82.0	82.0	13.4	7.0	6.7	3.7
Ca	237	276	39	0.51	0.49	0.40	0.05	0.05	0.20	6.00	6.00	1.10	0.62	0.59	0.41
Cl	138	145	7	2.0	2.0	1.8	0.8	0.8	1.1	24.0	24.0	2.0	2.7	2.7	1.6
Cu	117	155	38	0.80	0.50	0.29	0.10	0.10	0.11	3.49	3.49	3.24	0.84	0.74	0.45
K	169	207	38	0.22	0.20	0.10	0.05	0.05	0.05	1.80	1.80	1.00	0.29	0.27	0.16
Mg	312	372	60	0.62	0.60	0.50	0.05	0.05	0.20	8.10	8.10	1.30	0.70	0.68	0.56
Mn	263	322	59	5.3	5.0	4.4	0.50	0.50	1.44	180.0	180.0	26.3	9.6	8.8	4.4
Na	171	209	38	1.30	1.22	1.00	0.05	0.05	0.50	5.50	5.50	3.40	1.37	1.32	1.10
NH_4	89	97	8	0.01	0.01	0.006	0.01	0.002	0.002	0.18	0.18	0.008	0.023	0.021	0.005
NO_3	135	143	8	0.025	0.025	0.012	0.002	0.002	0.012	0.84	0.84	0.35	0.054	0.054	0.054
Pb	132	171	39	0.50	0.50	0.03	0.01	0.01	0.01	22.0	22.0	0.53	0.92	0.72	0.06
^{226}Ra	105	112	7	6.4	3.0	1.0	0.6	0.6	1.0	43.2	43.2	7.0	10.1	9.6	2.4
SO_4	271	331	60	0.27	0.26	0.20	0.03	0.03	0.05	9.30	9.30	2.90	0.59	0.56	0.40
U	316	375	60	0.10	0.05	0.030	0.013	0.002	0.002	24.95	24.95	0.765	0.52	0.45	0.044
Zn	112	150	38	2.0	1.9	1.2	0.5	0.3	0.3	140.7	140.7	20.9	9.7	7.9	2.5

Units for conductivity (EC) are µS/cm; for turbidity are NTU; for ca, Cl, Na, NH_4, NO_3 and SO_4 are mg/L; for Cu, Mn, Pb and U are µg/L; and for ^{226}Ra are mBq/L

Table 3.2 Summary of median, range and mean values at GS 821009 (unfiltered). Shaded rows show key variables

	n			Median			Minimum			Maximum			Mean		
Analyte	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01	1979–00	1979–01	2000–01
pH	653	689	36	6.10	6.10	6.10	4.50	4.50	5.19	7.70	7.70	7.25	6.12	6.13	6.12
EC	749	785	36	18	17	14	4	4	6	231	231	33	20	19	15
Turbidity	654	683	29	4.0	4.0	3.0	0.5	0.5	0.5	89.0	89.0	17.4	5.8	5.7	3.6
Ca	450	498	48	0.45	0.45	0.50	0.05	0.05	0.20	2.40	2.4	1.5	0.48	0.48	0.49
Cl	295	308	13	2.4	2.3	1.5	0.9	0.5	0.5	31.0	31.0	3.3	3.0	2.9	1.6
Cu	224	266	42	0.73	0.60	0.27	0.10	0.10	0.11	12.00	12.00	1.18	0.88	0.80	0.37
K	340	388	48	0.25	0.23	0.20	0.05	0.05	0.10	1.70	1.70	0.80	0.30	0.29	0.21
Mg	595	664	69	0.80	0.81	0.91	0.05	0.05	0.29	5.30	11.40	11.40	0.97	1.00	1.22
Mn	539	608	69	6.6	6.5	5.8	0.4	0.4	2.5	98.0	98.0	52.1	8.9	8.9	8.5
Na	331	378	47	1.40	1.34	1.20	0.05	0.05	0.70	6.9	6.9	2.6	1.4	1.4	1.2
NH_4	156	305	8	0.025	0.025	0.004	0.010	0.002	0.002	0.61	0.61	0.007	0.027	0.027	0.004
NO_3	291	164	14	0.010	0.010	0.011	0.001	0.001	0.002	1.36	1.36	0.057	0.052	0.052	0.012
Pb	191	232	41	0.21	0.20	0.03	0.005	0.005	0.005	6.90	6.90	0.25	0.46	0.39	0.05
^{226}Ra	243	250	7	2.8	2.7	2.0	0.8	0.8	1.0	63.0	63.0	8.0	7.4	7.2	3.4
SO_4	557	626	69	0.74	0.80	1.40	0.05	0.05	0.05	18.58	46.9	46.9	1.62	1.74	2.78
U	631	700	69	0.10	0.10	0.10	0.002	0.002	0.006	15.01	15.01	0.97	0.24	0.23	0.15
Zn	230	271	41	2.4	2.3	1.50	0.2	0.2	0.3	410.0	410.0	7.2	7.8	8.7	2.4

Units for conductivity (EC) are µS/cm; for turbidity are NTU; for ca, Cl, Na, NH_4, NO_3 and SO_4 are mg/L; for Cu, Mn, Pb and U are µg/L; and for ^{226}Ra are mBq/L

Table 3.3 Mean concentrations upstream and downstream of Ranger based on eriss data (8 December 2000–25 June 2001) showing level of significance using one-way ANOVA

Parameter	Upstream	Downstream	Significance
Al (µg/L)	32.0	22.8	$p<0.05$
Ca (mg/L)	0.39	0.45	NS
Cd (µg/L)	0.011	0.014	NS
Cr (µg/L)	0.53	0.48	NS
Cu (µg/L)	0.29	0.30	NS
Fe (µg/L)	64.8	68.2	NS
K (mg/L)	0.15	0.18	NS
Mg (mg/L)	0.53	1.17	$p<0.001$
Mn (µg/L)	4.83	9.13	$p<0.01$
Na (mg/L)	1.10	1.23	NS
Ni (µg/L)	0.48	0.43	NS
Pb (µg/L)	0.06	0.06	NS
SO_4 (mg/L)	0.48	2.40	$p = 0.001$
U (µg/L)	0.019	0.177	$p<0.001$
Zn (µg/L)	1.99	2.34	NS

Table 3.4 Mean concentrations upstream and downstream of Ranger based on a comparison of eriss and ERA data showing level of significance using one-way ANOVA

Parameter	Location	ERA	eriss	Significance
Mg (mg/L)	downstream	0.84	1.17	$p<0.05$
	upstream	0.58	0.53	NS
Mn (µg/L)	downstream	6.59	9.13	NS
	upstream	6.06	4.83	NS
SO_4 (mg/L)	downstream	1.16	2.40	$p<0.05$
	upstream	0.30	0.48	NS
U (µg/L)	downstream	0.094	0.177	$p<0.05$
	upstream	0.072	0.019	$p<0.05$

Table 3.5 Mean concentrations upstream and downstream of Ranger based on ERA data (29 November 2000–13 June 2001) showing level of significance using one-way ANOVA

Parameter	Upstream	Downstream	Significance
pH	6.03	6.03	NS
EC (µS/cm)	11	13	NS
Turbidity (NTU)	3.7	3.6	NS
Mg (mg/L)	0.58	0.84	$p<0.01$
Mn (µg/L)	6.06	6.59	NS
SO_4 (mg/L)	0.30	1.16	$p = 0.001$
U (µg/L)	0.072	0.094	NS

- higher mean concentrations of Mg^{2+} and SO_4^{2-} were monitored by ***eriss*** downstream compared to the mining company (Table 3.4).

3.3 Triggers and trends

Changes in the values of key variables over the 2000–01 wet season upstream and downstream of Ranger are summarised in Figs 3.1–3.6 in which the solid (downstream) and dotted (upstream) lines represent mining company data. These have been superimposed with ***eriss*** and NTDME data which are shown as scatterplots. The triggers and limits are also shown based upon advice provided to the Ranger MTC by the Supervising Scientist in November 2000-and contained in Klessa (2001). Since providing this advice, the uranium limit has been modified to take account of the results of further toxicity tests using *Chlorella* sp and is now 5.8 µg/L (Appendix)

3.3.1 pH

The majority of downstream samples (72%) were within the range $5.84<pH<6.50$ which are the $\pm\sigma$ boundaries of the mean. Overall, the data was biased towards relatively low pH values. Six samples were above the *focus* but below the *action* level (ie $5.51<pH\leq5.84$ and $6.50\leq pH<6.83$ as 4 and 2 samples respectively) and 3 samples above the *action* level but below the *limit* (ie $5.18<pH\leq5.51$ and $6.83\leq pH<7.16$ as 2 and 1 samples respectively). One sample taken by NTDME on 18 March 2001 was above the upper *limit* of pH 7.16.

Three pH monitoring results from the NTDME (9 January 2001, 18 March 2001 and 3 April 2001) appear unusually high (Fig 3.1). Discordantly high pH values monitored during the 1999–2000 wet season by NTDME have been commented upon previously (Klessa 2001).

Overall, there was excellent agreement between upstream and downstream pH trends for mining company data and excursions of downstream water quality showing unusually low values below the lower *focus* level were matched upstream (Fig 3.1). Hence there is no evidence to suggest a mine effect and downstream pH values were found to comply with pH guidelines contained in the Commonwealth ERs (Appendix).

3.3.2 EC

The large majority (86%) of downstream samples were below the *focus* level of 22 µS/cm. Four samples were above the *focus* level but below the *action* level and one sample was above the *action* level but below the limit (Fig 3.2). Interestingly, of these five samples four were taken by NTDME.

Mining company samples taken upstream and downstream of the mine showed similar trends with means and median values suggesting a small but insignificant mine effect on EC. However, the departure of NTDME data from company data, whilst not of environmental concern in terms of the actual EC values that were monitored, strongly warrants follow up to determine the reasons for the discrepancy.

In conclusion, there was no evidence of EC values breaching the Commonwealth ERs.

