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Ranger Stream Monitoring Program - changes to the surface water chemistry grab monitoring program in Magela Creek

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June 2009

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Executive summary

The surface water chemistry grab sampling component of the Ranger stream monitoring program will relocate from the reference site MCUS and statutory compliance site 009C to the continuous monitoring and in situ toxicity monitoring sites in Magela Creek at the commencement of the 2008/2009 wet season.

This new regime replaces that which has been in place since 2001, and will enhance the ability of the Supervising Scientist Division (SSD) to independently detect change while reducing replication of the compliance monitoring program carried out by Energy Resources Australia Ltd (ERA), and the check monitoring conducted by the Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR).

The key outcome of the new program will be closer integration of the grab sampling with continuous water quality monitoring and in situ toxicity monitoring.

Statistical comparison of data for key analytes collected from the historical water chemistry grab sampling sites and the proposed new sites (using creekside monitoring data) from 2002 to 2008 is presented in this report.

Statistically, concentration data acquired from the new reference site (to be named MCUGT) are similar to those derived from the historical upstream site, MCUS.

Concentration data acquired from the proposed new downstream site MCDW, are significantly higher ($p<0.05$) from those derived from the compliance site 009C for uranium, magnesium and sulfate. This is because the compliance site 009C is located in the central channel of Magela Creek while the new site is located in the west channel of Magela Creek. The west channel has historically shown elevated solute levels when compared to the central channel, particularly in relation to discharges of water from Ranger Retention Pond 1 (RP1). Water released from RP1 enters Coonjimba Billabong, which drains into the west side of Magela Creek. Continuous and grab sample electrical conductivity monitoring in previous years show that water from RP1 mixes incompletely in the west channel and preferentially follows the western bank, particularly during low flow periods.

While the concentrations measured at the MCDW location are statistically higher than values at the compliance site 009C further upstream, the actual magnitude of the difference is only minor, and is not regarded as sufficient to impact on the decision to relocate the grab sampling site, particularly since sampling in the west channel at the location of the current pontoons will result in a more conservative assessment of the contribution of the mine site to solute loads in Magela Creek.

Ranger Stream Monitoring Program – relocation of surface water chemistry grab monitoring sites in Magela Creek

J Brazier & C Humphrey

1 Introduction

Ongoing optimization of existing monitoring methods and relevant development of new methods is necessary to ensure that best practice continues to be employed for detection of possible environmental impacts arising from the Ranger mining operation. To this end, some significant changes were made to the wet season surface water chemistry grab monitoring program and implemented from 2008–09 wet season onwards. This new regime replaces that which has been in place since 2001, and will enhance the ability of the Supervising Scientist Division (SSD) to independently detect change while reducing replication of the compliance monitoring program (Schedule 1 Ranger Authorisation 0108-10 (April 2008) issued under the *Mining Management Act 2001* (NT)) carried out by Energy Resources Australia Ltd (ERA), and the check monitoring performed by the Northern Territory Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR 2009).

The key outcome of the new program will be closer integration of the grab sampling and continuous water quality monitoring with in situ toxicity monitoring[1]. This will be achieved by moving the current weekly routine water chemistry grab sampling sites to the same locations in Magela Creek as SSD's continuous monitoring and in situ biological monitoring infrastructure.

2 Site change

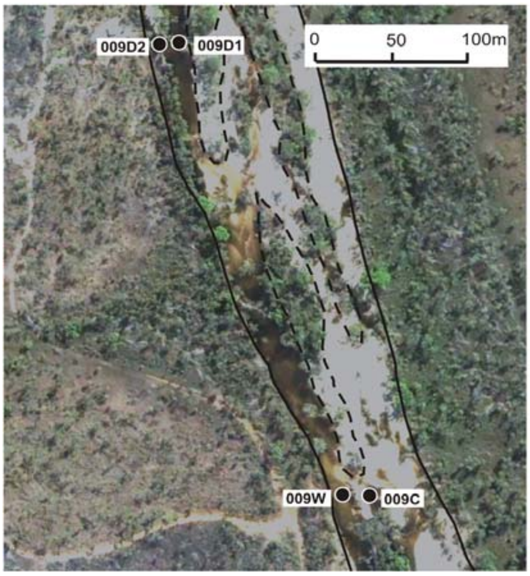
The upstream grab sampling site (MCUS) has relocated approximately 700 m downstream to the continuous monitoring pontoon. The site is called MCUGT (formerly named Georgetown or GTD1 and GTD2 while part of the creekside monitoring program and as discussed in this report). The downstream grab sampling site has relocated approximately 400 m downstream from GS009 to the downstream pontoon and is called MCDW (formerly 009D2 during the period of creekside monitoring). Locations are marked on Figure 1.

3 Statistical significance of the site changes

To examine any implications of changing the grab sampling sites upon the ability of SSD's program to detect environmental impacts from the minesite, the distributions of data for key

[1] Continuous monitoring is the gathering of physicochemical data in Magela Creek at regular intervals (scanned every 5 minutes and logged if there has been a change within defined parameters) using data loggers. Toxicity monitoring is a biological assessment technique used to measure the responses of sensitive aquatic organisms to an exposure of creek waters from upstream and downstream of the Ranger minesite. Toxicity monitoring may be perfomed in situ or using ex situ, creekside facilities (see descriptions in the 2008–09 Supervising Scientist Annual Report).

chemical analytes gathered between the 2001 and 2008 wet seasons as part of the creekside monitoring program (locations of the new routine grab sampling sites) were graphically and statistically compared with corresponding data from the compliance and reference sites used for the routine grab sample monitoring program for the same period.



A Upstream monitoring sites on Magela Creek near Ranger

B Downstream monitoring sites on Magela Creek

Figure 1 Upstream and downstream monitoring sites used in SSD's water chemistry (grab sampling and continuous) and toxicity monitoring programs. Channel boundaries are indicated by the continuous or broken (water-level-dependent) lines. GTD1 and GTD2 are on the same pontoon and will now be called MCUGT. Only the 009D2 pontoon will be used from 2008–09 wet season and the site will be called MCDW.

In each wet season of deployment, creekside monitoring commenced once flow in Magela Creek had reached the height of the creekside monitoring pumps and was conducted fortnightly thereafter (ie every other week) while the creek level was sufficiently high for the pumps to operate. During each creekside test, filtered water grab samples were collected twice during the monitoring week. Only weekly routine water chemistry data that overlapped with the deployment of creekside monitoring (December to April each wet season) were used for this comparison.

It should be noted, however, that the days on which the water samples were collected by the two programs (viz water quality grab sampling and creekside monitoring) were not necessarily the same. It should also be noted that the creekside monitoring samples were collected from a header tank located in the creekside infrastructure rather than directly from the creek. Since this resulted in water standing for some time (approximately 45 minutes) before replenishment from the creek, turbidity and pH were excluded from the data comparisons as they are significantly modified under standing conditions. Between 2001 and 2008 there were approximately 75 sample points for the creekside monitoring program and 90 sampling points for the routine grab sample program that were able to be used for this comparative analysis.

The statistical distributions of analyte concentrations amongst sites were plotted according to median, mean, range and percentiles (25^{th} and 75^{th}). Statistical comparisons were performed using Analysis of Variance (ANOVA) testing, with follow-up multiple comparison tests using the Tukey's procedure for cases where significant ANOVA results were found. Minitab 15 Statistical Software (2007) was used for these comparisons. Minitab session outputs are provided in Appendices 1 and 2.

For statistical comparisons, analyte concentrations were log(10) transformed. ANOVA assumptions of normality and homoscedasticity (ie the presence of equal variances across the range of analyte values) were assessed graphically. Transformation did not completely normalise the data but the distributions were unimodal and not markedly skewed (Appendix 1). Residual plots were examined for homogeneity of variances; the distribution of residuals was even in all cases, with lack of 'bow-tie' or fan shape that might indicate unequal variances (Appendix 1).

All data and data analysis files are located in the SSDX directory: \\Environmental Impact of Mining – Monitoring and Assessment\Water Chemistry\Administration\08/09 Wet\Routine monitoring site change Magela Creek.

Upstream sites comparison

Upstream comparisons were made amongst the MCUS routine statutory monitoring site and waters representing the two upstream creekside monitoring sites, GTD1 and GTD2, located immediately adjacent to one another on a common pontoon (700 m downsteam of MCUS, Figure 1A).

Table 1 provides a summary of the descriptive statistics for key analyte concentration data for MCUS, GTD1 and GTD2. For uranium, magnesium and calcium data, the 80th, 95th and 99.7th percentiles are similar among the three sites. Additionally for magnesium, the respective percentiles are also comparable to those reported from MCUS for the period 1993–2004 (Iles, 2004). For sulfate , the 80th, 95th and 99.7th percentiles are lower at MCUS than at GTD1 and GTD2.

Table 1 Descriptive statistics for uranium, magnesium, sulfate and calcium concentrations at the historical reference chemistry grab sampling site (MCUS) and the creekside monitoring reference sites (GTD1 and GTD2)

	Uranium µg/L			Magnesium mg/L			Sulfate mg/L			Calcium mg/L		
	MCUS	**GTD1**	**GTD2**	**MCUS**	**GTD1**	**GTD2**	**MCUS**	**GTD12**	**GTD2**	**MCUS**	**GTD1**	**GTD2**
Mean	0.02	0.02	0.02	0.46	0.52	0.51	0.26	0.29	0.30	0.30	0.34	0.34
SD	0.01	0.01	0.01	0.14	0.17	0.16	0.13	0.22	0.20	0.10	0.10	0.11
Median	0.02	0.02	0.02	0.43	0.50	0.50	0.20	0.20	0.20	0.30	0.30	0.30
99.7th %ile	0.06	0.06	0.06	0.87	1.00	0.98	0.70	1.36	1.18	0.50	0.59	0.59
95th %ile	0.04	0.04	0.04	0.70	0.83	0.73	0.46	0.70	0.73	0.40	0.50	0.50
80th %ile	0.03	0.03	0.03	0.60	0.70	0.63	0.31	0.40	0.40	0.40	0.40	0.40
Max	0.07	0.07	0.06	0.90	1.00	1.00	0.70	1.40	1.20	0.50	0.60	0.60
Min	0.01	0.01	0.01	0.10	0.10	0.20	0.05	0.05	0.10	0.05	0.20	0.20
N	90	73	73	90	75	74	90	76	75	46	30	30

Figure 2 (a–d) shows comparative data for calcium, uranium, magnesium and sulfate concentrations, respectively, in the filtered (<0.45 µm) water sample fractions collected for the creekside monitoring and the routine water chemistry program sites. The descriptive statistics that are the basis of these plots are shown in Table 1. The upstream sites compare well for magnesium, sulfate and uranium. As expected, concentrations between the two GT locations are practically indistinguishable (Figure 2). Though the range of uranium concentrations measured at the upstream creekside monitoring site (GTD1/2, Figure 1, essentially a single site as the two creekside pumps are located on the one pontoon) is greater compared with the corresponding range at the upstream statutory monitoring site (MCUS), the concentrations measured at either location are extremely low. There was only one sampling day in 2003 when the uranium concentration exceeded 0.1 µg/L (GTD, Figure 2c); still well below even the focus level for U in Magela Creek at 0.3 µg/L.

