Understanding Total Dissolved Solids in Selected Streams of the Independence Mountains of Nevada

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Summary

Operational and regulatory decisions depend on insights and knowledge gained from analyses of data collected in compliance with water quality permit conditions. These data need to be set in their spatial and temporal contexts and associated with aquatic biota, beneficial uses of the waters after leaving the project boundaries, and the geomorphic settings through which they flow. This report on the relationships of total dissolved solids (TDS) with selected minerals from a sample of streams on both sides of the Independence Mountains is the first aspect to be analyzed and reported.

Total dissolved solids (TDS) is not a pollutant. It is considered an æsthetic issue in drinking water (as a secondary standard) and might affect crops depending on the plant, soil, and constituents contributing to TDS in irrigation water. Aquatic organisms are well adapted to temporal and spatial variation in TDS concentrations. Because TDS is a measure of those molecular ions less than 2 μm in diameter, understanding its dynamics helps both company management and regulators make well-informed decisions appropriate to locations and beneficial uses of the receiving waters.

The Jerritt Canyon Mine property occupies approximately 125 square miles in the northern Independence Mountains. Streams in the various drainage basins ultimately flow into both the Owyhee River (a tributary of the Snake River) and the North Fork Humboldt River. This report reports results of the initial analyses characterizing TDS in 8 streams where water samples for permit compliance have been collected in different periods over the past 30 years.

The question answered here is what is TDS? The answer is TDS depends on the stream and various ions. Further analyses and modeling will incorporate available data on fish and macroinvertebrates and the geomorphic contexts of the different drainage basins, the stream networks that drain them, and differences among sites within a single stream. There is no one consistent chemical (calcium, chloride, magnesium, sodium, sulfate) or water characteristic (conductivity or specific conductance) that is a consistent predictor of total dissolved solids concentrations.

For the streams below RDAs there are many extreme outliers for constituents such as total dissolved solids, specific conductance, magnesium, and sulfate. However, these maximum values are far removed from the approximately 66% of all measured values of these constituents in these streams. This means that the most probable measurement is far less than the maximum recorded in a stream.

These analyses and results are preliminary and more insight will be gained by further analyses both statistical and spatial.

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1 Introduction

1.1 The Data Set

As operations at the Jerritt Canyon Mine, and regulatory permit monitoring requirements, have changed over the past 30 years streams and monitoring locations have been added and dropped. The result is high variability in number of measurements by location, time period, and constituents assayed. Yet the information and knowledge that can be extracted from these data are valuable in understanding the dynamics of the natural ecosystems, the effects of operational decisions made years ago, and how to appropriately set standards and limits, particularly for downstream cropland irrigation as the primary designated beneficial use.

1.1.1 Streams

There are 27 named streams in the Jerritt Canyon Mine historic water quality database. Of these, 8 streams were selected for these analyses: Burns Creek, Jerritt Canyon Creek, Snow Canyon Creek, and Gracie RDA seepage in the Owyhee River Basin and California Creek, DASH, the ranch springs, and Winters Creek in the North Fork Humboldt River Basin. Table 1.1.1 on the following page shows the time from initial sampling to final (or current) sampling and the total number of analytical results for each stream.

Later, these analyses will be repeated on all streams in the database. The 8 streams described here present high variability in the total number of sampling results, period of record, concentrations of measured constituents, and other factors characteristic of permit compliance monitoring data. This makes them suitable for an initial look at the dynamics of TDS measured in streams on the Jerritt Canyon Mine property.

1.1.2 Constituent Chemicals

Because TDS is a measure of the total cations and anions dissolved in the water sample measurements of conductivity (specific conductance) is frequently offered as a surrogate measurement that can be conducted quickly and inexpensively in the field. Therefore, conductivity measurements are included in this analysis.

Sodium and chloride are often mentioned in the scientific literature as the source of salinity, particularly as salinity affects cash crops such as alfalfa. Therefore, levels of these two constituents are included in the analyses.