3.3.3 Turbidity

Turbidity data was derived solely from mining company records. All downstream samples, with the exception of two successive samples (10 & 17 January 2001) signaling the first

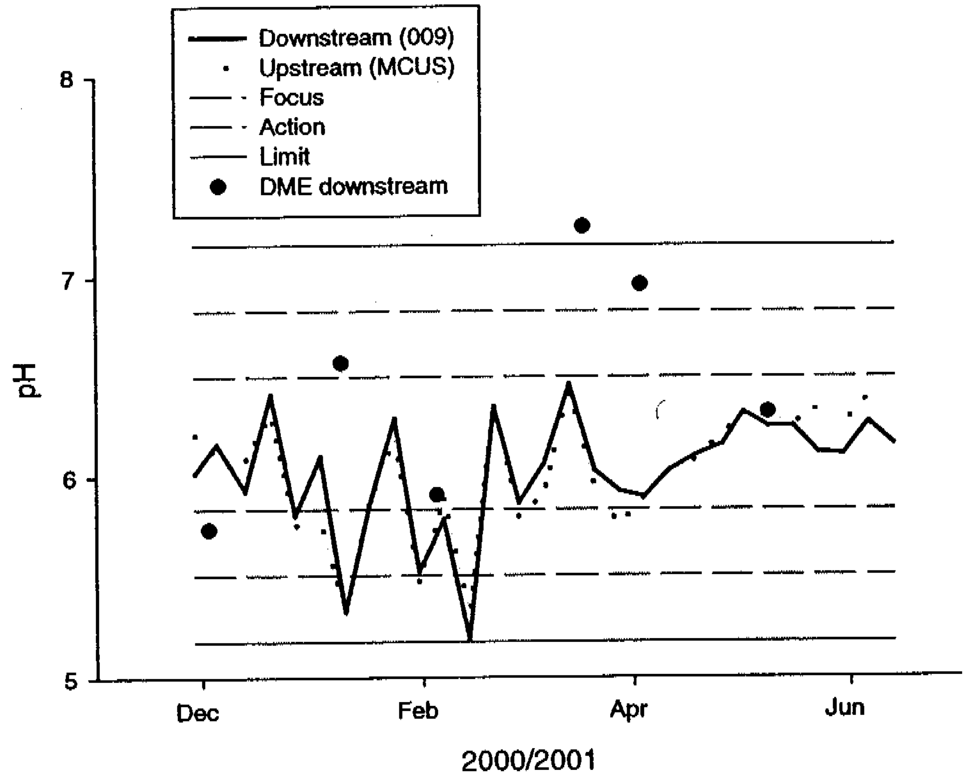


Fig 3.1 pH upstream and downstream of Ranger during 2000–01

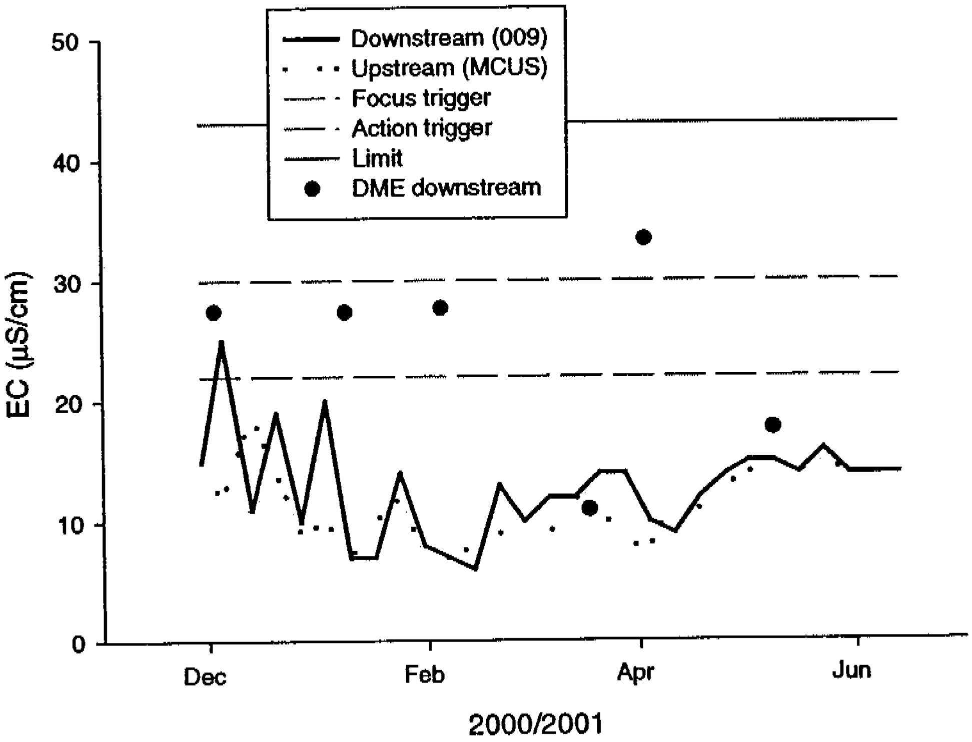


Fig 3.2 EC upstream and downstream of Ranger during 2000–01

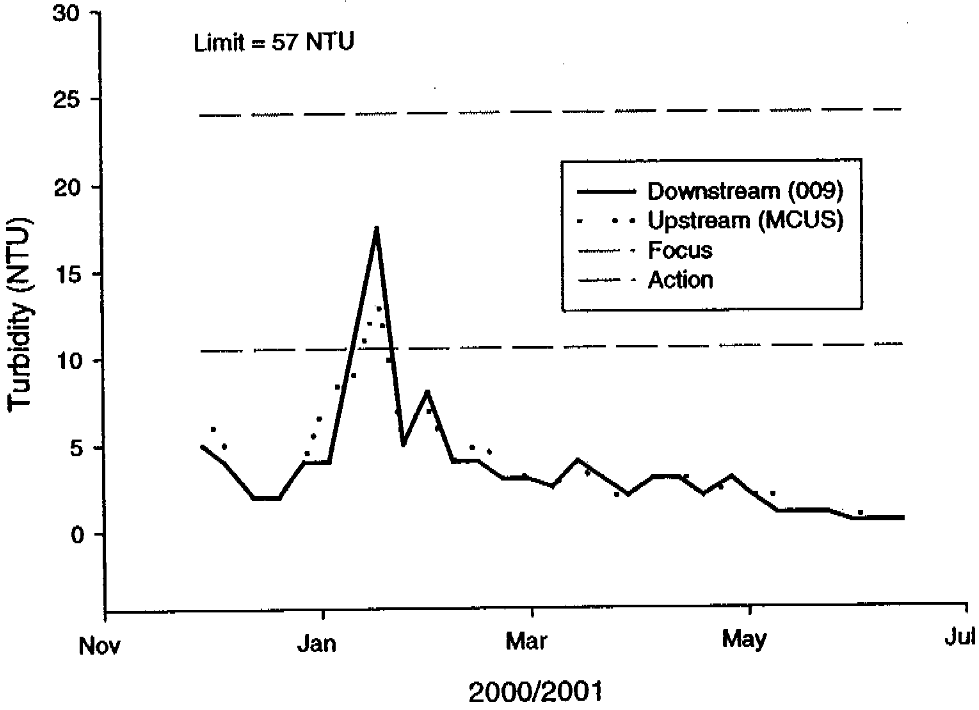


Fig 3.3 Turbidity upstream and downstream of Ranger during 2000-01

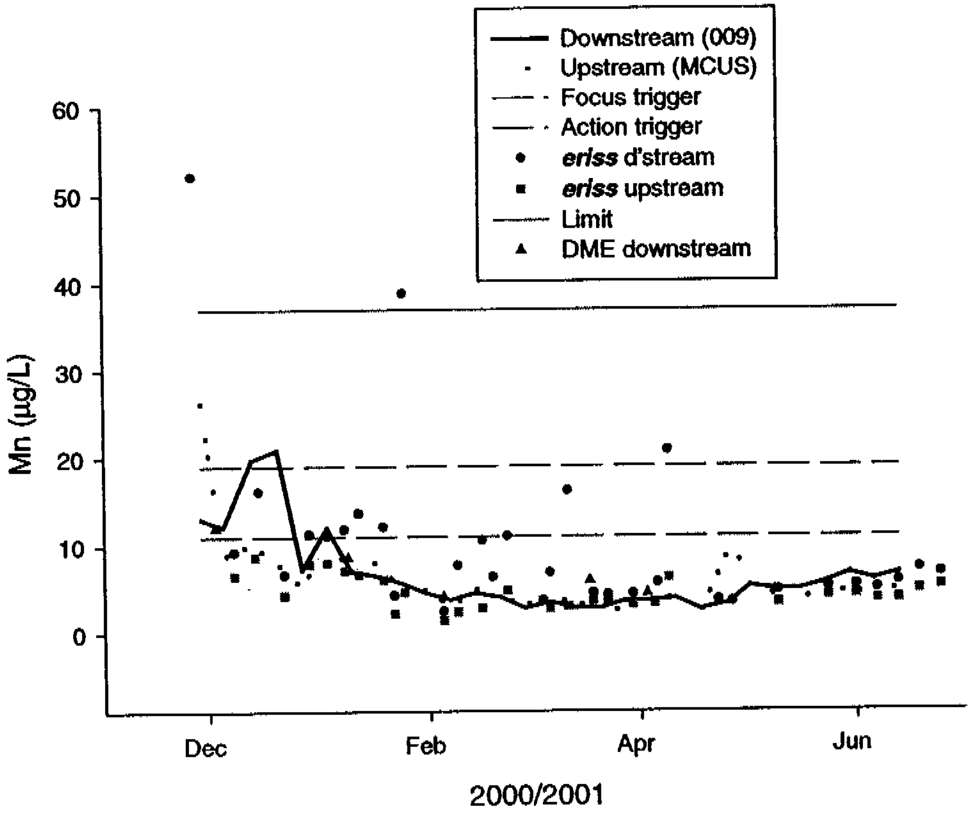


Fig 3.4 Soluble Mn upstream and downstream of Ranger during 2000-01

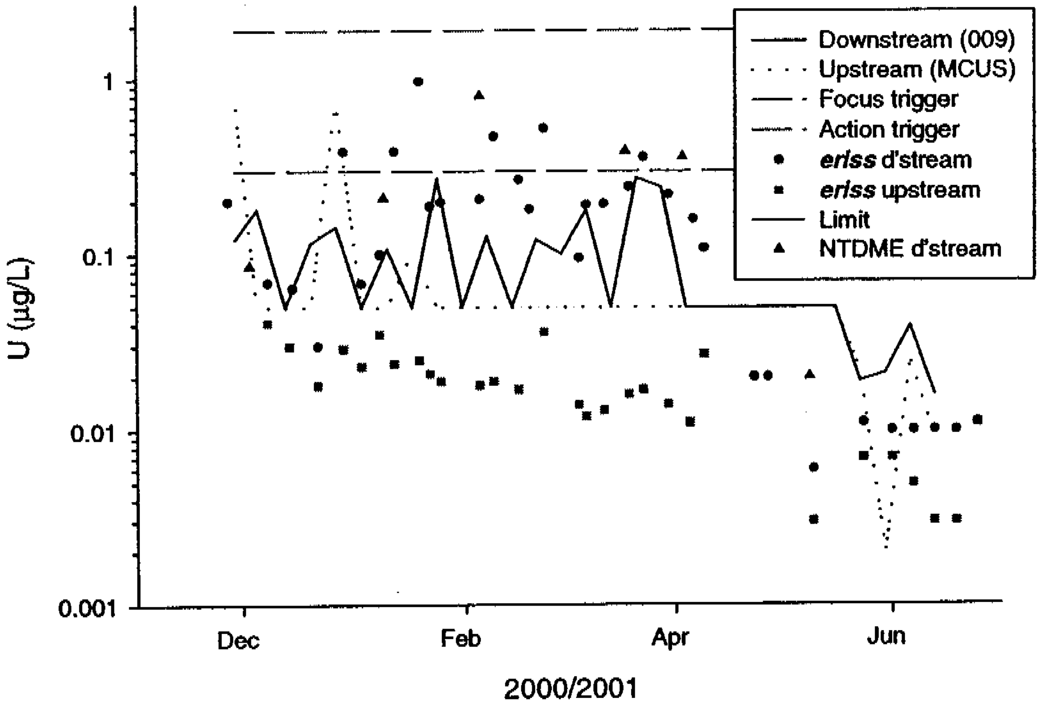


Fig 3.5 Soluble U upstream and downstream of Ranger during 2000-01

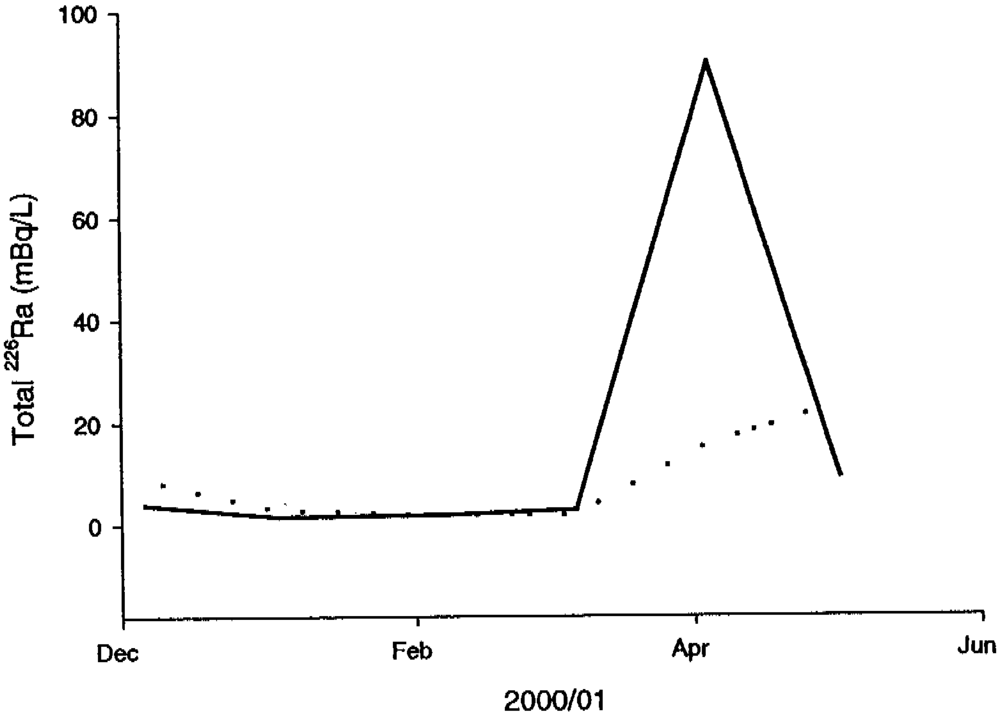


Fig 3.6 Total Ra-226 upstream (dot) and downstream of Ranger during 2000–01

major flow in Magela Creek, were below the *focus* level. The *action* level and *limit* were not breached and trends downstream mimicked those upstream throughout the wet season.

In conclusion, there was no evidence of turbidity values breaching the Commonwealth ERs.

3.3.4 Manganese

Most (74%) downstream samples (Fig 3.4) contained a dissolved Mn concentration of less than 11 µg/L (ie the *focus* level). Of the remainder, 19% were below the *action* level but above the *focus* level. In one period, made up by 3 successive samples (3, 8 and 12 January 2001), a rising trend was established above the *focus* level in samples taken by ***eriss***. Two ***eriss*** samples were above the *limit* of 37 µg/L which occurred at the start of the wet as first flush on 27 November 2000 (52.1 µg/L) and on 25 January 2001 (38.8 µg/L). Of the two 'events' only the latter is regarded as important in terms of considering compliance with the Commonwealth ERs. With regard to 25 January 2001, the nearest sampling dates of the mining company (ie 24 January and 30 January 