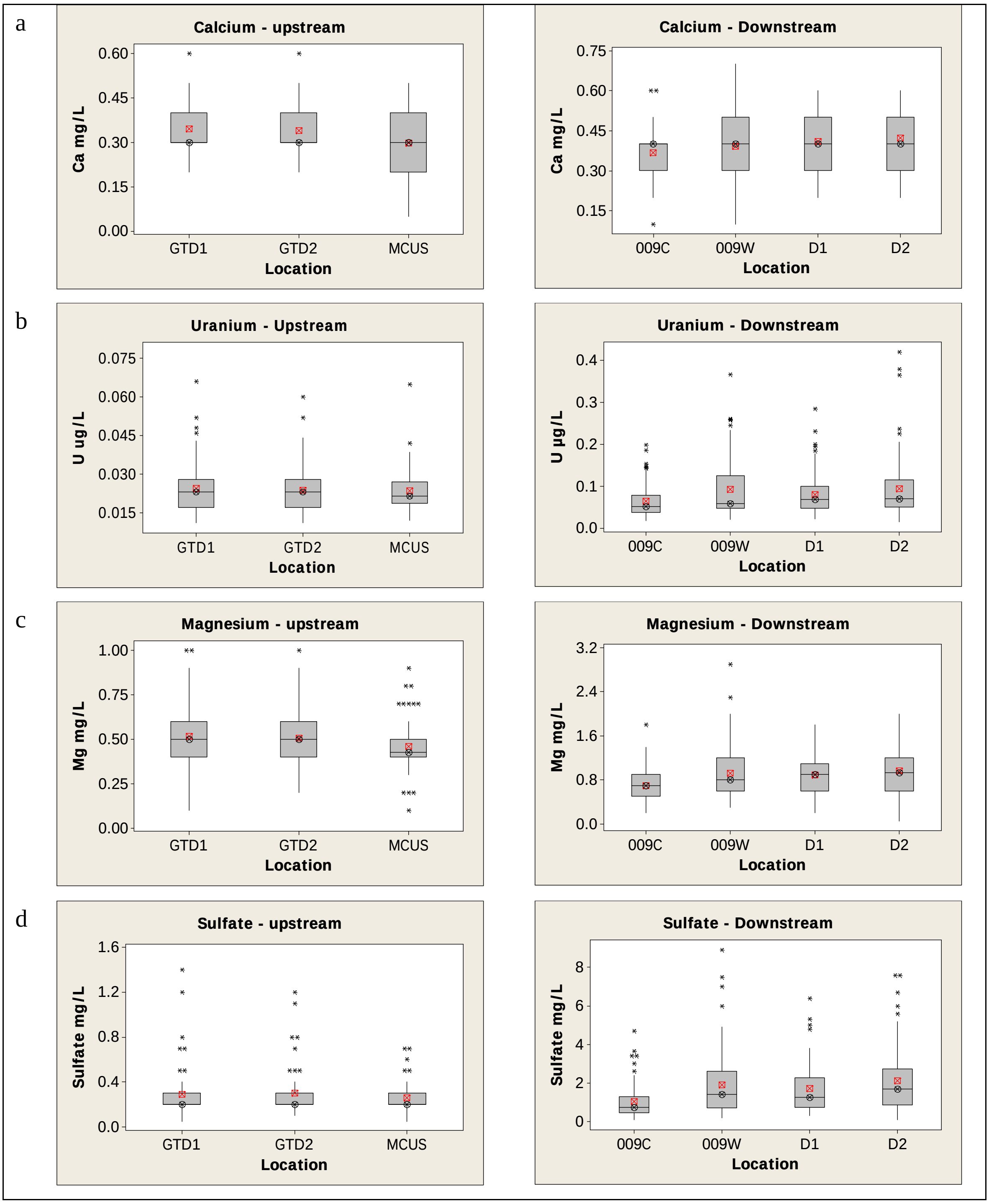


Figure 2 Box plots of concentrations measured between 2001 and 2008 for the upstream routine statutory monitoring site (MCUS), upstream creekside monitoring site (GTD1 and GTD2), downstream statutory compliance monitoring site (009C), downstream site adjacent to 009C but closer to the west bank (009W), and downstream creekside monitoring sites (D1 and D2 also know as 009D1 and 009D2). Box plots show median, mean (red square), range, and 25th and 75th percentile for (a) calcium, (b) uranium, (c) magnesium and (d) sulfate. See Figure 1 for site locations.

The observations above were generally confirmed with two-factor ANOVA using the factors ‘Year’ and ‘longitudinal location’ (MCUS versus GT site) (both factors fixed). (Differences between the two GT sites are not examined in this model, the data from the two sites representing duplicate information in the model.) Results of the ANOVA are provided in Table 2 and show that concentrations were statistically indistinguishable among years and between the MCUS and the GT sampling locations for magnesium and uranium ($P>0.05$). While sulfate was significantly different in behaviour among years, concentrations were not statistically different between the two sites. Calcium, however, was significantly lower at the MCUS site compared to the GT sites, with this difference being generally consistent among years (ie lack of significance of the ‘year’ and ‘year’ x ’longitudinal location’ interaction) (Table 2).

Table 2 Results (by P values) of two factor ANOVA examining differences in water quality among monitoring locations at the Magela Creek upstream site.

Analyte	ANOVA factor	
	Year	Longitudinal location
Calcium	0.089	0.008
Uranium	0.311	0.744
Magnesium	0.198	0.100
Sulfate	0.004	0.123

Downstream sites comparison

The downstream statutory compliance site (009) is located at a position in Magela Creek where there is a single (unbraided) channel (Figure 1). ERA collects a grab sample from a location close to the centre of the channel (009C). Historically, SSD has collected from two locations – one at 009C and one closer to the west bank at 009W (Figure 1). Approximately 50 m below 009, the creek divides into three channels. The two downstream pontoons associated with the continuous and toxicity monitoring programs were located in the west channel about 400 m downstream of the compliance site. One pontoon was located at 009 D1 on the eastern side of the west channel, while the other is located at 009 D2 closer to the west bank of the west channel (Figure 1).

The west channel has historically shown elevated contaminant levels when compared to the central channel, particularly in relation to discharges of water from Ranger Retention Pond 1 (RP1). Water released from RP1 enters Coonjimba Billabong, which then drains into the west side of Magela Creek. Continuous and grab sample electrical conductivity monitoring in previous years show that water from RP1 water mixes incompletely in the west channel and preferentially follows the western bank, particularly during low flow periods.

As a result of both the channel splitting below the compliance site and incomplete lateral mixing of mine site input waters (leading to a concentration gradient from west to east in Magela Creek at the 009 site), magnesium, sulfate and uranium in water samples collected from nearer the western bank (009W) are similar in concentration to the same measured variables at the pontoons (creekside, 009D) but appear higher in concentration to the same analytes measured at the central channel compliance site (009C) (Figure 2). A summary of the descriptive statistics for the downstream sites is provided in Table 3.

These observations were investigated further with three-factor ANOVA based upon concentration data for magnesium, sulfate, uranium and calcium using the factors ‘year’, ‘side of stream’ (west vs east/central) and ‘longitudinal location’ (upstream vs downstream) (all factors fixed). Results of the ANOVA are shown in Table 4.

Table 3 Descriptive statistics for uranium, magnesium, sulfate and calcium concentrations at the historical downstream chemistry grab sampling sites (009C and 009W) and the creekside monitoring downstream sites (009D1 and 009D2)

	Uranium µg/L				Magnesium mg/L				Sulfate mg/L				Calcium mg/L			
	009C	**009W**	**009D1**	**009D2**	**009C**	**009W**	**009D1**	**009D2**	**009C**	**009W**	**009D1**	**009D2**	**009C**	**009W**	**009D1**	**009D2**
Mean	0.06	0.09	0.08	0.09	0.70	0.92	0.89	0.97	1.05	0.39	0.09	0.92	0.37	0.06	0.70	1.05
SD	0.04	0.07	0.05	0.08	0.29	0.46	0.36	0.41	0.86	0.13	0.07	0.46	0.11	0.04	0.29	0.86
Median	0.05	0.06	0.07	0.07	0.70	0.80	0.90	0.94	0.75	0.40	0.06	0.80	0.40	0.05	0.70	0.75
Max	0.20	0.37	0.29	0.42	1.80	2.90	1.80	2.00	4.70	0.70	0.37	2.90	0.60	0.20	1.80	4.70
Min	0.02	0.02	0.02	0.02	0.20	1.00	0.20	0.05	0.10	0.10	0.02	1.00	0.10	0.02	0.20	0.10
N	90	92	76	75	89	91	75	73	87	47	92	91	47	90	89	87

Table 4 Results of three-factor ANOVA and Tukey pairwise tests examining differences in water quality among monitoring locations at the Magela Creek downstream site. None of the ANOVA interactions* was significant for any of the analytes. Emboldened, italicised Tukey comparisons indicate significant (P<0.05) pairwise differences.

Analyte	ANOVA factor			Tukey pairwise comparison	
	Year	**Side of stream**	**Longitudinal location**	**Site pair**	**P value**
Calcium	0.337	0.376	0.034	009C–009W	0.1035
				009C–009D1	0.1456
				009C–009D2	0.1635
Uranium	0.000	0.023	0.075	009C–009W	0.0782
				009C–009D1	0.2438
				009C–009D2	***0.0250***
Magnesium	0.309	0.009	0.065	***009C–009W***	***0.0197***
				009C–009D1	0.1614
				009C–009D2	***0.0074***
Sulfate	0.083	0.001	0.005	***009C–009W***	***0.0003***
				009C–009D1	***0.0050***
				009C–009D2	***0.0001***

* Year and Side of stream; Year and Longitudinal location; Side of stream and Longitudinal location; Year, Side of stream and Longitudinal location

While ‘year’ was significant for uranium only and ‘longitudinal location’ significant for sulfate only (though near-significant for U and Mg), ‘side of stream’ was significantly different for all three analytes (Table 4), confirming the distinct lateral (west to east) concentration gradient.

The interaction between ‘side of stream’ and ‘longitudinal location’ was examined more closely using the Tukey’s multiple comparison test. This test provided a pairwise comparison of all four sites, enabling greater interpretation of the significant or near-significant ‘side of stream’ and ‘longitudinal location’ factors (Table 4). None of the Tukey pairwise comparisons 009W–009D1, 009W–009D2 nor 009D1–009D2 showed significant differences for any of the three analytes, confirming the similarity in water quality in these west-side waters. For uranium, magnesium and sulfate, concentrations were significantly different between the central channel compliance site (009C) and the downstream western pontoon site (009D2). For magnesium, this significant lateral concentration difference with 009C values also applied to the adjacent 009W site, while for sulfate it applied to both 009W and 009D1 sites. This stronger lateral gradient in magnesium and sulfate compared with uranium, reflects, presumably, the close proximity of these downstream monitoring sites to the main source of $MgSO_4$ in Magela Creek, ie RP1 input via Coonjimba Billabong (not far upstream), and thus, less distance available for mixing.