Table 1.1.1: Time periods of available data, and the total number of analytical results, for each stream.

Stream Name	Start Date	End Date	Number of Total Analyses
Burns Creek	1978-09-01	2011-05-18	2472
California Creek	1996-07-29	1996-10-18	82
DASH	2006-12-06	2010-10-26	102
Gracie RDA Seepage	1992-09-22	2011-09-07	1847
Italian Creek	1986-03-20	2011-05-21	1224
Jerritt Canyon Creek	1978-03-28	2009-05-29	2152
Marlboro Canyon Creek	1993-11-16	2010-05-04	736
Mill Creek	1979-03-01	2011-05-18	1370
Ranch Springs- East	1993-06-10	1996-12-27	380
Ranch Springs - West	1978-09-01	2011-05-18	3469
Sheep Creek	1993-11-15	2011-06-28	1392
Snow Canyon Creek	1986-03-20	2011-06-06	2263
Stump Creek	1993-05-18	2009-05-28	729
Winters Creek	1987-07-23	2011-06-06	1171

Concern over levels of magnesium sulfate ($MgSO_4$) in drainage from some waste rock disposal areas (RDAs) on the mine property lead to the inclusion of these two constituents. Calcium is a common mineral in fresh water that is necessary to build shells in snails and mussels so it is expected to be present and a component of TDS. This set of 7 variables is used in the statistical analyses.

2 Methods

All data analyses and statistical modeling use the R language for statistical computing and graphics[1]. R is similar to the S language and environment which was developed at Bell Laboratories (formerly AT&T, now Lucent Technologies) by John Chambers and colleagues. R can be considered as a different implementation of S.

R provides a wide variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, etc.) and graphical techniques, and is highly extensible.

One of R's strengths is the ease with which well-designed publication-quality plots can be produced, including mathematical symbols and formulas where needed. Great care has been taken over the defaults for the minor design choices in graphics, but the user retains full control.

R is available as Free Software under the terms of the Free Software Foundation's GNU General Public License (GPL) in source code form. It compiles and runs on a wide variety of UNIX platforms and similar systems (including FreeBSD and Linux), Windows and MacOS.

2.1 Describing the data

2.1.1 Numeric summaries

All statistical modeling and analyses should begin with simple characterizations of the data in terms of summary statistics and graphics. For single variables these summaries usually include the mean, standard deviation, and fit to a probability distribution (such as the normal distribution). The mean (average of all data) is usually used to test whether a sample adequately represents the entire population while the standard deviation indicates how broadly dispersed data are from the central (mean) value.

The analyses reported here involve multiple variables and our interest is on the associations among them. Specifically, we are interested in the distribution of measured values for each chemical and for the set of 7 parameters measured in each stream. As discussed in detail below, looking at the values for the mean and the median of each chemical reveals the role of very high (or very low) values in characterizing all measurements of that chemical in a stream system.

[1] `http://www.r-project.org/`

2.1.2 Graphic summaries

When working with a single variable the numeric summaries are usually sufficient for us to understand the characteristics of the data by looking at the numbers themselves. However, when looking at summary statistics for 7 variables we cannot easily see similarities and differences. The solution is to plot the data since a visual image communicates better than do the numbers by themselves.

A common graphic applied to understanding a data set is the histogram (or bar graph, although there are differences between the two). The numeric span of each bar in the histogram (the "bin" size) affects the appearance of the distribution of measured values, and it is difficult to compare the histograms of two variables to each other. It is even more difficult to comprehend the relationships among the 7 variables analyzed here. Rather than histograms, box plots (also called box-and-whisker plots) are used.