2001) provided Mn concentrations of approximately 5 µg/L. Discharges from RP1 and Djalkmara Billabong at the time are highly unlikely to have been the cause because Mn concentrations were approximately 12 and 30 µg/L respectively in these waters. However, there is no evidence from ***eriss*** data in terms of the signatures of other analytes or from mining company data at around the same time that this was none other than an isolated and unusually high Mn concentration which may or may not be a true record.Consequently, no infringement of the Commonwealth ERs was deemed to have occurred.

3.3.5 Uranium

Of 69 downstream samples, 87% were below the *focus* level. Nine samples were above the *focus* level but below the *action* level (Fig 3.5).

3.3.6 Radium

Changes in total ^{226}Ra are shown in Fig 3.6. With the exception of one sample taken on 4 April 2001, activities downstream were very low and in the order of <10 mBq/L. However, this one sample whose relatively high activity was attributed solely to its residual fraction has a large effect on the downstream average for the 6 month period spanning 6 December 2000–2 May 2001. This has resulted in a downstream mean of 18.4 mBq/L total ^{226}Ra compared to an upstream mean of 9.2 mBq/L. Hence the difference is below a *limit* of 10 mBq/L difference which is to be adjudged over any 12 month continuous period.

3.3.7 Magnesium and sulphate

Unlike the afore listed, Mg^{2+} and SO_4^{2-} are not considered key variables under the current Commonwealth ERs. In the absence of a well-defined baseline for sulphate and locally-determined toxicological limits for magnesium and sulphate, EC has been adopted as a surrogate key variable for these two ions (Appendix).

Variations in downstream Mg^{2+} and SO_4^{2-} concentrations are given in Figs 3.7 and 3.8. The same data is also shown in Fig 3.9 expressed as the concentration ratio of SO_4^{2-}:Mg^{2+}.