There was a significant longitudinal difference in calcium (higher at the 009D1/2 location), consistent among years but not significant for ‘side of stream’ (ie lack of significance of the ‘year’ and ‘side of stream’ factors, and all interactions associated with ‘year’ and ‘side of stream’) (Table 4).

While the concentrations of uranium, magnesium and sulfate measured at the 009D2 pontoon location are statistically higher than values at the compliance site 009C further upstream, the actual magnitude of the differences are only minor, and is not regarded as sufficient to impact on the decision to relocate the grab sampling site. This is particularly so, since sampling in the west channel at the location of the current pontoons will result in a more conservative assessment of the contribution of the mine site to solutes in Magela Creek. Further, given that there is no statistical difference between the D1 and D2 locations, it has been decided to base all sampling (both continuous and grab) at the D2 pontoon located closest to the creek bank. This offers improved access conditions, and lower OH&S risk, as well as allowing for the provision of two datasondes on the pontoon, providing redundancy in the case of equipment malfunction.

In further support of the decision to relocate grab sampling to the west channel at the location of the current pontoons, there have only been two occasions in the last eight years of grab sample monitoring where higher uranium concentrations were recorded in the central channel (009C) than in the west channel (009W). This occurred for two consecutive weekly samples of water collected on the 12 and 19 February 2002 when the west channel had a uranium concentration of 0.049 and 0.031 µg/L compared to 0.198 and 0.127 µg/L in the central channel, respectively. On all other occasions, the west channel has had higher or similar EC and uranium concentrations compared to the central channel (continuous monitoring and grab sample data).

The above analysis supports the view that water quality between 009C and the downstream pontoon sites operated by SSD is sufficiently similar that the integrity of the program will be retained with the proposed relocation of the grab sampling site. In particular, the collection of weekly samples from the west channel should enhance SSD’s ability to detect inputs of solutes from the mine site.

4 Physicochemical measurements

Field measurements

Commencing with the 2008–09 wet season, physicochemical parameters such as turbidity, pH and electrical conductivity (EC), were measured in the field only. This decision follows several years of good agreement between field and laboratory measurements (Figure 3), demonstrating that it is possible to obtain reliable measurements in the field using carefully calibrated instruments equipped with probes optimised for use in very low EC media (characteristic of natural Magela Creek waters during the wet season). Using a well-calibrated and maintained field instrument should be more reliable than measuring samples later in the laboratory, particularly for parameters such as pH and turbidity that change relatively rapidly in samples over time.

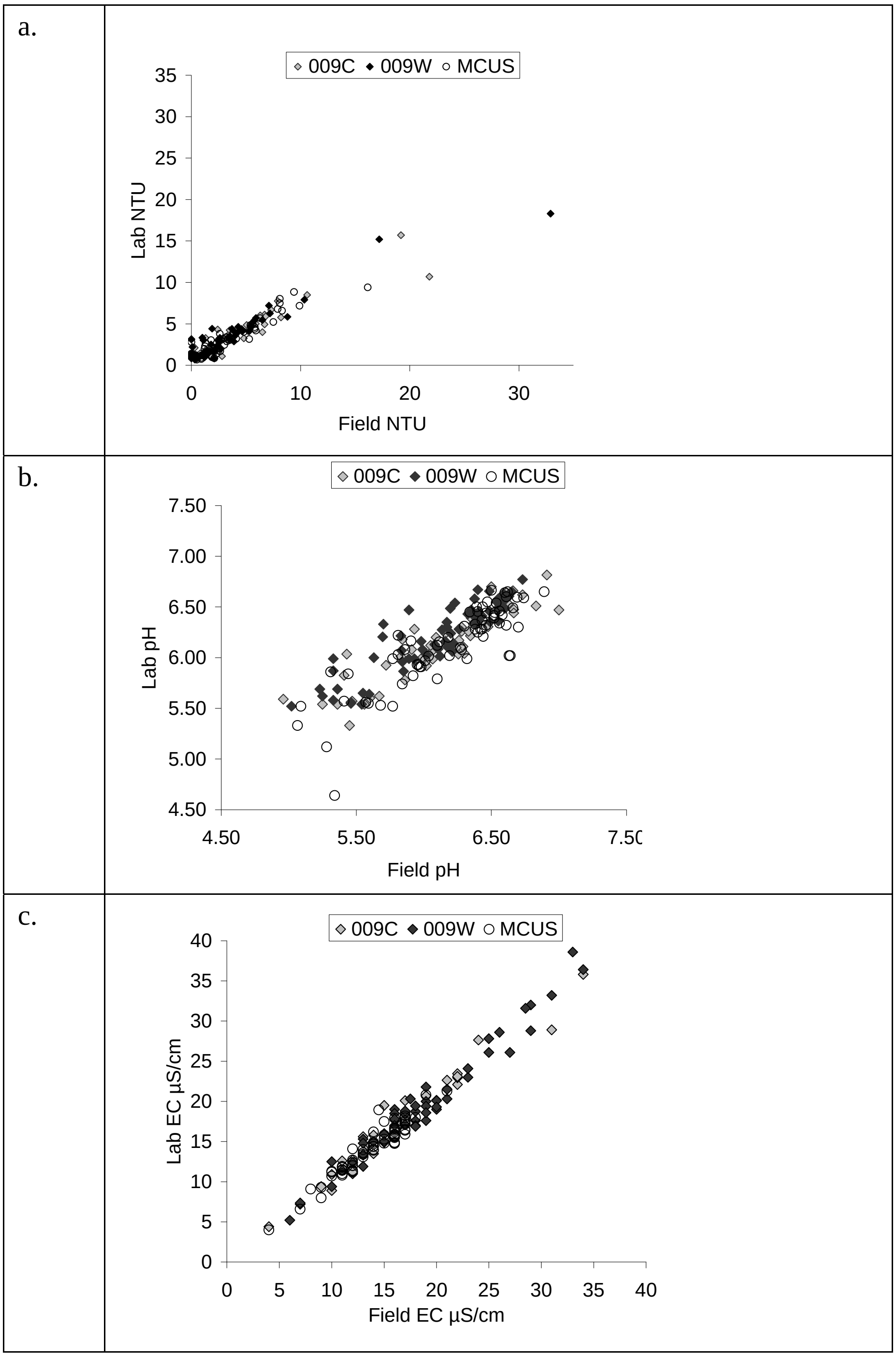


Figure 3 Comparison of field and laboratory (a) turbidity, (b) pH and (c) electrical conductivity measurements from 2006–07 and 2007–08 in Magela Creek. MCUS is the upstream monitoring site and 009C is the downstream compliance monitoring site. 009W is a downstream site adjacent to 009C but closer to the west bank.

Table 5 shows the level of correlation (R^2) and the relative difference between laboratory and field measurements (regression equation of the trend line) for turbidity, pH and EC.

From the linear regression relationships shown in Table 5, if the turbidity is <2 in the field, then the laboratory measurement generally will measure higher by about a half again. This is largely due to the lower accuracy of the field instrument which measures in whole units while the laboratory instrument measures to two decimal places (NTU units). When turbidity is between 2 and 10 NTU, then the laboratory measurements comparatively underestimate by about 25%. As turbidity increases beyond 10 NTU, then agreement with the laboratory measurement decreases further. This is likely an artefact of higher suspended sediment in the sampled water and the inevitable settling and adhering of this sediment to the bottle walls on transfer back to the laboratory. Thus, and as implied above, for turbidity values >2 (ie those that are environmentally relevant), the field measurements will be the more reliable measure.

Table 5 Descriptive statistics of field and laboratory measurements of turbidity, pH and electrical conductivity at the historical routine water chemistry grab sampling sites MCUS (upstream reference), 009C (downstream compliance) and 009W (downstream west channel). All regression equations significant at P<0.001.

Site	R^2	Field (x) and laboratory (y) relationship	Median	Max	Min
Turbidity (NTU)					
MCUS	0.87	y = 0.6459x + 0.9498	(Field) 2.5 (Lab) 2.68	(Field) 16.15 (Lab) 9.4	(Field) 0 (Lab) 0.7
009C	0.86	y = 0.6125x + 1.1847	(Field) 2.4 (Lab) 3.09	(Field) 21.8 (Lab) 15.7	(Field) 0 (Lab) 0.71
009W	0.91	y = 0.5936x + 1.3476	(Field) 2.1 (Lab) 2.7	(Field) 32.9 (Lab) 18.3	(Field) 0 (Lab) 0.71
pH					
MCUS	0.74	y = 0.7787x + 1.3145	(Field) 6.33 (Lab) 6.21	(Field) 6.89 (Lab) 6.67	(Field) 5.07 (Lab) 4.64
009C	0.83	y = 0.7045x + 1.8301	(Field) 6.24 (Lab) 6.2	(Field) 7.00 (Lab) 6.8	(Field) 4.96 (Lab) 5.33
009W	0.80	y = 0.6841x + 2.0469	(Field) 6.20 (Lab) 6.32	(Field) 6.73 (Lab) 6.77	(Field) 5.02 (Lab) 5.52
Electrical Conductivity (µS/cm)					
MCUS	0.91	y = 0.9934x + 0.4545	(Field) 14 (Lab) 14.8	(Field) 21 (Lab) 21.3	(Field) 4 (Lab) 4
009C	0.94	y = 1.0037x + 0.6885	(Field) 18 (Lab) 18.4	(Field) 34 (Lab) 35.8	(Field) 4 (Lab) 4.4
009W	0.96	y = 1.0874x - 0.8558	(Field) 18 (Lab) 19	(Field) 34 (Lab) 38.6	(Field) 6 (Lab) 5.2

Comparison of pH measurements between the field and laboratory instruments show the lowest correlation of the three variables. This is expected as pH alters on standing (in the case of poorly buffered waters such as those characteristic of Magela Creek, pH will rise) and there can be up to an 8 or 9 hour difference between the field measurement and when the sample is measured back in the laboratory. For this reason, more confidence is placed on the measurement of pH in the field using a well-calibrated low ionic pH probe than in a sample transported back to the laboratory and measured a number of hours later on a similarly calibrated pH instrument.

Electrical conductivity, for any EC range typically measured, shows good agreement between the field and laboratory measurements and excellent correlation (Table 5).

Quality assurance of field measurement data

To provide further quality assurance of the field measurement, the field technician now compares the readings measured with the field meter with the recorded measure at the same time by the continuous monitoring sonde. If the data agree within limits set in Table 6 (this process will be reviewed before the 2009–10 season), then the field measurements are recorded as valid and reported to stakeholders. If there is significant disagreement as set out in Table 6, then a sample collected in the field is measured with the laboratory instruments on the same day.