Box plots (see Figure 3.1.1 on page 9 as an example) provide convenient visual summaries of the five important numbers for a variable or group of variables: the minimum value, the lower quartile (1^{st} Quartile), the median (2^{nd} Quartile), the upper quartile (3^{rd} Quartile), and the maximum value. The box plot also identifies outliers (which may or may not influence results of statistical analytical models). When the focus of interest is on populations of observations (the 7 parameters here), box plots display differences without assumptions about underlying probability distributions; that is, they are non-parametric. Box plots indicate differences in dispersion (spread) and skewness (more large or small values rather than equal numbers) of the data. Visually, box plots let us immediately see the relationships among the 7 parameters in a stream.

Box plots are drawn by arranging all data in sequential order, from smallest to largest. The median is that value with as many smaller values as larger values; it is not the same as the mean. The first quartile (1Q) is the middle value between the minimum and the median, while the third quartile (3Q) is the middle value between the median and the maximum. The distance between 1Q and 3Q is called the interquartile range (IQR) and can be used as a robust equivalent of the standard deviation. The IQR is drawn as a box and the median is a dot (or bar). A dotted line extends beyond the box to either the smallest and largest values or to 1.5 times the box width (the IQR), whichever distance is smaller. Values beyond this dotted line are considered to be outliers. Box plots for the 9 streams are presented in the Part III of this report.

When box plots overlap in their IQR or the medians are about the same value, the two constituents are likely closely associated (correlated). When there is no overlap the two variables are unrelated. These visual impressions are qualitative, not quantitative, but they provide an easily grasped summary of all values and they offer suggestions for further analyses.

2.1.3 Cause-and effect

Sometimes there is confusion between association (correlation) and cause-and-effect (regression). Correlations that have no cause-and-effect relationship are common in everyday life as well as in compliance monitoring data. For example, TDS concentrations in two streams may rise and fall together, but it is not likely that the concentration in one stream directly influences the concentration in the other stream. To answer the question asked above on the meaning of TDS in the 8 streams on the Jerritt Canyon Mine property we need to examine the cause-and-effect relationships between TDS and the other 5 constituents (Ca, Cl, Mg, Na, and SO_4) and the specific conductance (electrical conductivity) of the water. The model used for this analysis is called multiple linear regression, an extension of simple linear regression.

Simple linear regression model is given by

$$y_i = \alpha + \beta x_i + \epsilon_i$$

in which the ϵ_i are assumed independent and $N(0, \sigma^2)$. The error term, ϵ_i, is the amount of variability not explained by the slope and is called the residual. That is, any value not on the slope line needs to be accounted for in the equation.

The model used to determine the effects of conductivity and the five ions on TDS is an extension of the above, namely

$$y_i = lm(TDS_i \sim Cond_i + Ca_i + Cl_i + Mg_i + Na_i + SO_{4_i})$$

with the results presented as text.

3 Analytical Results

The descriptive statistics, linear regression results, and graphics will be presented and discussed for each stream. You will see that the box-and-whisker plots of the descriptive statistics visually explain the numbers in the tables. Where the multiple linear regressions indicate significance between an explanatory variable and TDS the scatter plots usually show data in relatively straight lines from the lower left to the upper right, regardless of the quantity of data or numeric range of concentrations. Where there is no significant relationship the plots illustrate this very clearly. This is not always the case (for example, conductivity and TDS in Jerritt Canyon Creek), but the plots help to understand the numeric regression results.

3.1 Owyhee River Basin

The west side of the Jerritt Canyon Mine property has streams that drain into the Owyhee River. Most of these streams flow generally westward. These are isolated streams that are lost to ground water infiltration and eventually re-emerge in the Owyhee River. The receiving waters flow northward around the Independence Mountains and eventually flow into the Snake River.

3.1.1 Burns Creek

3.1.1.1 Descriptive Statistics

Table 3.1.1 on the following page displays the key points in the data for each of the 7 parameters analyzed. Notice that the ranges for all parameters other than sodium are very large and, in most cases, the mean is substantially higher than the median. This tells us that there are comparatively few high concentrations that influence the mean, but not the median concentration. It is generally accepted that if the medians (the black dots in Figure 3.1.1 on page 9) do not overlap then the medians are significantly different at the 5% level.