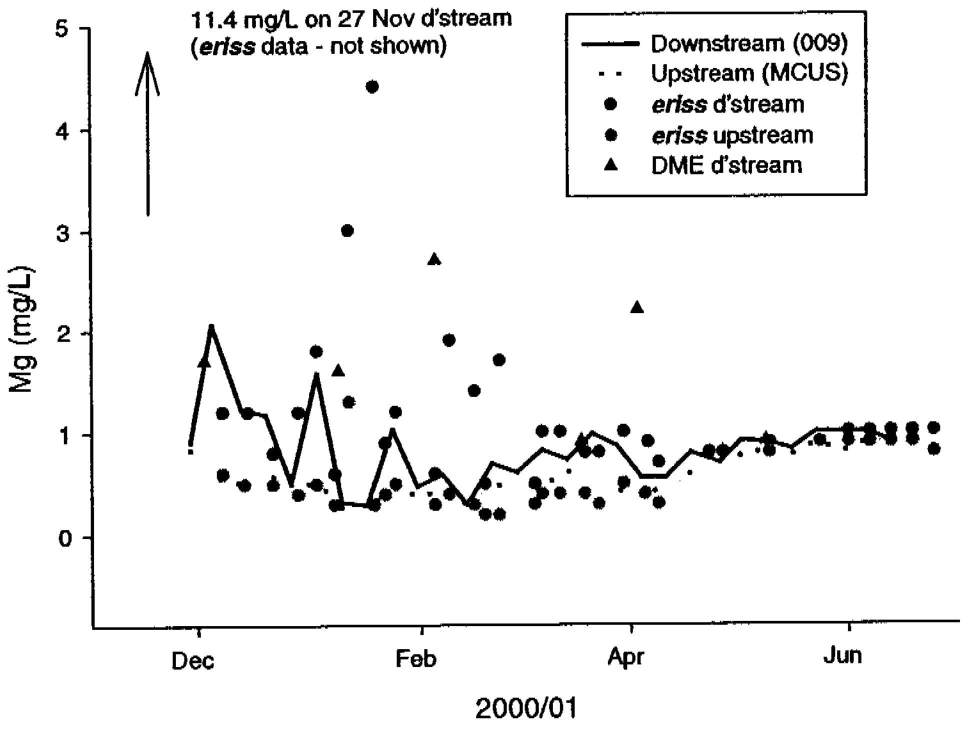


Fig 3.7 Mg upstream and downstream of Ranger during 2000–01

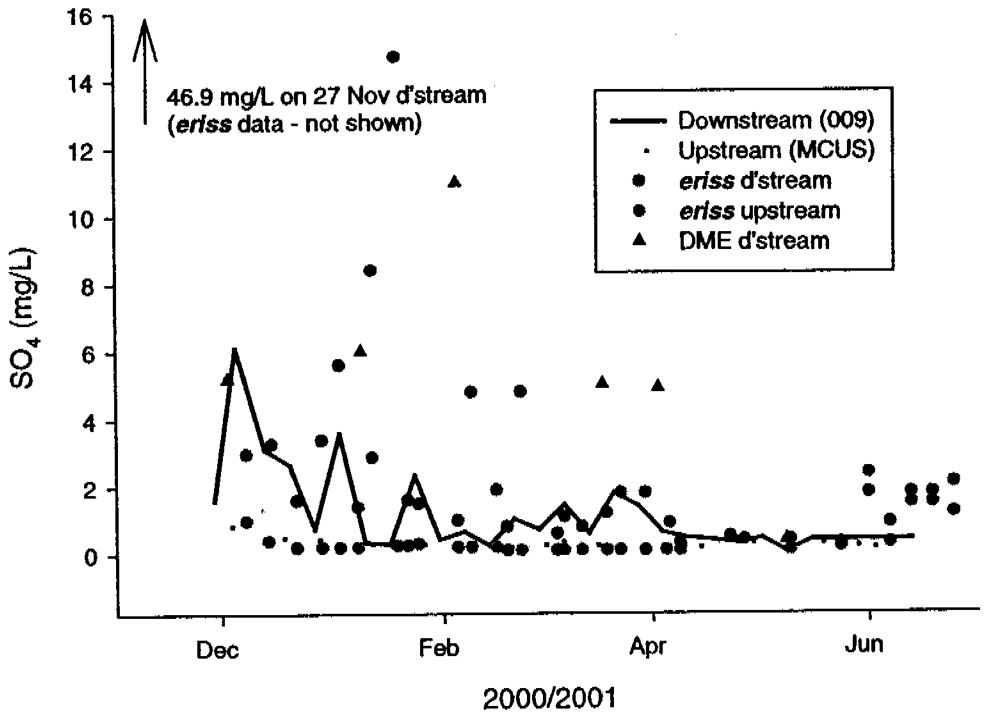


Fig 3.8 SO_4 upstream and downstream of Ranger during 2000–01

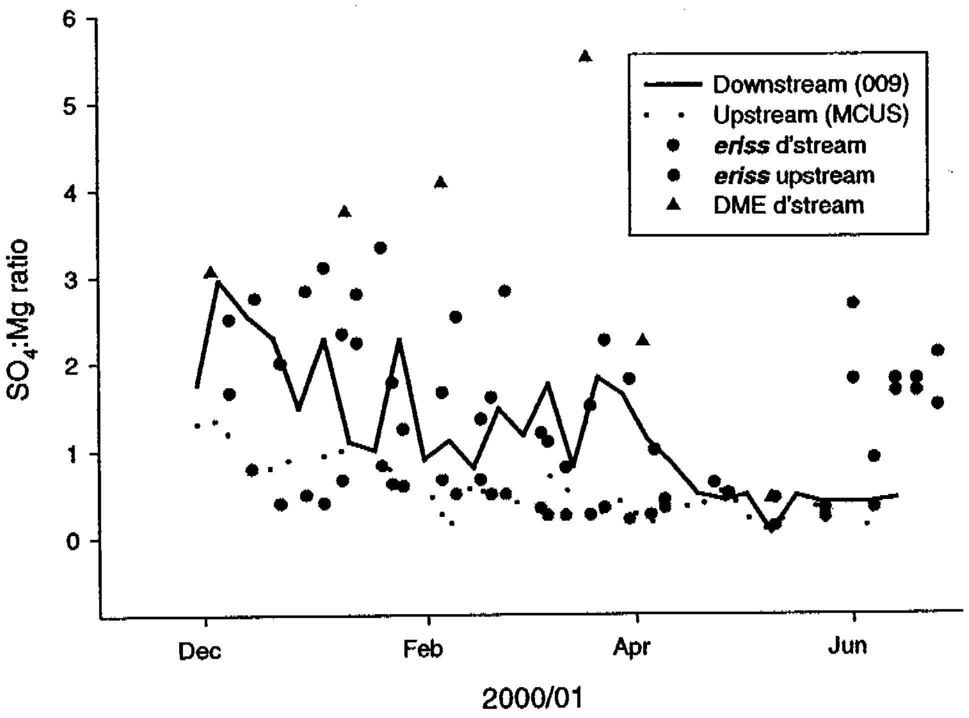


Fig 3.9 SO_4:Mg ratio upstream and downstream of Ranger during 2000–01

There was excellent agreement between mining company and ***eriss*** results upstream of the mine (Figs 3.7–3.9). However, downstream, ***eriss*** and DME data not only tended to show higher results but provided a much stronger $MgSO_4$ signature although this was not consistent throughout the wet season. This, together with the anomaly of the high ***eriss*** Mn results, the higher mean U concentration measured by ***eriss*** downstream (Table 3.4), and, possibly, the anomalous high NTDME pH results, suggests a disparity that is non-random and probably sampling-derived.

The procedure followed by mining company staff is to sample from the west bank of the western channel at relatively low flows and at moderate to high flows to use a boat and sample from the middle channel. Both ***eriss*** and NTDME sample from the west bank of the western channel. This obviously raises the potential problem of disparity between datasets and, more seriously, that of interpretation, particularly of compliance.

Work by Noller (1994) and the NT Water Resources Department (1984; cited by Noller 1994) showed that flow is favoured in the western channel over the middle and eastern channels in the ratio 45:30:25 respectively. Consequently, if mine water is discharged into the western channel, there is a risk at low flows especially of incomplete mixing taking place before Magela Creek exits the mine lease. However, in Noller's study of the release of RP4 water, it was estimated that at a flow rate of 11 m^3/s in Magela Creek, a reach of 1.2 km was required downstream of the discharge point to achieve complete mixing. This was well within the distance between the point of discharge and GS 009.

In relation to the current problem, the issue of mixing is probably of less relevance to point sources but rather to the diffuse expression of salts from the Magela land application area into the saturated zone of nearest proximity ie the western channel. The question is therefore one of whether by sampling the western channel a mine effect on the overall quality of Magela

Creek is exaggerated or whether by sampling the middle section, effects are underestimated. There is therefore some urgency to determining the preferred downstream sampling point which should be agreed and adopted by all parties to ensure the compatibility of data and equity in determining Ranger's environmental performance.

3.4 Adjustments to baseline

There were some minor changes to the frequency distributions of water quality parameters as a result of incorporating 2000–01 results into the baseline. These are summarised in Table 3.6 for normally distributed parameters and in Figs 3.10–3.16. Non-normally distributed parameters are shown in Figs 3.17–3.26 as percentile distributions.

Table 3.6 Mean and standard deviation of normally distributed baseline parameters (1979–2001)

	pH	EC (µS/cm)	Turb (NTU)	Mg (mg/L)†	Ca (mg/L)†	Na (mg/L)	Mn (µg/L)†
n	434	549	421	345	262	192	298
Mean	6.17	1.1823	0.6409	-0.2228	-0.3206	1.23	0.7316
σ	0.33	0.1492	0.3683	0.1833	0.2095	0.33	0.2572

†Denotes $\log_{10}$ values for the mean and σ

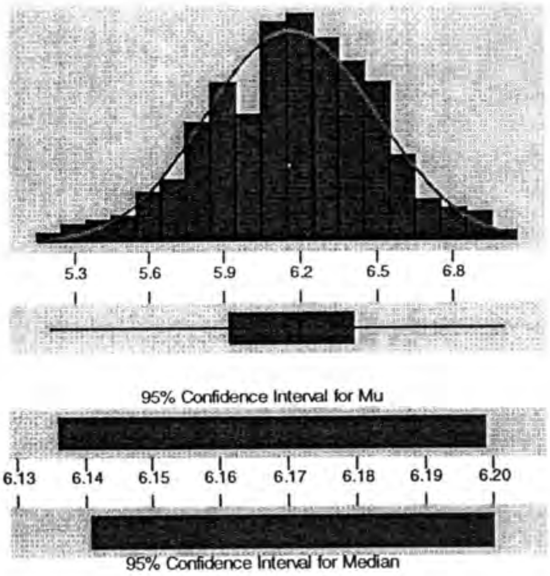
Trigger values and limits for 2001–2002 are given in Table 3.7. The continued improvement in the quality of the Mn and U baselines has resulted in a slight decrease in the Mn *limit* and to the *focus* and *action* triggers for U. pH, EC and turbidity remain unchanged except for some very minor adjustments. pH has been rounded up to 1 decimal place.

Table 3.7 Trigger values and limits at GS 009 for 2001-2002

Key variable	Focus level	Action level	Limit
pH	5.8, 6.5	5.5, 6.8	5.2, 7.2
EC (µS/cm)	21	30	43
Turbidity (NTU)	10	24	56
U (µg/L)	0.20	1.40	5.80
Mn (µg/L)	10	18	32
Mg (mg/L)		Use EC triggers and limit	
SO_4 (mg/L)		Use EC triggers and limit	

4 Conclusions and recommendations

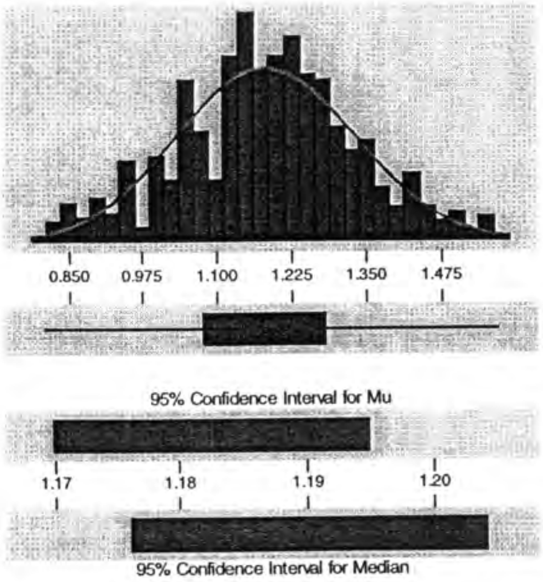
Monitoring data collected by the mining company and from the limited number of check monitoring samples taken by NTDME indicated that mining activities did not breach water quality objectives in Magela Creek at GS 009 during the 2000–01 wet season as determined by Commonwealth Environmental Requirements. Chemical monitoring upstream and downstream of Ranger was also undertaken for the first time by ***eriss*** as part of a routine programme of water quality assessment. However, disparity between ***eriss*** and mining company results at GS009 is of concern and recommendations to further investigate and correct this inconsistency are provided below.