Table 6 Interim guidelines for assessing the quality of the field physicochemical grab data with continuous monitoring data for turbidity, pH and electrical conductivity (EC)

Parameter	If the measure is	Allow for difference up to:
Turbidity	< 5 NTU	± 100%
	≥ 5 NTU	± 20%
	≥ 10 NTU	± 10%
pH	Within water quality guideline values and the relatvie percent difference between upstream and downstream is less than 5%	-0.2 to +0.6 unit of the continuous monitoring pH
EC	< 20 µS/cm	± 20%
	≥ 20 µS/cm	± 10%
	≥ 30 µS/cm	± 5 %

All changes have been incorporated into the Water Chemistry Field and Laboratory Manual.

5 Conclusion

The changes discussed in this report will provide for a more cost efficient and better integrated monitoring program with in situ field toxicity monitoring, continuous physicochemical monitoring and surface water chemistry grab sampling all conducted at the same sites, thereby allowing more reliable comparisons among the three programs.

In the second half of 2009, a review of the surface water chemistry results since the report by Iles (2004) will be undertaken to further enhance our understanding of changing water conditions at Magela Creek and to review our current trigger level framework.

6 Acknowledgements

The authors thank Duncan Buckle and Keith McGuinness for toxicity monitoring data (DB) and their statistical advice.

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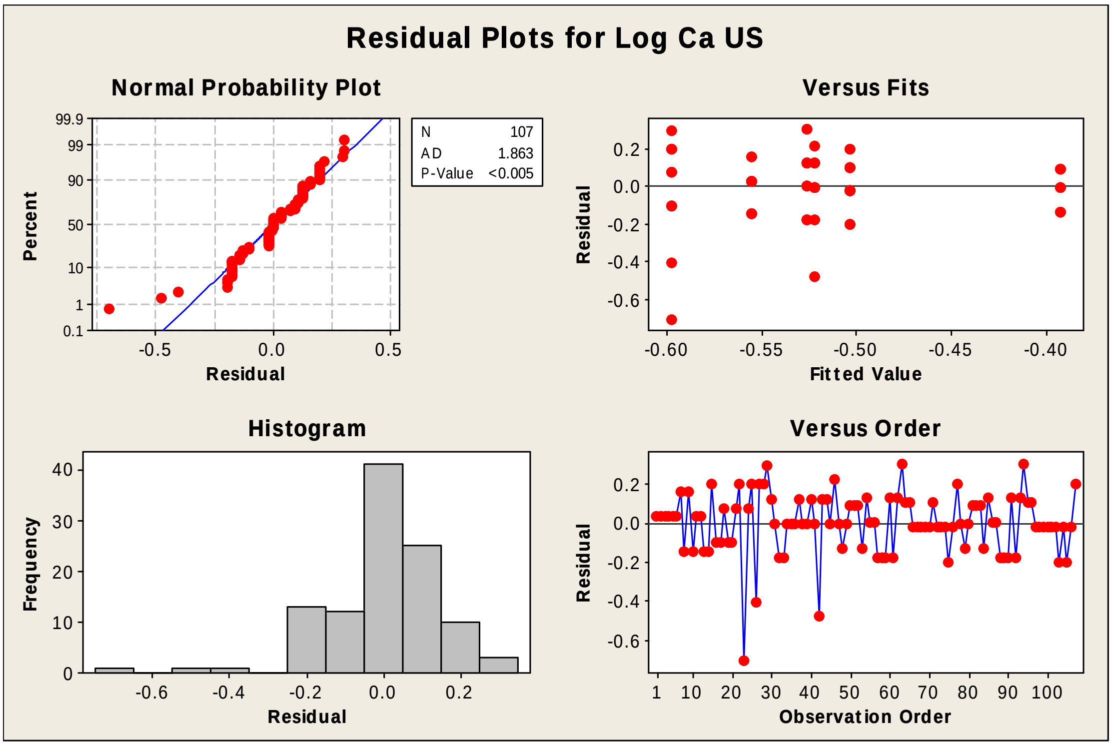
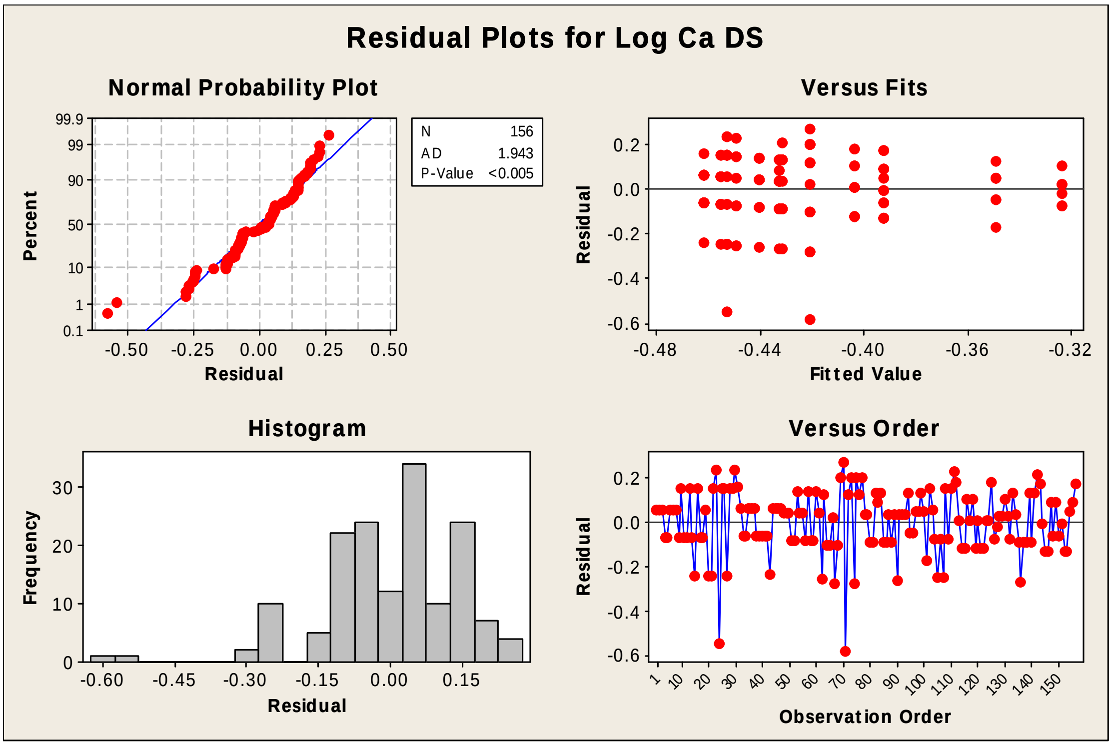
Appendix 1 Minitab residual plots for calcium, uranium, magnesium and sulfate from Magela Creek upstream and downstream sites

(1) Residual plots for calcium (log transformed data)

(a) Upstream

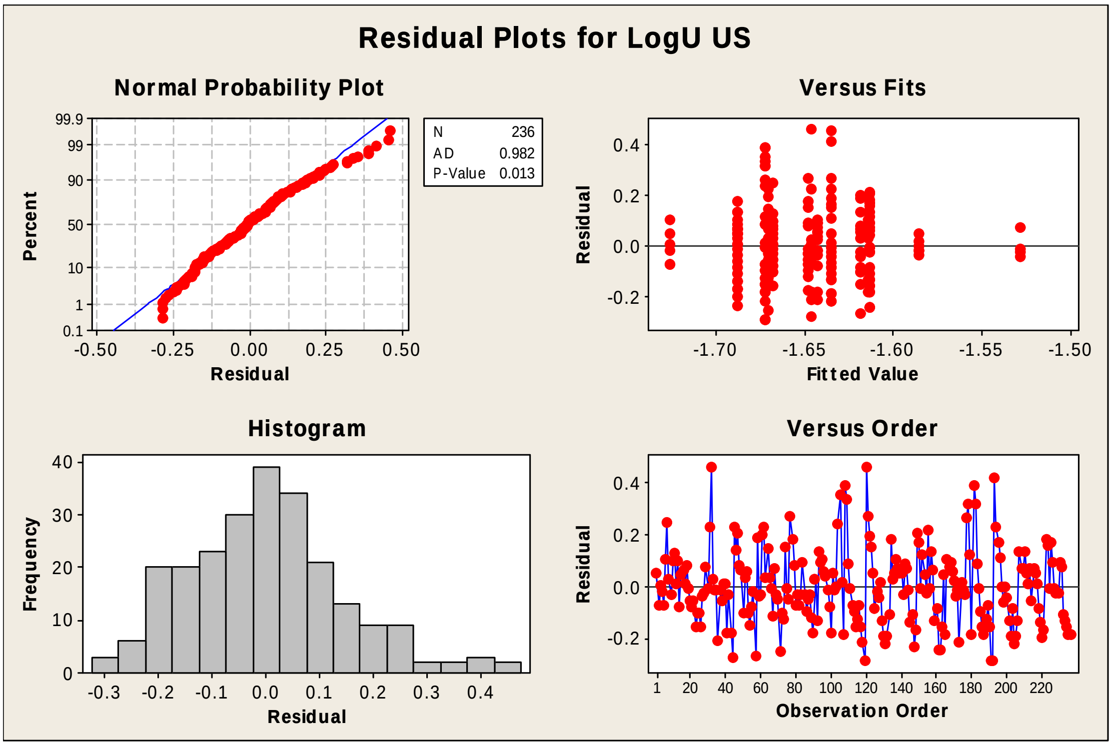


(b) Downstream

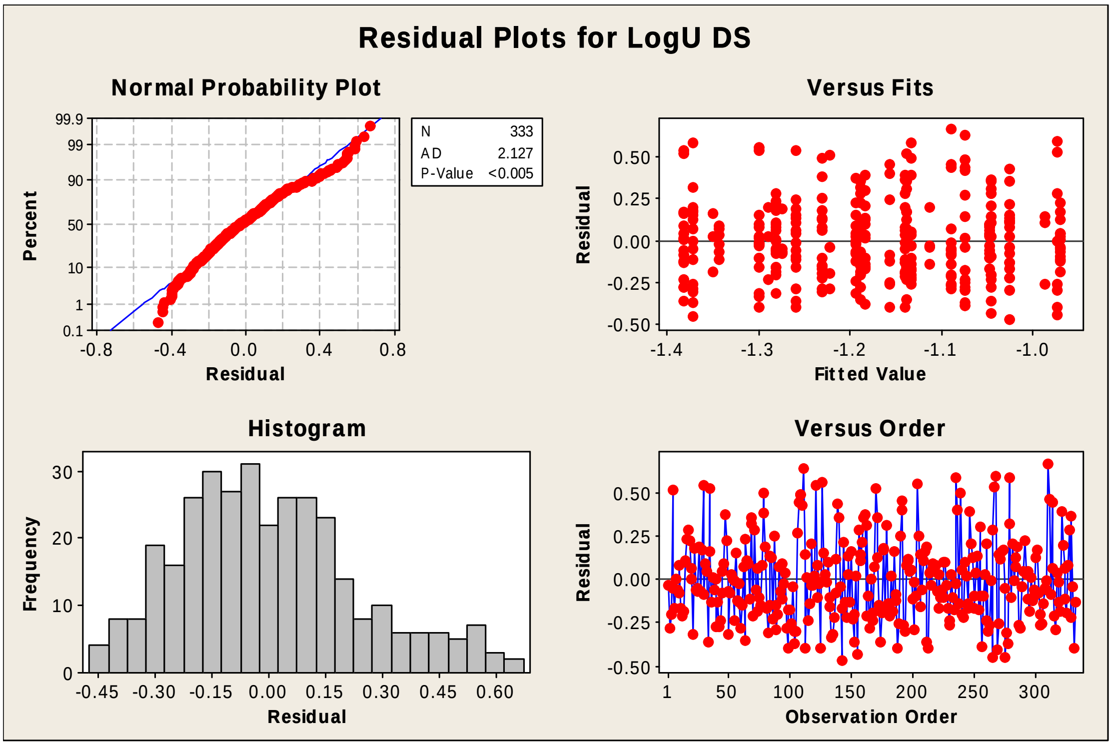


(2) Residual plots for uranium (log transformed data)