For TDS, most measurements (approximately 66%) range from 255 mg/L to 399 mg/L. Only about 17% of the measurements are greater than 399 mg/L but have been as high as 1470 mg/L. The specific conductance (conductivity) is even more extreme in Burns Creek. The maximum value (2058.0 $\mu S/cm$) is more than 1200 times greater than the minimum value (1.7 $\mu S/cm$). Sulfate, too, has a range almost 100 times the minimum value. Both operational and regulatory decisions should be based on the most likely outcome (the

Table 3.1.1: Descriptive statistics for Burns Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	14.0	255.0	295.0	358.8	399.0	1470.0	100
Ca	32.20	51.40	59.70	69.36	79.80	198.00	192
Cl	1.000	3.000	4.000	7.046	6.820	61.500	111
Mg	11.00	25.20	29.55	39.93	44.12	161.00	192
Na	3.450	4.615	5.115	5.233	5.462	9.600	222
SC	1.7	4.16.0	487.0	576.4	657.0	2058.0	163
SO_4	8.10	36.25	58.75	108.80	140.80	784.00	102

standard deviation around the mean value where about two-thirds of all measurements are found). Querying the database will identify when and where the maximum (and other high outlier) measurements occurred, but may not provide insights and guidance on how to avoid these infrequent values in the future.

These numbers are all more apparent in Figure 3.1.1 on the facing page. What can be seen in the figure but not the table is that there is little apparent relationship between conductivity and TDS; the boxes do not overlap, yet both have outlier values well above the majority of measurements. There are no obvious relationships between ion pairs such as Na-Cl and Mg-SO_4 and conductivity does not appear to be a good substitute for TDS.

3.1.1.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on Burns Creek are:

```
Call:
lm(formula = TDS ~ Ca + Cl + Cond + Mg + Na + SO4)
Residuals:
    Min      1Q  Median      3Q     Max
-34.148  -6.998   1.110   8.847  29.894
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 28.20620   23.64249   1.193    0.246
Ca           4.19812    0.73132   5.741 1.07e-05 ***
Cl           0.27131    0.20136   1.347    0.192
Cond        -0.04009    0.02792  -1.436    0.166
Mg          -1.22008    1.02618  -1.189    0.248
Na           2.26127    6.58249   0.344    0.735
SO4          1.07778    0.17088   6.307 2.96e-06 ***
---
```

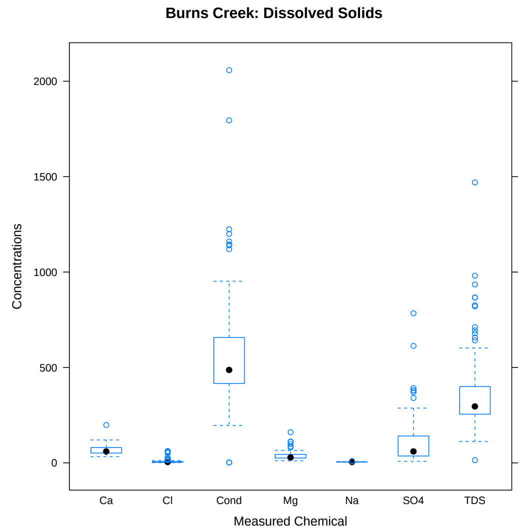


Figure 3.1.1: Box plots of Burns Creek water quality parameters related to total dissolved solids.