Variable: pH

```
Anderson-Darling Normality Test
  A-Squared:            1.010
  P-Value:              0.012

  Mean                6.16738
  StDev               0.33238
  Variance           0.110477
  Skewness           -2.3E-01
  Kurtosis           -1.5E-02
  N                       434

  Minimum             5.20000
  1st Quartile        5.92000
  Median              6.20000
  3rd Quartile        6.40000
  Maximum             7.00000

95% Confidence Interval for Mu
  6.13602             6.19874
95% Confidence Interval for Sigma
  0.31164             0.35610
95% Confidence Interval for Median
  6.14092             6.20000
```

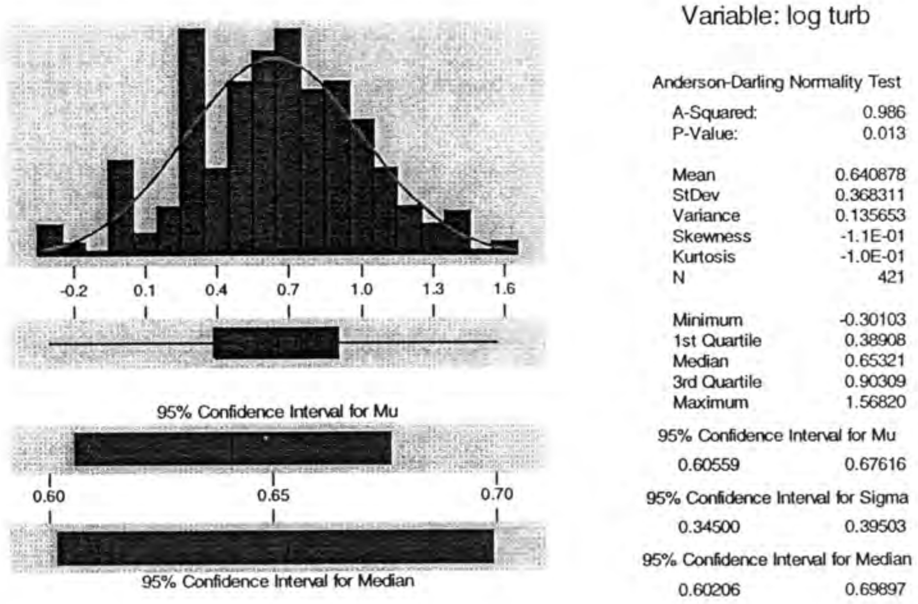
Fig 3.10 Frequency distribution of pH baseline values



Variable: log EC

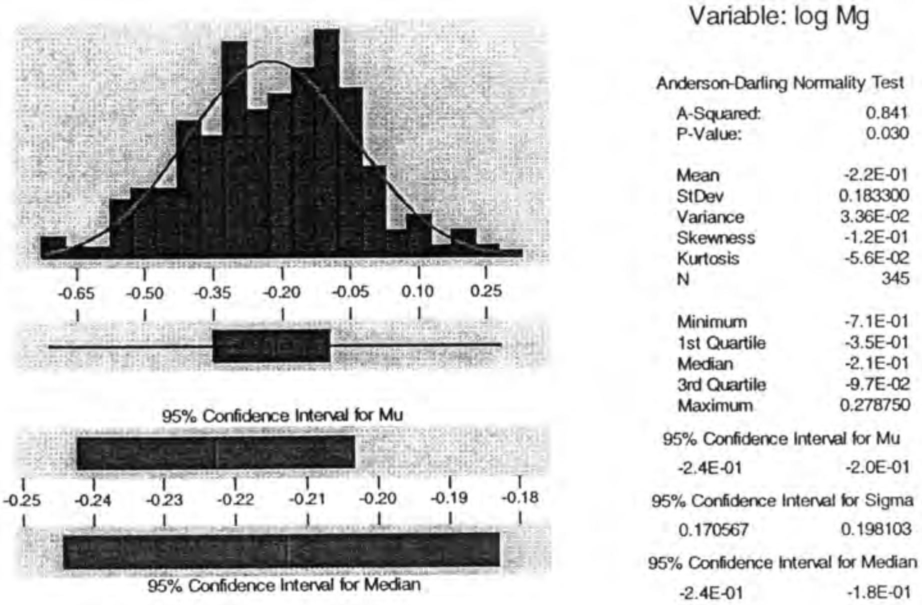
```
Anderson-Darling Normality Test
  A-Squared:            0.771
  P-Value:              0.045

  Mean                1.18233
  StDev               0.14917
  Variance           2.23E-02
  Skewness           -4.6E-02
  Kurtosis           -8.8E-02
  N                       549

  Minimum             0.80821
  1st Quartile        1.07918
  Median              1.17609
  3rd Quartile        1.27875
  Maximum             1.56820

95% Confidence Interval for Mu
  1.16982             1.19483
95% Confidence Interval for Sigma
  0.14083             0.15855
95% Confidence Interval for Median
  1.17609             1.20412
```

Fig 3.11 Frequency distribution of (log) EC (μS/cm) values



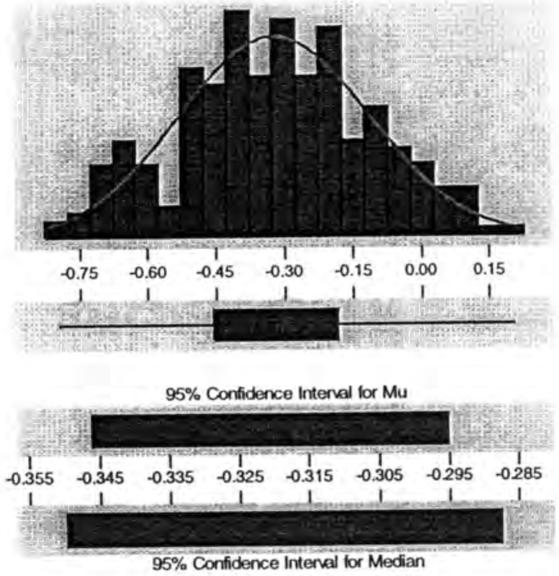
```
Variable: log turb

Anderson-Darling Normality Test
  A-Squared:              0.986
  P-Value:                0.013

  Mean                 0.640878
  StDev                0.368311
  Variance             0.135653
  Skewness             -1.1E-01
  Kurtosis             -1.0E-01
  N                         421

  Minimum              -0.30103
  1st Quartile          0.38908
  Median                0.65321
  3rd Quartile          0.90309
  Maximum               1.56820
 95% Confidence Interval for Mu
  0.60559               0.67616
95% Confidence Interval for Sigma
  0.34500               0.39503
95% Confidence Interval for Median
  0.60206               0.69897
```

Fig 3.12 Frequency distribution of (log) turbidity (NTU) baseline values



```
Variable: log Mg

Anderson-Darling Normality Test
  A-Squared:              0.841
  P-Value:                0.030

  Mean                 -2.2E-01
  StDev                0.183300
  Variance             3.36E-02
  Skewness             -1.2E-01
  Kurtosis             -5.6E-02
  N                         345

  Minimum              -7.1E-01
  1st Quartile         -3.5E-01
  Median               -2.1E-01
  3rd Quartile         -9.7E-02
  Maximum              0.278750
 95% Confidence Interval for Mu
  -2.4E-01             -2.0E-01
95% Confidence Interval for Sigma
  0.170567             0.198103
95% Confidence Interval for Median
  -2.4E-01             -1.8E-01
```

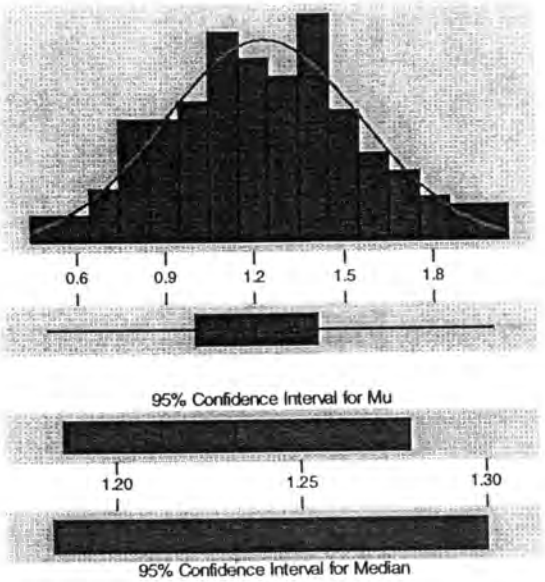
Fig 3.13 Frequency distribution of (log) magnesium (mg/L) baseline values



Variable: log Ca

```
Anderson-Darling Normality Test
  A-Squared:               0.442
  P-Value:                 0.286

  Mean                  -3.2E-01
  StDev                 0.209520
  Variance              4.39E-02
  Skewness              -1.6E-02
  Kurtosis              -4.9E-01
  N                          262

  Minimum               -8.0E-01
  1st Quartile          -4.6E-01
  Median                -3.1E-01
  3rd Quartile          -1.9E-01
  Maximum               0.204120

 95% Confidence Interval for Mu
  -3.5E-01              -3.0E-01

95% Confidence Interval for Sigma
  0.192984              0.229179

95% Confidence Interval for Median
  -3.5E-01              -2.9E-01
```

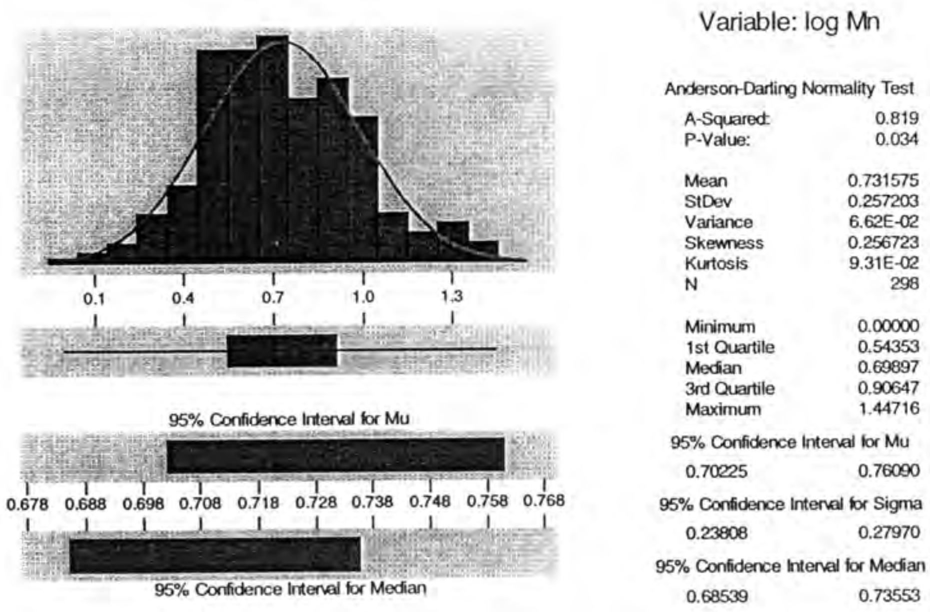
Fig 3.14 Frequency distribution of (log) calcium (mg/L) baseline values



Variable: Na

```
Anderson-Darling Normality Test
  A-Squared:               0.531
  P-Value:                 0.173

  Mean                   1.23246
  StDev                  0.32905
  Variance              0.108272
  Skewness              0.127191
  Kurtosis              -3.3E-01
  N                          192

  Minimum                0.50000
  1st Quartile           1.00000
  Median                 1.20000
  3rd Quartile           1.40427
  Maximum                2.00000

 95% Confidence Interval for Mu
  1.18562                1.27930

95% Confidence Interval for Sigma
  0.29910                0.36571

95% Confidence Interval for Median
  1.18315                1.30000
```