(a) Upstream

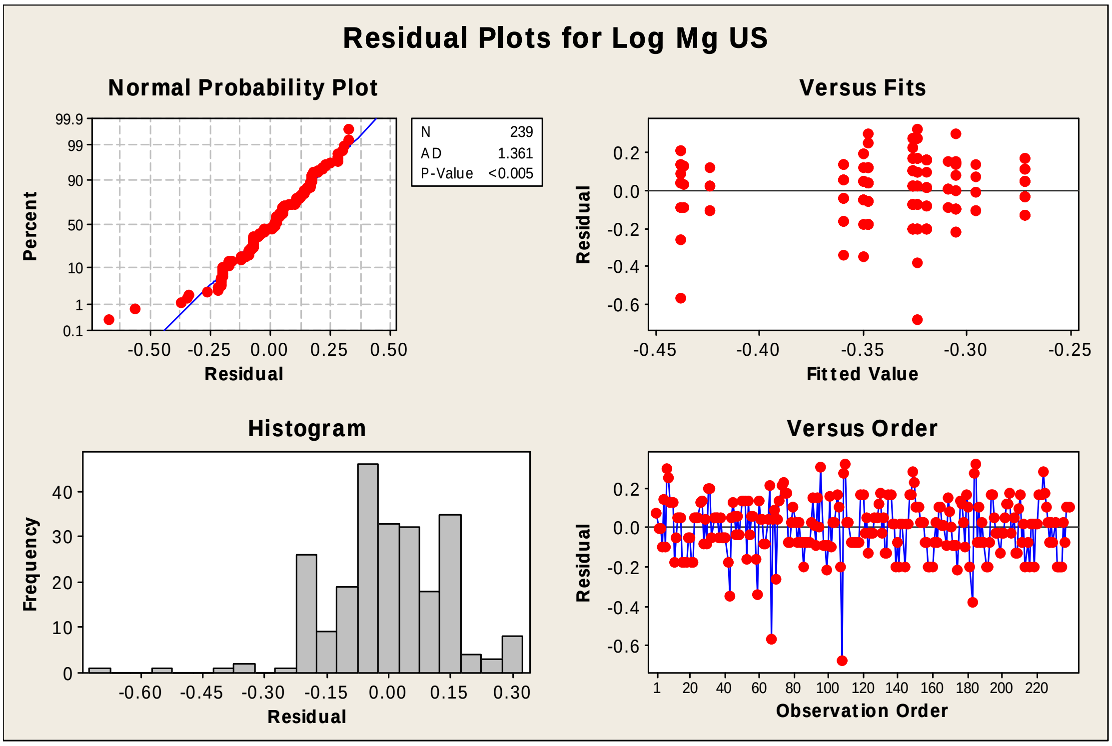


(b) Downstream

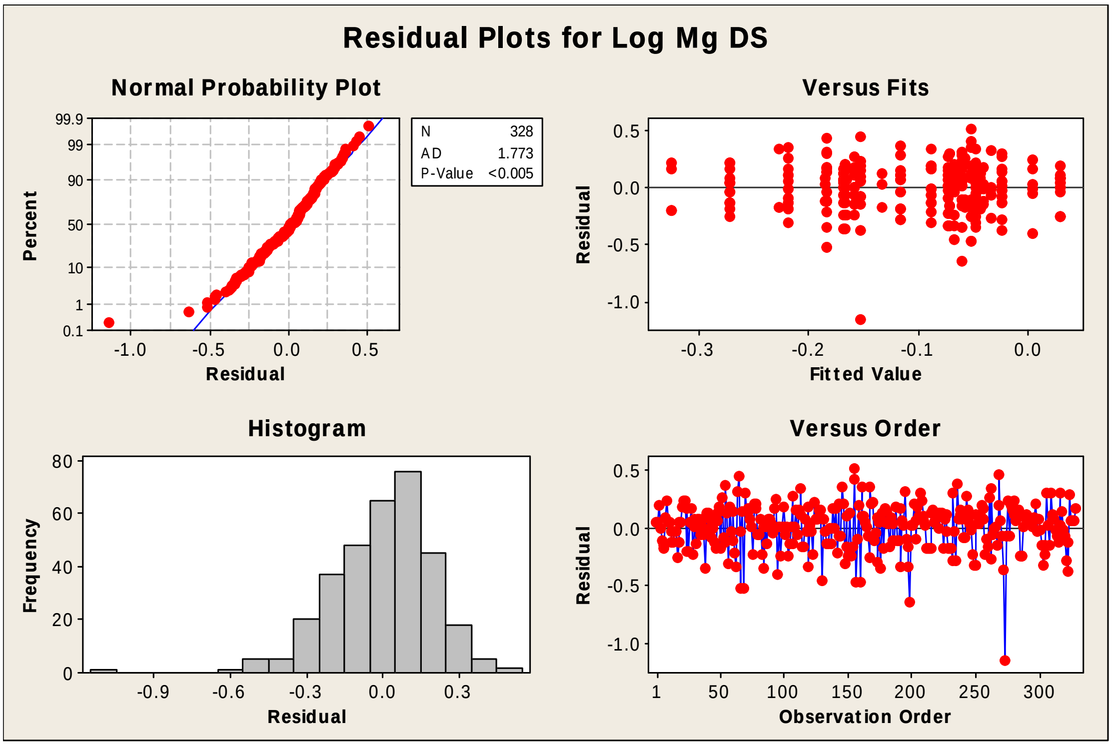


(3) Residual plots for magnesium (log transformed data)

(a) Upstream

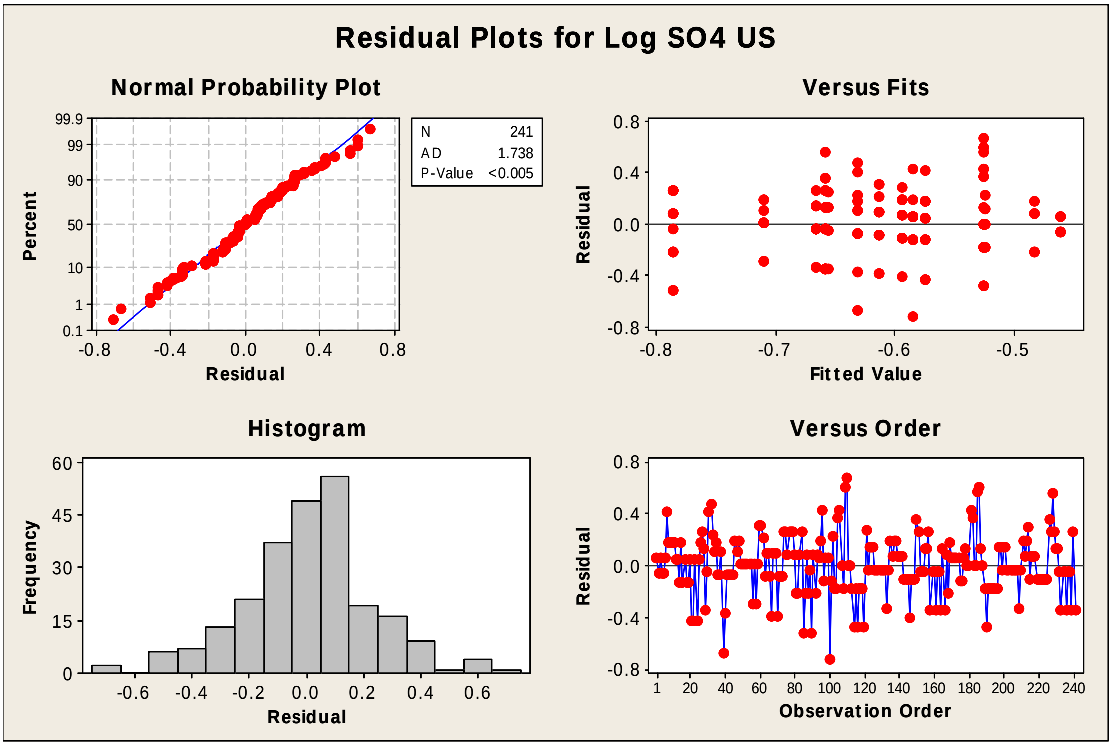


(b) Downstream

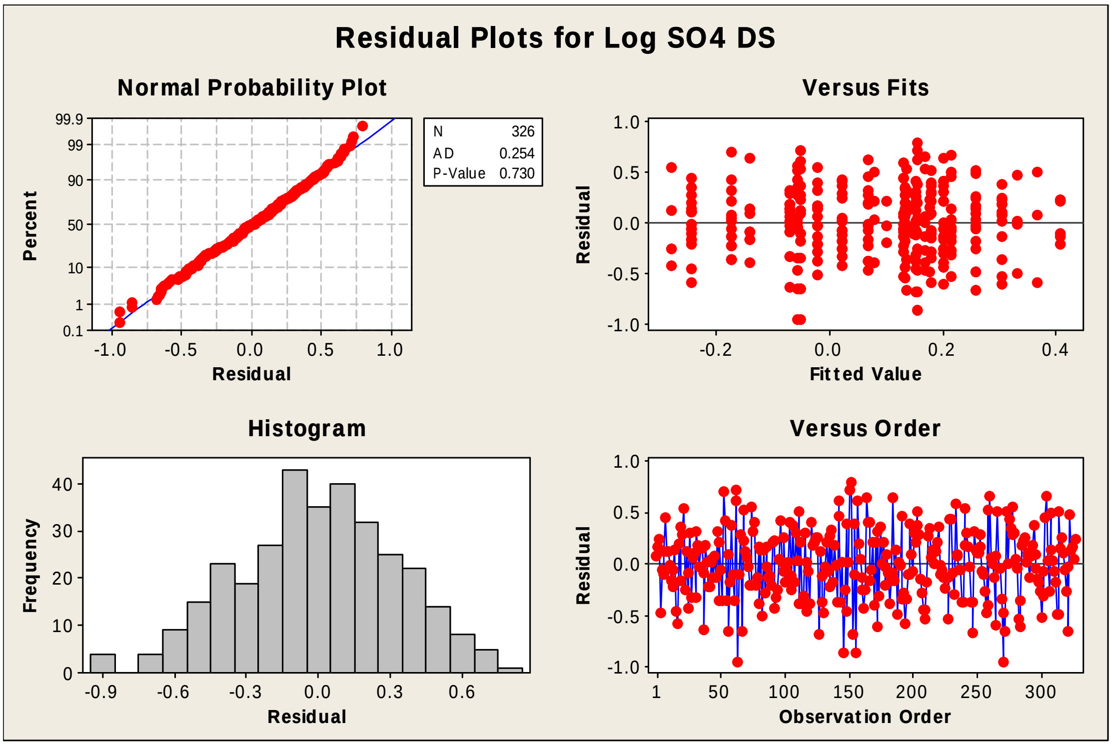


(4) Residual plots for sulfate (log transformed data)