Fig 3.15 Frequency distribution of sodium (mg/L) baseline values



Variable: log Mn

Anderson-Darling Normality Test

A-Squared:	0.819
P-Value:	0.034
Mean	0.731575
StDev	0.257203
Variance	6.62E-02
Skewness	0.256723
Kurtosis	9.31E-02
N	298
Minimum	0.00000
1st Quartile	0.54353
Median	0.69897
3rd Quartile	0.90647
Maximum	1.44716

95% Confidence Interval for Mu

0.70225 0.76090

95% Confidence Interval for Sigma

0.23808 0.27970

95% Confidence Interval for Median

0.68539 0.73553

Fig 3.16 Frequency distribution of (log) manganese (mg/L) baseline values

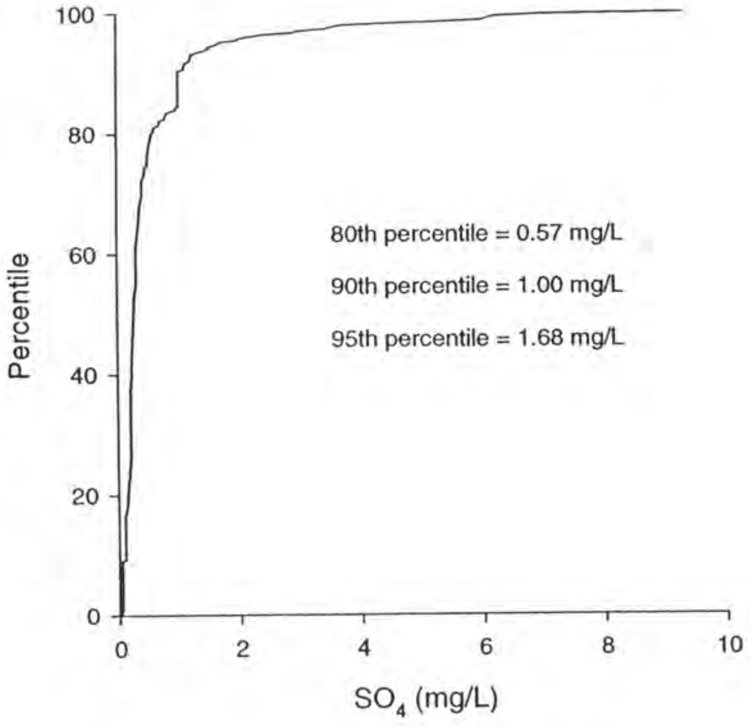


Fig 3.17 Percentile values for baseline sulphate

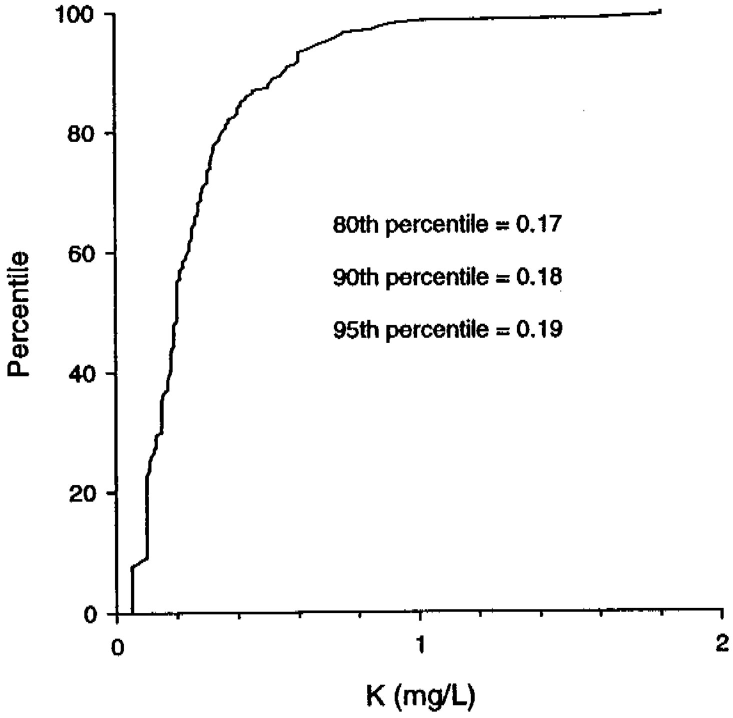


Fig 3.18 Percentile values for baseline potassium

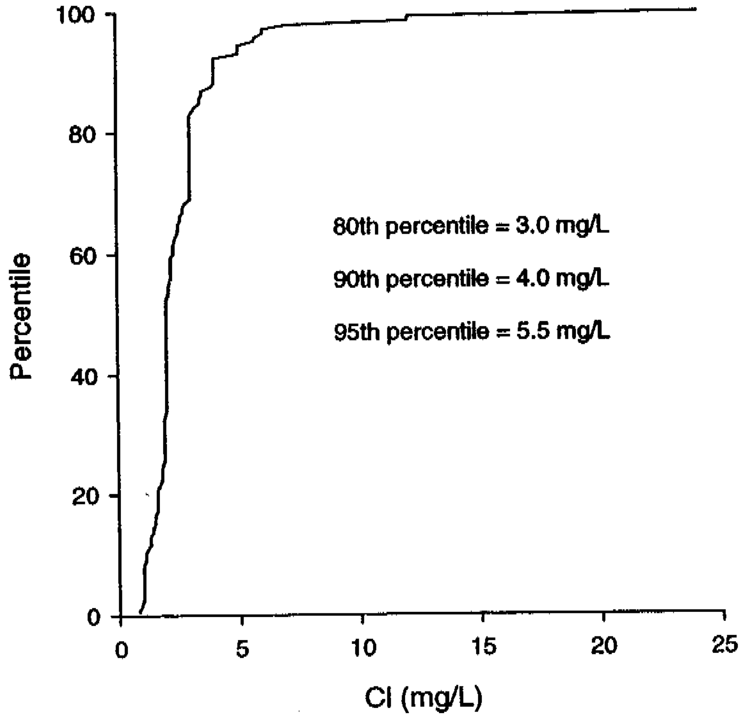


Fig 3.19 Percentile values for baseline chloride

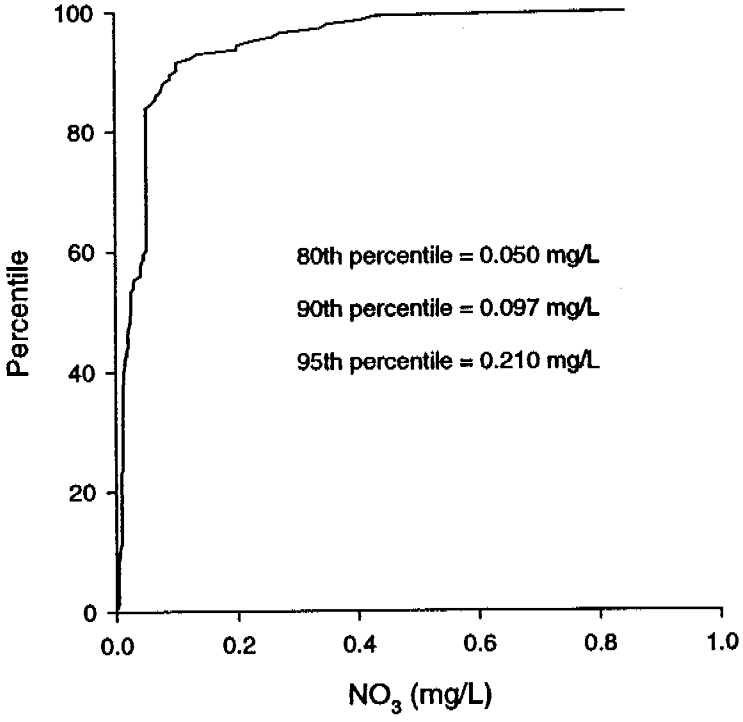


Fig 3.20 Percentile values for baseline nitrate

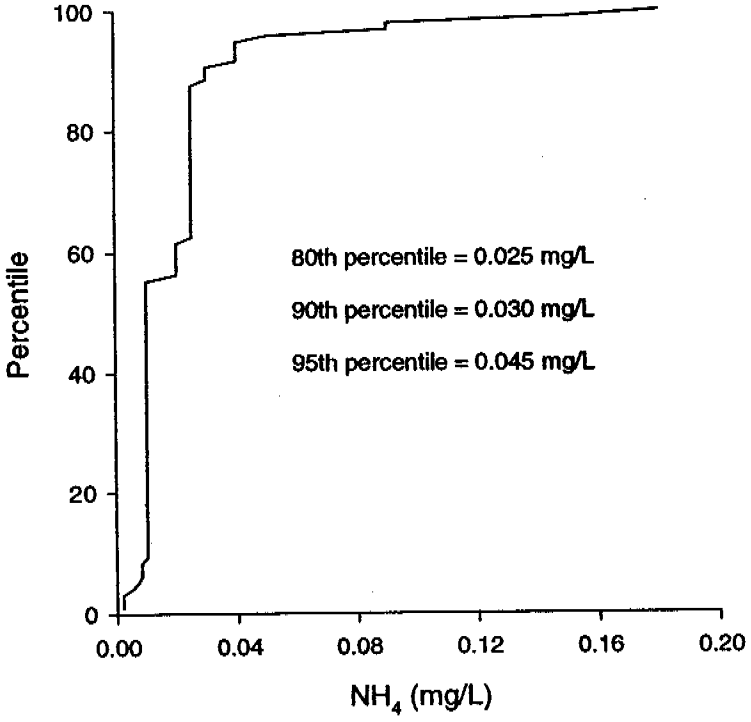


Fig 3.21 Percentile values for baseline ammonium

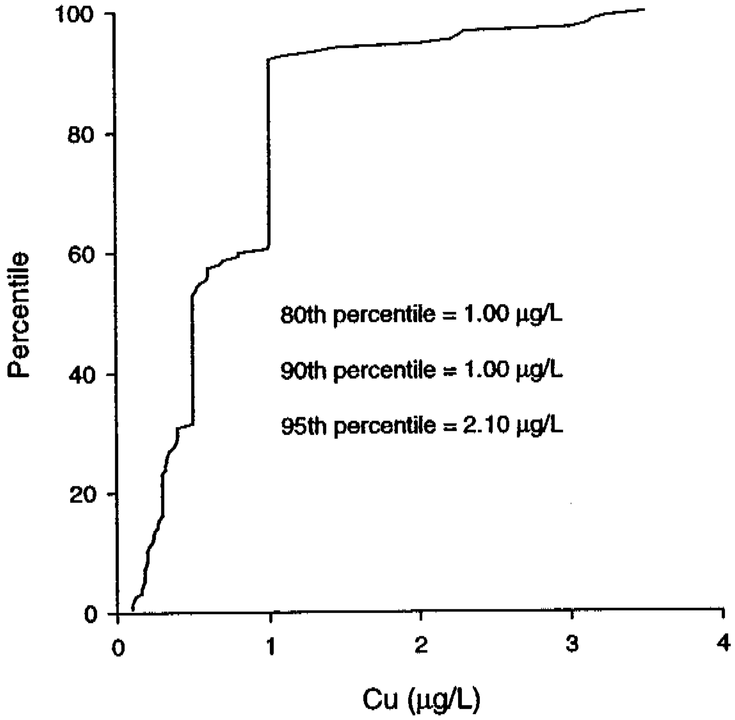


Fig 3.22 Percentile values for baseline dissolved copper

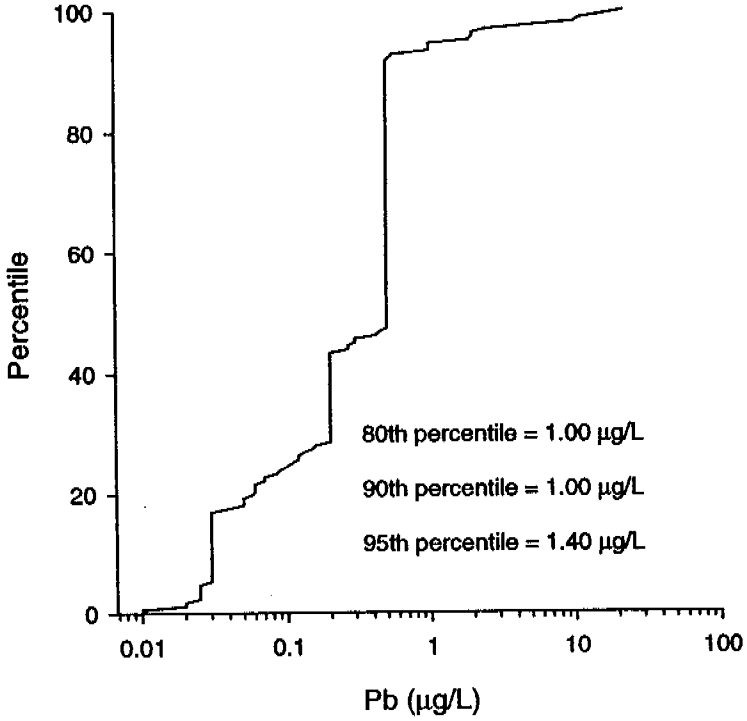


Fig 3.23 Percentile values for baseline dissolved lead

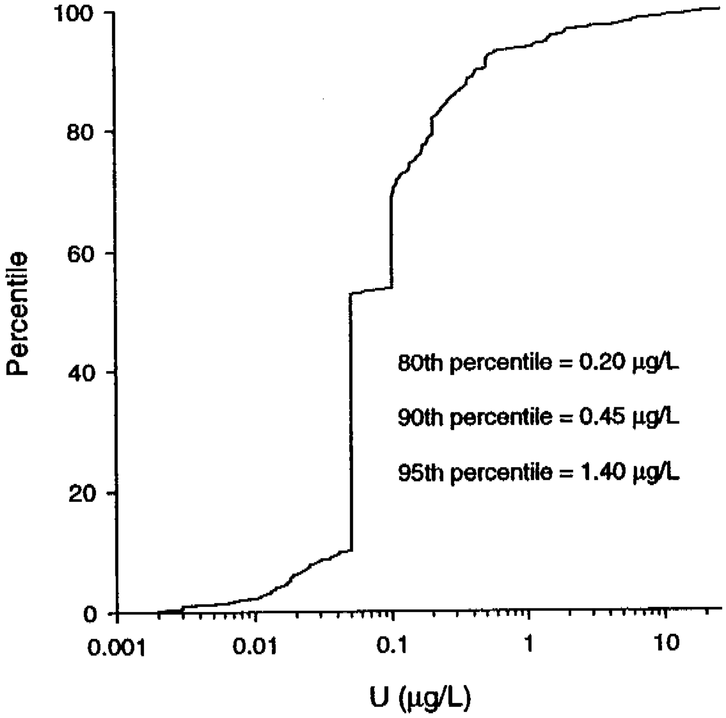


Fig 3.24 Percentile values for baseline dissolved uranium

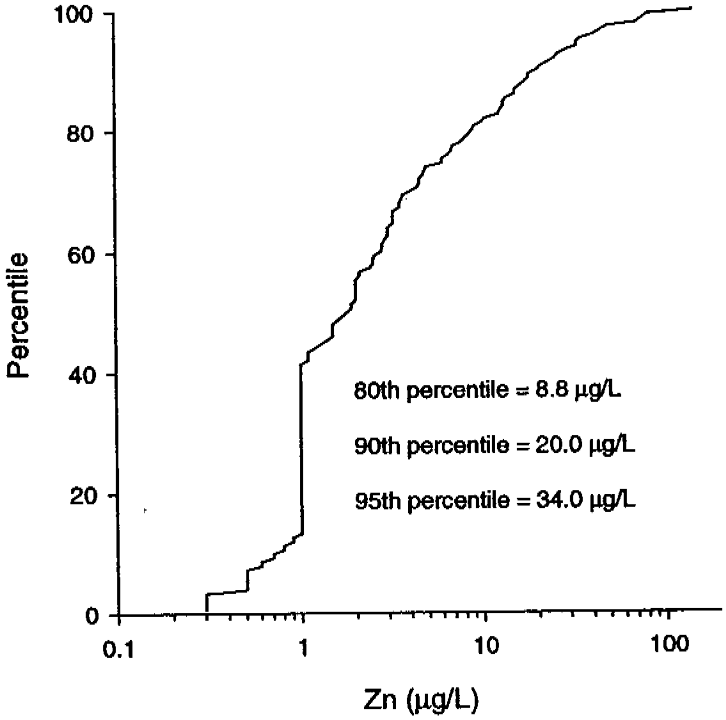


Fig 3.25 Percentile values for baseline dissolved zinc

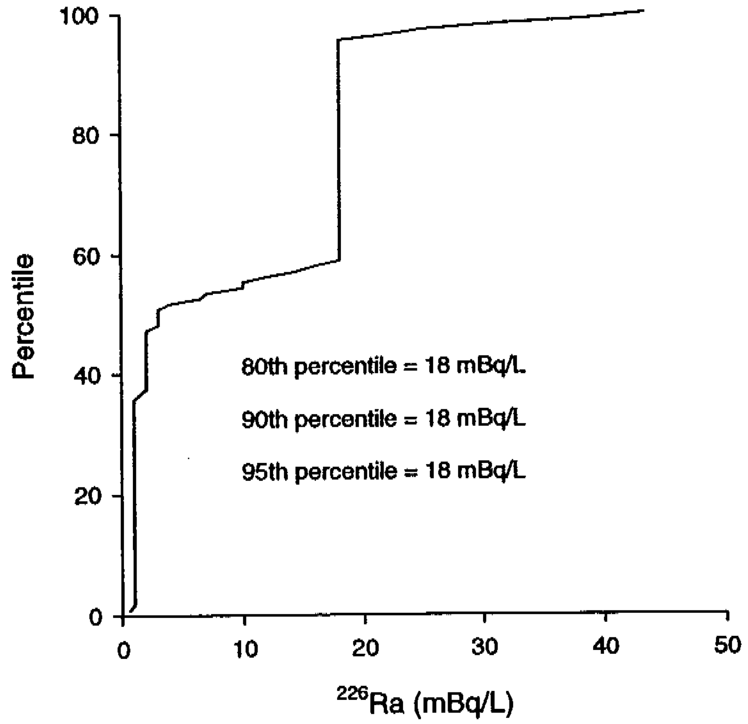


Fig 3.26 Percentile values for baseline dissolved radium-226

The continued provision of chemistry data upstream of Ranger has allowed further tuning of trigger values and limits which has been bolstered by the addition of ***eriss*** data. This has resulted in some small decreases in U triggers compared to last year. With ICPMS now the common analytical procedure for metal analyses by ***eriss*** and the mining company, further falls in U trigger values in particular are expected over future years.

The report has drawn attention to a number of shortcomings and information needs. There are also some other issues which have not been specifically addressed by the report but which need to be considered as part of the need to continually revise and improve the compliance framework. These are as follows:

1. Priority during the 2001–02 wet season should be given to determining cross channel variation in chemistry at GS009 under a range of flow conditions. Results should be presented to the Ranger MTC and then be used to determine a common (to the mining company, Supervising Scientist and NTDME) protocol for the collection of samples.
2. Arrangements should be made by the Supervising Scientist, NTDME and the mining company to regularly exchange and provide duplicate samples for quality control and assurance purposes. A protocol for this should be written by the Supervising Scientist and provided to the Ranger MTC for discussion and agreement. The Supervising Scientist should collate the results from this interchange of samples and report these regularly through the Ranger MTC.
3. It is likely under the prevailing conditions of Magela Creek that concentrations of soluble Mn downstream of the mine which are in the order of $<10^2$ µg/L do not pose a risk to ecosystem condition. For example, the default value for 99% protection according to

ANZECC & ARMCANZ (2000) is 1200 µg/L. It is desirable that this be verified under local conditions. Currently, Mn triggers and the limit are derived from the chemistry baseline. Consideration should therefore be given by the Supervising Scientist to deriving a site-specific Mn limit by testing using local species.

5 References

Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) 2000. *Australian and New Zealand guidelines for fresh and marine water quality. Volume 1, The guidelines.* ANZECC& ARMCANZ.

Klessa DA 2000. *The chemistry of Magela Creek: A baseline for assessing change downstream of Ranger.* Supervising Scientist Report 151, Supervising Scientist, Darwin.

Klessa DA 2001. *Water quality in Magela Creek upstream and downstream of Ranger: A summary of findings for the 1999–2000 Wet season.* Internal Report 360, Supervising Scientist, Darwin. Unpublished paper.

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- Chris leGras and staff for ***eriss*** monitoring data.
- Gretal Parker, David Jones Arthur Johnston and Alex Zapantis for useful comments and corrections.

Appendix

Ranger Environmental Requirements

Explanatory Material relating to Section 3.3 (Amended November 2001)

Water Quality

Foreword

Section 19.2 of the Environmental Requirements of the Commonwealth of Australia for the Operation of the Ranger Uranium Mine (the Ranger ERs) provides for the publication of explanatory material agreed to by the major stakeholders to assist in the interpretation of provisions of the Ranger ERs.