(a) Upstream



(b) Downstream



Appendix 2 Minitab ANOVA (General Linear Model) session outputs for comparison of Magela Creek upstream and downstream sites

Results for: Calcium upstream (US)

General Linear Model: Log Ca US versus Year, USDS

```
Factor  Type   Levels  Values
Year    fixed       3  1, 2, 3
USDS    fixed       2  1, 2


Analysis of Variance for Log Ca US, using Adjusted SS for Tests

Source      DF   Seq SS   Adj SS   Adj MS     F      P
Year         2  0.10839  0.12082  0.06041  2.48  0.089
USDS         1  0.14659  0.18094  0.18094  7.43  0.008
Year*USDS    2  0.08734  0.08734  0.04367  1.79  0.172
Error      101  2.45908  2.45908  0.02435
Total      106  2.80140


S = 0.156036   R-Sq = 12.22%   R-Sq(adj) = 7.87%


Unusual Observations for Log Ca US

Obs  Log Ca US       Fit   SE Fit  Residual  St Resid
 23   -1.30103  -0.59709  0.04029  -0.70394     -4.67 R
 26   -1.00000  -0.59709  0.04029  -0.40291     -2.67 R
 42   -1.00000  -0.52186  0.03784  -0.47814     -3.16 R

R denotes an observation with a large standardized residual.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log Ca US
All Pairwise Comparisons among Levels of Year
Year = 1  subtracted from:

Year    Lower    Center     Upper  --------+---------+---------+--------
2     -0.1821  -0.08768  0.006745  (--------*---------)
3     -0.1292  -0.03865  0.051919       (--------*--------)
                                   --------+---------+---------+--------
                                        -0.10      0.00      0.10

Year = 2  subtracted from:

Year     Lower   Center   Upper  --------+---------+---------+--------
3     -0.03641  0.04904  0.1345              (--------*-------)
                                 --------+---------+---------+--------
                                      -0.10      0.00      0.10

Tukey Simultaneous Tests
Response Variable Log Ca US
All Pairwise Comparisons among Levels of Year
Year = 1  subtracted from:

      Difference       SE of           Adjusted
Year    of Means  Difference  T-Value   P-Value
2       -0.08768     0.03975   -2.206    0.0750
3       -0.03865     0.03812   -1.014    0.5699


Year = 2  subtracted from:

      Difference       SE of           Adjusted
Year    of Means  Difference  T-Value   P-Value
3        0.04904     0.03597    1.363    0.3639
Tukey 95.0% Simultaneous Confidence Intervals
```

```
Response Variable Log Ca US
All Pairwise Comparisons among Levels of USDS
USDS = 1  subtracted from:

USDS    Lower   Center   Upper  ---+---------+---------+---------+---
2     0.02302  0.08453  0.1460  (----------------*-----------------)
                                ---+---------+---------+---------+---
                                 0.035     0.070     0.105     0.140


Tukey Simultaneous Tests
Response Variable Log Ca US
All Pairwise Comparisons among Levels of USDS
USDS = 1  subtracted from:

      Difference       SE of           Adjusted
USDS    of Means  Difference  T-Value   P-Value
2        0.08453     0.03101    2.726    0.0076
```

Results for: Calcium downstream (DS)

General Linear Model: Log Ca DS versus Year, US DS, Side of Stream

```
Factor          Type   Levels  Values
Year            fixed       3  1, 2, 3
US DS           fixed       2  1, 2
Side of Stream  fixed       2  1, 2


Analysis of Variance for Log Ca DS, using Adjusted SS for Tests

Source                       DF   Seq SS   Adj SS   Adj MS     F      P
Year                          2  0.01559  0.04635  0.02317  1.10  0.337
US DS                         1  0.08490  0.09681  0.09681  4.58  0.034
Side of Stream                1  0.01867  0.01666  0.01666  0.79  0.376
Year*Side of Stream           2  0.00041  0.00018  0.00009  0.00  0.996
Year*US DS                    2  0.06985  0.06985  0.03493  1.65  0.195
US DS*Side of Stream          1  0.00082  0.00048  0.00048  0.02  0.881
Year*US DS*Side of Stream     2  0.00129  0.00129  0.00064  0.03  0.970
Error                       144  3.04116  3.04116  0.02112
Total                       155  3.23269


S = 0.145324   R-Sq = 5.92%   R-Sq(adj) = 0.00%


Unusual Observations for Log Ca DS

Obs  Log Ca DS       Fit   SE Fit  Residual  St Resid
 24   -1.00000  -0.45270  0.03752  -0.54730     -3.90 R
 71   -1.00000  -0.42066  0.03752  -0.57934     -4.13 R

R denotes an observation with a large standardized residual.


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log Ca DS
All Pairwise Comparisons among Levels of US DS*Side of Stream
US DS = 1
Side of Stream = 1  subtracted from:

       Side of
US DS  Stream       Lower   Center   Upper
1      2         -0.05283  0.02531  0.1035
2      1         -0.03386  0.05585  0.1456
2      2         -0.01586  0.07384  0.1635
```

```
       Side of
US DS  Stream    --+---------+---------+---------+----
1      2             (-----------*----------)
2      1                (------------*------------)
2      2                   (------------*-----------)
                 --+---------+---------+---------+----
                -0.070     0.000     0.070     0.140


US DS = 1
Side of Stream = 2  subtracted from:

       Side of
US DS  Stream      Lower   Center   Upper
2      1        -0.05917  0.03054  0.1202
2      2        -0.04117  0.04853  0.1382

       Side of
US DS  Stream    --+---------+---------+---------+----
2      1             (-----------*------------)
2      2               (------------*-----------)
                 --+---------+---------+---------+----
                -0.070     0.000     0.070     0.140


US DS = 2
Side of Stream = 1  subtracted from:

       Side of
US DS  Stream      Lower   Center   Upper
2      2        -0.08194  0.01799  0.1179

       Side of
US DS  Stream    --+---------+---------+---------+----
2      2         (--------------*-------------)
                 --+---------+---------+---------+----
                -0.070     0.000     0.070     0.140


Tukey Simultaneous Tests
Response Variable Log Ca DS
All Pairwise Comparisons among Levels of US DS*Side of Stream
US DS = 1
Side of Stream = 1  subtracted from:

       Side of  Difference       SE of            Adjusted
US DS  Stream     of Means  Difference  T-Value   P-Value
1      2           0.02531     0.03003   0.8429    0.8339
2      1           0.05585     0.03447   1.6201    0.3706
2      2           0.07384     0.03447   2.1420    0.1449


US DS = 1
Side of Stream = 2  subtracted from:

       Side of  Difference       SE of            Adjusted
US DS  Stream     of Means  Difference  T-Value   P-Value
2      1           0.03054     0.03447   0.8858    0.8122
2      2           0.04853     0.03447   1.4078    0.4966


US DS = 2
Side of Stream = 1  subtracted from:

       Side of  Difference       SE of            Adjusted
US DS  Stream     of Means  Difference  T-Value   P-Value
2      2           0.01799     0.03841   0.4685    0.9658
```

Results for: Uranium US

General Linear Model: LogU US versus Year, UsDs

Factor	Type	Levels	Values
Year	fixed	7	1, 2, 3, 4, 5, 6, 7
UsDs	fixed	2	1, 2

Analysis of Variance for LogU US, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	6	0.18025	0.15733	0.02622	1.19	0.311
UsDs	1	0.00072	0.00234	0.00234	0.11	0.744
Year*UsDs	6	0.07433	0.07433	0.01239	0.56	0.759
Error	222	4.88130	4.88130	0.02199		
Total	235	5.13660				

S = 0.148283   R-Sq = 4.97%   R-Sq(adj) = 0.00%

Unusual Observations for LogU US

Obs	LogU US	Fit	SE Fit	Residual	St Resid	
27	-1.56864	-1.52875	0.07414	-0.03988	-0.31	X
28	-1.55284	-1.52875	0.07414	-0.02409	-0.19	X
29	-1.45593	-1.52875	0.07414	0.07282	0.57	X
30	-1.53760	-1.52875	0.07414	-0.00885	-0.07	X
32	-1.18709	-1.64639	0.03829	0.45930	3.21	R
105	-1.31876	-1.67181	0.02621	0.35305	2.42	R
108	-1.28400	-1.67181	0.02621	0.38781	2.66	R
109	-1.33724	-1.67181	0.02621	0.33457	2.29	R
120	-1.18046	-1.63525	0.02802	0.45479	3.12	R
178	-1.35655	-1.67181	0.02621	0.31526	2.16	R
181	-1.28400	-1.67181	0.02621	0.38781	2.66	R
182	-1.35655	-1.67181	0.02621	0.31526	2.16	R
193	-1.22185	-1.63525	0.02802	0.41340	2.84	R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Results for: Uranium DS

General Linear Model: LogU DS versus Year, UsDs, SideOfstream

Factor	Type	Levels	Values
Year	fixed	7	1, 2, 3, 4, 5, 6, 7
UsDs	fixed	2	1, 2
SideOfstream	fixed	2	1, 2

Analysis of Variance for LogU DS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	6	2.88160	2.95307	0.49218	8.03	0.000
UsDs	1	0.21559	0.19525	0.19525	3.19	0.075
SideOfstream	1	0.58448	0.32154	0.32154	5.25	0.023
Year*UsDs	6	0.22480	0.23237	0.03873	0.63	0.705
Year*SideOfstream	6	0.44087	0.37354	0.06226	1.02	0.415
UsDs*SideOfstream	1	0.14182	0.04436	0.04436	0.72	0.396
Year*UsDs*SideOfstream	6	0.13171	0.13171	0.02195	0.36	0.905
Error	305	18.69093	18.69093	0.06128		
Total	332	23.31180				

S = 0.247552   R-Sq = 19.82%   R-Sq(adj) = 12.72%

Unusual Observations for LogU DS

Obs	LogU DS	Fit	SE Fit	Residual	St Resid	
4	-0.70333	-1.22296	0.12378	0.51962	2.42	R
29	-0.83863	-1.38214	0.06189	0.54351	2.27	R
34	-0.85699	-1.38214	0.06189	0.52516	2.19	R
78	-0.73283	-1.23113	0.06004	0.49830	2.07	R
108	-0.58336	-1.07530	0.05679	0.49194	2.04	R
109	-0.58670	-1.07530	0.05679	0.48860	2.03	R
111	-0.43533	-1.07530	0.05679	0.63997	2.66	R
121	-0.75696	-1.30110	0.06189	0.54414	2.27	R
126	-0.74232	-1.30110	0.06189	0.55878	2.33	R
170	-0.60995	-1.13784	0.06004	0.52789	2.20	R
183	-1.32790	-1.35086	0.14292	0.02296	0.11	X
184	-1.53760	-1.35086	0.14292	-0.18674	-0.92	X
185	-1.18709	-1.35086	0.14292	0.16378	0.81	X
204	-0.71220	-1.25999	0.06189	0.54779	2.29	R
236	-0.54516	-1.13366	0.06392	0.58850	2.46	R
239	-0.63639	-1.13366	0.06392	0.49727	2.08	R
259	-1.25964	-1.28957	0.14292	0.02993	0.15	X
260	-1.52288	-1.28957	0.14292	-0.23331	-1.15	X
261	-1.08619	-1.28957	0.14292	0.20338	1.01	X
267	-0.43771	-0.97385	0.08752	0.53614	2.32	R
268	-0.37675	-0.97385	0.08752	0.59710	2.58	R
270	-1.24413	-0.98622	0.14292	-0.25791	-1.28	X
271	-0.84164	-0.98622	0.14292	0.14458	0.72	X
272	-0.87290	-0.98622	0.14292	0.11332	0.56	X
279	-0.78252	-1.37306	0.06189	0.59054	2.46	R
311	-0.42022	-1.08999	0.06392	0.66977	2.80	R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable LogU DS
All Pairwise Comparisons among Levels of UsDs*SideOfstream
UsDs = 1
SideOfstream = 1 subtracted from:

UsDs	SideOfstream	Lower	Center	Upper
1	2	-0.00756	0.10477	0.2171
2	1	-0.03316	0.08791	0.2090
2	2	0.01206	0.13592	0.2598

```
UsDs  SideOfstream    -+---------+---------+---------+-----
1     2                         (---------*--------)
2     1                       (---------*---------)
2     2                             (---------*---------)
                      -+---------+---------+---------+-----
                    -0.12      0.00      0.12      0.24
```

UsDs = 1
SideOfstream = 2 subtracted from:

UsDs	SideOfstream	Lower	Center	Upper
2	1	-0.1351	-0.01686	0.1013
2	2	-0.0899	0.03115	0.1522

```
UsDs  SideOfstream    -+---------+---------+---------+-----
2     1               (---------*--------)
2     2                   (---------*---------)
```

```
                    -+---------+---------+---------+-----
                  -0.12      0.00      0.12      0.24


UsDs = 2
SideOfstream = 1  subtracted from:

UsDs  SideOfstream     Lower   Center   Upper
2     2             -0.08119  0.04802  0.1772

UsDs  SideOfstream    -+---------+---------+---------+-----
2     2                   (----------*----------)
                      -+---------+---------+---------+-----
                    -0.12      0.00      0.12      0.24


Tukey Simultaneous Tests
Response Variable LogU DS
All Pairwise Comparisons among Levels of UsDs*SideOfstream
UsDs = 1
SideOfstream = 1  subtracted from:

                    Difference       SE of           Adjusted
UsDs  SideOfstream    of Means  Difference  T-Value   P-Value
1     2                0.10477     0.04376    2.394    0.0782
2     1                0.08791     0.04717    1.864    0.2438
2     2                0.13592     0.04826    2.817    0.0250


UsDs = 1
SideOfstream = 2  subtracted from:

                    Difference       SE of           Adjusted
UsDs  SideOfstream    of Means  Difference  T-Value   P-Value
2     1               -0.01686     0.04605  -0.3662    0.9832
2     2                0.03115     0.04717   0.6605    0.9119


UsDs = 2
SideOfstream = 1  subtracted from:

                    Difference       SE of           Adjusted
UsDs  SideOfstream    of Means  Difference  T-Value   P-Value
2     2                0.04802     0.05034   0.9539    0.7756
```

Results for: Magnesium upstream

General Linear Model: Log Mg US versus Year, UsDS

```
Factor  Type   Levels  Values
Year    fixed       7  1, 2, 3, 4, 5, 6, 7
UsDS    fixed       2  1, 2


Analysis of Variance for Log Mg US, using Adjusted SS for Tests

Source      DF   Seq SS   Adj SS   Adj MS     F      P
Year         6  0.17707  0.18818  0.03136  1.45  0.198
UsDS         1  0.11969  0.05915  0.05915  2.73  0.100
Year*UsDS    6  0.10550  0.10550  0.01758  0.81  0.562
Error      225  4.87960  4.87960  0.02169
Total      238  5.28187


S = 0.147266   R-Sq = 7.62%   R-Sq(adj) = 2.28%
```

Unusual Observations for Log Mg US

Obs	Log Mg US	Fit	SE Fit	Residual	St Resid	
7	-0.04576	-0.34727	0.03293	0.30152	2.10	R
27	-0.30103	-0.43618	0.07363	0.13515	1.06	X
28	-0.52288	-0.43618	0.07363	-0.08670	-0.68	X
29	-0.39794	-0.43618	0.07363	0.03824	0.30	X
30	-0.52288	-0.43618	0.07363	-0.08670	-0.68	X
43	-0.69897	-0.34989	0.03802	-0.34908	-2.45	R
59	-0.69897	-0.35929	0.03936	-0.33968	-2.39	R
67	-1.00000	-0.43764	0.03936	-0.56236	-3.96	R
96	0.00000	-0.30521	0.03682	0.30521	2.14	R
108	-1.00000	-0.32373	0.02603	-0.67627	-4.67	R
110	0.00000	-0.32373	0.02603	0.32373	2.23	R
183	-0.69897	-0.32373	0.02603	-0.37524	-2.59	R
185	0.00000	-0.32373	0.02603	0.32373	2.23	R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Results for: Magnesium DS

General Linear Model: Log Mg DS versus Year, UsDS, Side of stream

Factor	Type	Levels	Values
Year	fixed	7	1, 2, 3, 4, 5, 6, 7
UsDS	fixed	2	1, 2
Side of stream	fixed	2	1, 2

Analysis of Variance for Log Mg DS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	6	0.54308	0.30002	0.05000	1.20	0.309
UsDS	1	0.24030	0.14334	0.14334	3.43	0.065
Side of stream	1	0.43391	0.29215	0.29215	6.98	0.009
Year*UsDS	6	0.36253	0.36674	0.06112	1.46	0.191
Year*Side of stream	6	0.16445	0.13967	0.02328	0.56	0.765
UsDS*Side of stream	1	0.14593	0.04635	0.04635	1.11	0.293
Year*UsDS*Side of stream	6	0.08660	0.08660	0.01443	0.34	0.913
Error	300	12.55205	12.55205	0.04184		
Total	327	14.52886				

S = 0.204549   R-Sq = 13.61%   R-Sq(adj) = 5.83%

Unusual Observations for Log Mg DS

Obs	Log Mg DS	Fit	SE Fit	Residual	St Resid	
65	0.25527	-0.18313	0.05281	0.43840	2.22	R
66	-0.69897	-0.18313	0.05281	-0.51584	-2.61	R
69	-0.69897	-0.18313	0.05281	-0.51584	-2.61	R
95	-0.39794	0.00484	0.08351	-0.40278	-2.16	R
114	0.11394	-0.22731	0.11810	0.34126	2.04	RX
115	-0.39794	-0.22731	0.11810	-0.17063	-1.02	X
116	-0.39794	-0.22731	0.11810	-0.17063	-1.02	X
130	-0.52288	-0.06705	0.04961	-0.45583	-2.30	R
155	0.36173	-0.05145	0.05281	0.41318	2.09	R
156	0.46240	-0.05145	0.05281	0.51385	2.60	R
157	-0.52288	-0.05145	0.05281	-0.47143	-2.39	R
160	-0.52288	-0.05145	0.05281	-0.47143	-2.39	R
181	0.00000	-0.13265	0.11810	0.13265	0.79	X

```
182   -0.09691  -0.13265  0.11810   0.03574      0.21  X
183   -0.30103  -0.13265  0.11810  -0.16838     -1.01  X
184   -0.09691  -0.18428  0.11810   0.08737      0.52  X
185   -0.15490  -0.18428  0.11810   0.02938      0.18  X
186   -0.30103  -0.18428  0.11810  -0.11675     -0.70  X
199   -0.69897  -0.06024  0.04574  -0.63873     -3.20  R
256    0.00000  -0.16495  0.11810   0.16495      0.99  X
257   -0.09691  -0.16495  0.11810   0.06804      0.41  X
258   -0.39794  -0.16495  0.11810  -0.23299     -1.40  X
259   -0.15490  -0.05754  0.11810  -0.09736     -0.58  X
260   -0.22185  -0.05754  0.11810  -0.16431     -0.98  X
261    0.20412  -0.05754  0.11810   0.26166      1.57  X
269    0.30103  -0.15308  0.04821   0.45411      2.28  R
273   -1.30103  -0.15308  0.04821  -1.14795     -5.77  R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log Mg DS
All Pairwise Comparisons among Levels of UsDS*Side of stream
UsDS = 1
Side of stream = 1  subtracted from:

      Side of
UsDS  stream      Lower   Center   Upper  ---+---------+---------+---------
+---
1     2         0.01201  0.10510  0.1982              (---------*--------)
2     1        -0.01959  0.08258  0.1848           (---------*---------)
2     2         0.02548  0.12781  0.2301                (---------*-------
--)
                                          ---+---------+---------+---------
+---
                                          -0.10      0.00      0.10
0.20


UsDS = 1
Side of stream = 2  subtracted from:

      Side of
UsDS  stream     Lower    Center    Upper
2     1        -0.1267  -0.02251  0.08165
2     2        -0.0816   0.02271  0.12702

      Side of
UsDS  stream   ---+---------+---------+---------+---
2     1        (----------*---------)
2     2             (---------*----------)
               ---+---------+---------+---------+---
               -0.10      0.00      0.10      0.20


UsDS = 2
Side of stream = 1  subtracted from:

      Side of
UsDS  stream      Lower   Center   Upper  ---+---------+---------+---------
+---
2     2        -0.06727  0.04522  0.1577        (-----------*----------)
                                          ---+---------+---------+---------
+---
                                          -0.10      0.00      0.10
0.20


Tukey Simultaneous Tests
```

Response Variable Log Mg DS
All Pairwise Comparisons among Levels of UsDS*Side of stream
UsDS = 1
Side of stream = 1 subtracted from:

UsDS	Side of stream	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
1	2	0.10510	0.03627	2.898	0.0197
2	1	0.08258	0.03981	2.075	0.1614
2	2	0.12781	0.03987	3.206	0.0074

UsDS = 1
Side of stream = 2 subtracted from:

UsDS	Side of stream	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2	1	-0.02251	0.04058	-0.5548	0.9453
2	2	0.02271	0.04064	0.5588	0.9442

UsDS = 2
Side of stream = 1 subtracted from:

UsDS	Side of stream	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2	2	0.04522	0.04383	1.032	0.7307