This document has been published by the Supervising Scientist under section 19.2 to assist in the interpretation of the Ranger ERs (ER3.3) which relates to water management and should be read in conjunction with ER3.3.

1. Key variables (ie water quality parameters) for monitoring, interpretation and reporting at GS 009

In this paper, *key variables* are those identified as

- pH, EC and U as referred to by the *Commonwealth Environmental Requirements for Ranger Uranium Mine* (Annex 2), and
- having the capacity to significantly influence the extent to which secondary environmental objectives related to water quality (ER 3) are met, or
- being important either as 'master' variables or confounding factors influencing the toxicity of other solutes.

Key variable	Relevance
pH	Stipulated under ER 3.3; master variable influencing speciation and toxicity of potential contaminants; and ecosystem character (ie structure and function)
EC	As given above for pH
U†	Stipulated under ER 3.3; principal contaminant of public concern; potential ecological impact
Turbidity	No evidence of mine effect but becomes increasingly important as physico-chemical indicator of potential ecological impact from surface disturbance during rehabilitation
Mg†	Evidence of mine effect; potential water potability impacts; potential ecological impact unclear
SO_4†	As given above for Mg
Mn†	Evidence of mine effect; contaminant arising primarily from use of pyrollusite in U_3O_8 production; potential ecological impact
^{226}Ra	No evidence of mine effect; potential human health impact
Ca†	No direct effect envisaged but required for the interpretation of potential ecological impact from Mg imbalance (ie Ca:Mg ratio)

†refers to the soluble (<0.45 µm) fraction; ^{226}Ra is measured as a total fraction

2. Triggers of change in water quality at GS 009

The triggers are (with the exception of ^{226}Ra) as follows:

Type of data	Trigger Level	Trigger
Normal distribution	Focus	$\pm\sigma$†
	Action	$\pm 2\sigma$†
	Limit‡	$\pm 3\sigma$†
Non-normal distribution	Focus	x>80th percentile
	Action	x>95th percentile
	Limit	Toxicologically derived

† $-\sigma$, -2σ and -3σ triggers are only relevant for pH; ‡ Guideline only for pH

- The methodology used in the derivation of triggers is contained in Klessa (2000, 2001). Normal distribution of baseline data is shown for pH, and by logarithmic transformation of EC, turbidity, Mg, Ca and Mn.
- Three trigger levels are set in accordance with the distributional properties of baseline data from which they are derived.
- For normal distributed baseline data, and with the exception of pH, trigger levels are +1, 2 and 3 standard deviations (σ) from the mean. In the case of pH, trigger levels are ±1, 2 and 3σ from the mean.
- For non-normal distributed baseline data, trigger levels are the 80th percentile, the 95th percentile and a maximum which in the case of U is a site-specific value derived in accordance with national water quality guidelines (ANZECC 2000) from toxicity testing of local aquatic species (Van Dam 2000)
- Triggers for ^{226}Ra are based on human health considerations and details are provided in Section 3.

3. Trigger and maximum values at GS 009 (1979–2001 baseline)

The values for the triggers are as follows:

Key variable	Focus Level	Action Level	Limits
pH	5.8, 6.5	5.5, 6.8	5.2, 7.2
EC (µS/cm)	21	30	43
Turbidity (NTU)	10	24	56
U (µg/L)	0.20	1.40	5.80
Mn (µg/L)	10	18	32
Mg (mg/L)	Use EC triggers		Use EC maximum
SO_4 (mg/L)	Use EC triggers		Use EC maximum
^{226}Ra (mBq/L)†	>10 mBq/L	>10 mBq/L over 90 consecutive days	Wet season arithmetic mean difference of 10 mBq/L

†based upon an operation effect (ie the difference in ^{226}Ra concentration between paired samples upstream and downstream of the mine).

- The limit for ^{226}Ra has been defined for human radiological protection purposes and applies to the increase above natural background in total ^{226}Ra concentration in surface waters downstream of Ranger. It has been derived based on the following;

- a dose constraint of 0.3 mSv per year above natural background from the ingestion of ^{226}Ra in mussels
  - a 10 year old child consuming 2 kg of mussels annually, and
  - a concentration factor for mussels of 19000 for ^{226}Ra.
- For Mg and SO_4, a recommended working maximum is set using EC data (refer to Annex 1). This is an interim measure until research is completed by ***eriss*** into the ecotoxicological effects of Mg^{2+} and SO_4.
- The triggers and limits will be reviewed regularly and updated annually by the Supervising Scientist.
- If in the opinion of the Supervising Scientist the exceedance of a limit, with the possible exception of pH, is due to operations at Ranger, the Supervising Scientist will advise the Minister with regard to
  - the circumstances surrounding the exceedance of the limit, and
  - whether there has been a breach of the Ranger ERs.

  In the case of pH, the limit is a guideline, the exceedence of which will be interpreted with regard to the values of other key variables.
- In drawing a conclusion that exceedance of the limit for ^{226}Ra constitutes a breach of the ERs, the Supervising Scientist must be convinced that the anthropogenic dose to the critical group has exceeded 1 mSv in one year.

4. Company action

This section decribes in general terms the action to be taken by the company where a focus or action level or limit, as defined in this explanatory material, is exceeded.

4.1 Focus level

- Values which are maintained higher than the *focus level* but lower than the *action level* will result in a *watching brief* and may require further sampling to verify whether an upward trend is occurring.

4.2 Action level

- Values which are maintained higher than the *action level* but lower than the *limit* will result in *investigation and corrective action*. Confirmation of such a value by virtue of
  - an abrupt change from background values, or
  - a trend away from background values (other than associated with first flush)

  must be reported to the Supervising Authorities immediately.
- Interpretation of notifiable high values should take account of the composition of samples taken upstream of Ranger.

4.3 Limit

- With the possible exception of pH (refer to 4.4), values in excess of the *limit* will result in the company providing a written report to the Supervising Authorities detailing
  - all relevant data
  - the circumstances surrounding the exceedance of the *limit*

- ☐ the corrective actions taken to date; and
- ☐ options for further corrective action.

4.4 pH guideline limit

- For pH, the *limit* is a guideline whose exceedence will be interpreted with regard to the values of the other key variables.
- Values which exceed the guideline limit will result in a *watching brief* and prompt liaison with the Supervising Authorities. Further sampling will be undertaken to verify a trend and interpretation of values should take account of the composition of samples taken upstream at Ranger.

5. Quarterly and annual reporting of results

- The presence or absence of short- and long-term trends in chemistry at 009 should be reported by the company and incorporated as appropriate into quarterly and annual environmental monitoring reports.

6. Glossary of terms and abbreviations

abrupt change	an abrupt change is one where values exceed trigger values and are maintained over at least two consecutive samples.
EC	electrical conductivity.
eriss	Environmental Research Institute of the Supervising Scientist.
ERs	Environmental Requirements
first flush	the natural occurrence of relatively high (or low) values of key variables.
Minister	Minister means the Minister for the time being administering section 41 of theAtomic Energy Act 1953.
trend	an upward trend is established when three consecutive values x_1, x_2 and x_3, show $x_1<x_2<x_3$.

7. References

ANZECC 2001. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ)

Klessa DA 2000. *The chemistry of Magela Creek: A baseline for assessing change downstream of Ranger.* Supervising Scientist Report 151, Supervising Scientist, Darwin.

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Van Dam R 2000. *Derivation of a site-specific water quality trigger value for uranium in Magela Creek.* Internal Report 350, Supervising Scientist, Darwin.

Annex 1

Setting recommended trigger and maximum values for Mg and SO_4

- A comparison of upstream (ie baseline) data with concentrations at GS009 has shown not unexpectedly that an increase in Mg and SO_4 concentrations has arisen downstream which is attributed to mining at Ranger.
- To date, a mining effect on Mg and SO_4 concentrations at GS009 has not been linked to any observed ecological impact in Magela Creek downstream of Ranger
- In the absence of definitive data on the ecotoxicology of $MgSO_4$, and hence the difficulty of establishing trigger and maximum values for Mg and SO_4, an alternative approach has been sought to ensure that water quality objectives are met in accordance with the Commonwealth ERs.
- $MgSO_4$ is the dominant salt in mine runoff including retention pond water. Should mine water be polished passively by wetland filters, there are extensive data to show that Mg^{2+} and SO_4^{2-} are conservative.
- Using the composition of RP2 water as an example, a strong relationship can be demonstrated between Mg^{2+} (or SO_4^{2-}) and EC and that the mass relationship between Mg^{2+} and SO_4^{2-} of 1:4 implies $MgSO_4$ stoichiometry.

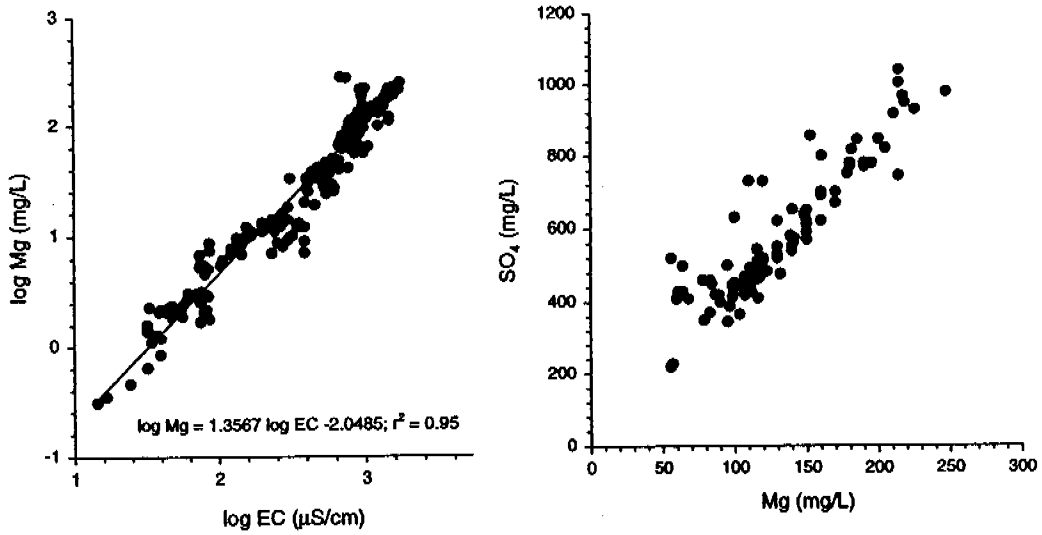

Fig 4 Relationship between Mg and EC, and scattergraph of SO_4 vs Mg for RP2 water

Hence by subjecting a measure of control on EC, a similar relative effect is exercised on Mg and SO4 concentrations.