Results for: Sulfate US

General Linear Model: Log SO4 US versus Year, UsDS

Factor	Type	Levels	Values
Year	fixed	7	1, 2, 3, 4, 5, 6, 7
UsDS	fixed	2	1, 2

Analysis of Variance for Log SO4 US, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	6	1.02061	1.04507	0.17418	3.31	0.004
UsDS	1	0.19897	0.12607	0.12607	2.39	0.123
Year*UsDS	6	0.16934	0.16934	0.02822	0.54	0.781
Error	227	11.95729	11.95729	0.05268		
Total	240	13.34621				

S = 0.229511 R-Sq = 10.41% R-Sq(adj) = 5.28%

Unusual Observations for Log SO4 US

Obs	Log SO4 US	Fit	SE Fit	Residual	St Resid	
27	-0.39794	-0.65495	0.11476	0.25701	1.29	X
28	-0.52288	-0.65495	0.11476	0.13207	0.66	X
29	-1.00000	-0.65495	0.11476	-0.34505	-1.74	X
30	-0.69897	-0.65495	0.11476	-0.04402	-0.22	X
32	-0.15490	-0.63135	0.05926	0.47644	2.15	R
39	-1.30103	-0.63135	0.05926	-0.66968	-3.02	R
85	-1.30103	-0.78583	0.05566	-0.51520	-2.31	R
90	-1.30103	-0.78583	0.05566	-0.51520	-2.31	R
100	-1.30103	-0.58473	0.05738	-0.71630	-3.22	R
109	0.07918	-0.52436	0.04057	0.60354	2.67	R
110	0.14613	-0.52436	0.04057	0.67049	2.97	R
114	-1.00000	-0.52436	0.04057	-0.47564	-2.11	R

```
116    -1.00000  -0.52436  0.04057  -0.47564     -2.11 R
120    -1.00000  -0.52436  0.04057  -0.47564     -2.11 R
185     0.04139  -0.52436  0.04057   0.56575      2.50 R
186     0.07918  -0.52436  0.04057   0.60354      2.67 R
190    -1.00000  -0.52436  0.04057  -0.47564     -2.11 R
228    -0.09691  -0.65729  0.03995   0.56038      2.48 R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log SO4 US
All Pairwise Comparisons among Levels of Year
Year = 1  subtracted from:

Year    Lower   Center     Upper  ----+---------+---------+---------+--
2     -0.3361  -0.1080   0.12011         (-----------*----------)
3     -0.4139  -0.1181   0.17776     (--------------*--------------)
4     -0.3309  -0.1066   0.11776         (-----------*----------)
5     -0.4433  -0.2165   0.01020    (----------*-----------)
6     -0.3579  -0.1318   0.09436        (----------*-----------)
7     -0.4723  -0.2503  -0.02825  (----------*-----------)
                                  ----+---------+---------+---------+--
                                   -0.40     -0.20     -0.00      0.20


Year = 2  subtracted from:

Year    Lower   Center    Upper  ----+---------+---------+---------+--
3     -0.2586  -0.0101  0.23840           (-----------*------------)
4     -0.1553   0.0014  0.15811                (-------*-------)
5     -0.2686  -0.1085  0.05156           (-------*-------)
6     -0.1830  -0.0238  0.13546               (-------*-------)
7     -0.2957  -0.1423  0.01109         (-------*-------)
                                 ----+---------+---------+---------+--
                                  -0.40     -0.20     -0.00      0.20


Year = 3  subtracted from:

Year    Lower   Center   Upper  ----+---------+---------+---------+--
4     -0.2335   0.0115  0.2566            (------------*-----------)
5     -0.3457  -0.0984  0.1488       (-----------*-----------)
6     -0.2603  -0.0137  0.2330           (-----------*------------)
7     -0.3752  -0.1322  0.1108     (-----------*------------)
                                ----+---------+---------+---------+--
                                 -0.40     -0.20     -0.00      0.20


Year = 4  subtracted from:

Year    Lower   Center     Upper  ----+---------+---------+---------+--
5     -0.2646  -0.1099  0.044753            (-------*------)
6     -0.1790  -0.0252  0.128624                (-------*------)
7     -0.2915  -0.1437  0.004036          (-------*------)
                                  ----+---------+---------+---------+--
                                   -0.40     -0.20     -0.00      0.20


Year = 5  subtracted from:

Year    Lower    Center   Upper  ----+---------+---------+---------+--
6     -0.0725   0.08477  0.2420                     (-------*-------)
7     -0.1851  -0.03377  0.1176                (------*-------)
                                 ----+---------+---------+---------+--
                                  -0.40     -0.20     -0.00      0.20
```

```
Year = 6  subtracted from:

Year    Lower   Center    Upper  ----+---------+---------+---------+--
7     -0.2690  -0.1185  0.03189            (------*-------)
                                 ----+---------+---------+---------+--
                                  -0.40     -0.20     -0.00      0.20
```

Tukey Simultaneous Tests
Response Variable Log SO4 US
All Pairwise Comparisons among Levels of Year
Year = 1 subtracted from:

Year	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2	-0.1080	0.07662	-1.409	0.7964
3	-0.1181	0.09938	-1.188	0.8980
4	-0.1066	0.07536	-1.414	0.7937
5	-0.2165	0.07616	-2.843	0.0715
6	-0.1318	0.07596	-1.735	0.5935
7	-0.2503	0.07459	-3.356	0.0160

Year = 2 subtracted from:

Year	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3	-0.0101	0.08348	-0.121	1.0000
4	0.0014	0.05264	0.027	1.0000
5	-0.1085	0.05378	-2.018	0.4061
6	-0.0238	0.05349	-0.444	0.9994
7	-0.1423	0.05153	-2.762	0.0883

Year = 3 subtracted from:

Year	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4	0.0115	0.08232	0.140	1.0000
5	-0.0984	0.08305	-1.185	0.8992
6	-0.0137	0.08286	-0.165	1.0000
7	-0.1322	0.08161	-1.620	0.6697

Year = 4 subtracted from:

Year	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
5	-0.1099	0.05197	-2.116	0.3470
6	-0.0252	0.05166	-0.487	0.9990
7	-0.1437	0.04963	-2.896	0.0622

Year = 5 subtracted from:

Year	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
6	0.08477	0.05283	1.6047	0.6794
7	-0.03377	0.05084	-0.6642	0.9944

Year = 6 subtracted from:

Year	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
7	-0.1185	0.05053	-2.346	0.2271

Results for: Sulphate DS

General Linear Model: Log SO4 DS versus Year, UsDS, Side of stream

Factor	Type	Levels	Values
Year	fixed	7	1, 2, 3, 4, 5, 6, 7
UsDS	fixed	2	1, 2
Side of stream	fixed	2	1, 2

Analysis of Variance for Log SO4 DS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	6	1.8581	1.3561	0.2260	1.88	0.083
UsDS	1	1.3236	0.9616	0.9616	8.02	0.005
Side of stream	1	2.0093	1.4592	1.4592	12.16	0.001
Year*UsDS	6	1.1855	1.1949	0.1991	1.66	0.131
Year*Side of stream	6	0.6731	0.6403	0.1067	0.89	0.503
UsDS*Side of stream	1	0.5367	0.4207	0.4207	3.51	0.062
Year*UsDS*Side of stream	6	0.5190	0.5190	0.0865	0.72	0.633
Error	298	35.7462	35.7462	0.1200		
Total	325	43.8516				

S = 0.346344   R-Sq = 18.48%   R-Sq(adj) = 11.10%

Unusual Observations for Log SO4 DS

Obs	Log SO4 DS	Fit	SE Fit	Residual	St Resid	
53	0.53148	-0.17273	0.08943	0.70421	2.10	R
63	0.67210	-0.05111	0.08943	0.72321	2.16	R
64	-1.00000	-0.05111	0.08943	-0.94889	-2.84	R
127	-0.52288	0.15341	0.08943	-0.67629	-2.02	R
146	-0.69897	0.15671	0.08943	-0.85568	-2.56	R
151	0.87506	0.15671	0.08943	0.71835	2.15	R
152	0.94939	0.15671	0.08943	0.79268	2.37	R
153	-0.52288	0.15671	0.08943	-0.67959	-2.03	R
156	-0.69897	0.15671	0.08943	-0.85568	-2.56	R
177	0.32222	0.10150	0.19996	0.22072	0.78	X
178	0.07918	0.10150	0.19996	-0.02232	-0.08	X
179	-0.09691	0.10150	0.19996	-0.19841	-0.70	X
253	0.32222	0.14760	0.19996	0.17462	0.62	X
254	0.07918	0.14760	0.19996	-0.06842	-0.24	X
255	0.04139	0.14760	0.19996	-0.10621	-0.38	X
260	0.82607	0.16915	0.12245	0.65693	2.03	R
264	-0.22185	0.36871	0.19996	-0.59056	-2.09	RX
265	0.44716	0.36871	0.19996	0.07845	0.28	X
266	0.88081	0.36871	0.19996	0.51211	1.81	X
270	-1.00000	-0.05478	0.08943	-0.94522	-2.82	R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Log SO4 DS
All Pairwise Comparisons among Levels of UsDS*Side of stream
UsDS = 1
Side of stream = 1 subtracted from:

UsDS	Side of stream	Lower	Center	Upper
1	2	0.09305	0.2504	0.4078
2	1	0.04988	0.2197	0.3896
2	2	0.12122	0.2952	0.4692

```
      Side of
UsDS  stream      +---------+---------+---------+------
1     2                          (-------*------)
2     1                       (--------*-------)
2     2                           (--------*-------)
                  +---------+---------+---------+------
               -0.20      0.00      0.20      0.40
```

UsDS = 1
Side of stream = 2 subtracted from:

UsDS	Side of stream	Lower	Center	Upper
2	1	-0.1957	-0.03066	0.1344
2	2	-0.1245	0.04478	0.2141

```
      Side of
UsDS  stream      +---------+---------+---------+------
2     1           (-------*--------)
2     2               (-------*--------)
                  +---------+---------+---------+------
               -0.20      0.00      0.20      0.40
```

UsDS = 2
Side of stream = 1 subtracted from:

UsDS	Side of stream	Lower	Center	Upper
2	2	-0.1055	0.07544	0.2564

```
      Side of
UsDS  stream      +---------+---------+---------+------
2     2                (--------*--------)
                  +---------+---------+---------+------
               -0.20      0.00      0.20      0.40
```

Tukey Simultaneous Tests
Response Variable Log SO4 DS
All Pairwise Comparisons among Levels of UsDS*Side of stream
UsDS = 1
Side of stream = 1 subtracted from:

UsDS	Side of stream	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
1	2	0.2504	0.06131	4.085	0.0003
2	1	0.2197	0.06618	3.321	0.0050
2	2	0.2952	0.06778	4.355	0.0001

UsDS = 1
Side of stream = 2 subtracted from:

UsDS	Side of stream	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2	1	-0.03066	0.06430	-0.4768	0.9642
2	2	0.04478	0.06595	0.6790	0.9051

UsDS = 2
Side of stream = 1 subtracted from:

UsDS	Side of stream	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2	2	0.07544	0.07050	1.070	0.7078