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 15.61 on 21 degrees of freedom
  (228 observations deleted due to missingness)
Multiple R-squared: 0.9973, Adjusted R-squared: 0.9965
F-statistic:  1288 on 6 and 21 DF,  p-value: < 2.2e-16
```

The model formula specifies that TDS is to be described by the other parameters. In this stream, calcium and sulfate are very highly significant; there is less than 0.1% probability that such results would occur randomly. The adjusted R^2reveals that 99.65% of all variability in the data is explained by this model. The p-value of the F-statistic on the bottom line confirms the significance of the model results.

The basis for the multiple linear regression model is seen in plots of each explanatory parameter (on the x-axis) and TDS (on the y-axis) by sampling location on each creek. These plots also illustrate the difference in relationships between TDS and the explanatory parameters from location to location. See Figure 3.1.2 on the next page through Figure 3.1.4 on page 11. While several parameters display somewhat linear relationships with TDS at some sites the appearances are not strong evidence of statistical cause-and-effect relationships. The regression table provides the stronger explanation of which parameters are most influential on measured TDS values for the stream as a whole.

To predict TDS concentrations in Burns Creek use this equation: $TDS = 28.21 + 4.20 * Ca + 1.08 * SO_4$.

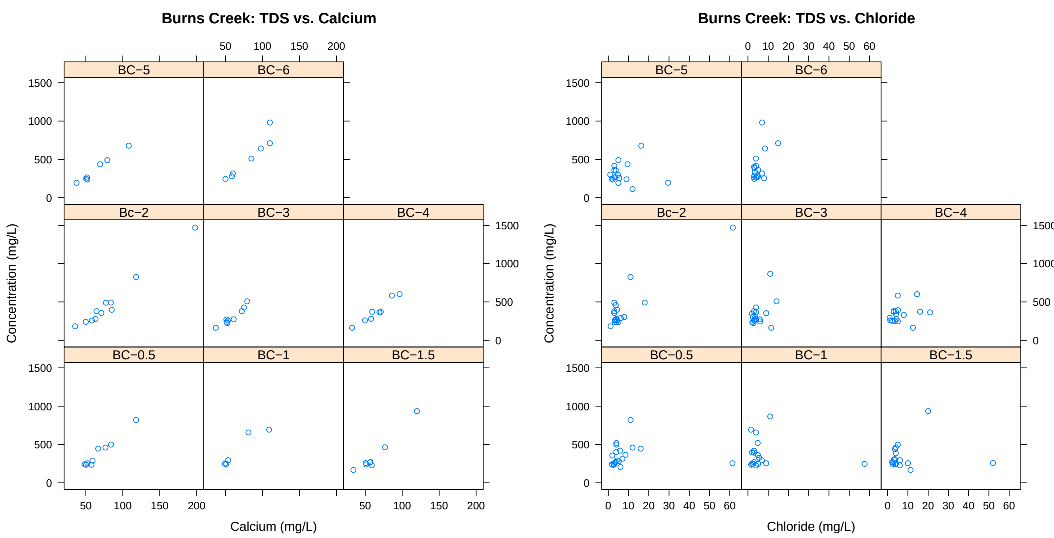


Figure 3.1.2: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along Burns Creek.

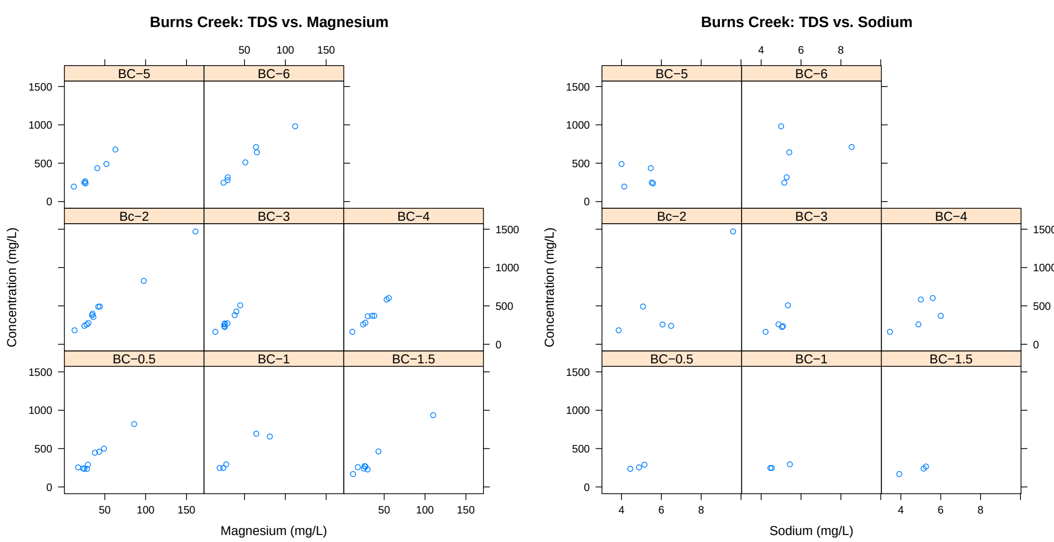


Figure 3.1.3: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations in Burns Creek.

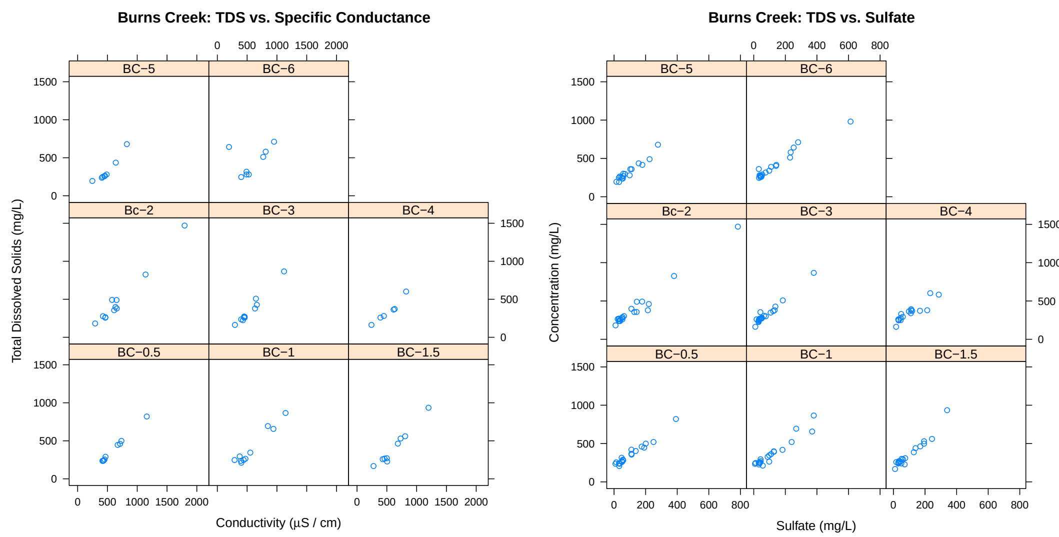


Figure 3.1.4: Relationships between conductivity (left) and sulfate (right) on TDS at sampling locations in Burns Creek.

3.1.2 Gracie RDA Seepage

3.1.2.1 Descriptive Statistics

Table 3.1.2 describes the values for the measured parameters from samples taken in the Gracie RDA drainage. The concentrations of TDS, specific conductance, and sulfate have large ranges and skewed distributions (Figure 3.1.5 on the following page . All constituents other than sodium have large concentration ranges and tend to be skewed toward the higher values.

Table 3.1.2: Descriptive statistics for the Gracie RDA seepage water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1^{st} Quar.	Median	Mean	3^{rd} Quar.	Max.	NA's
TDS	248.0	450.2	3900.0	4641.7	7285.0	12000.0	27
Ca	53.0	65.75	184.00	224.89	384.0	520.0	89
Cl	1.680	4.480	6.710	8.624	9.255	110.000	33
Mg	29.3	34.0	193.0	383.3	613.8	1540.00	89
Na	5.01	7.63	9.86	10.41	14.00	17.09	114
SC	108	560	1250	2465	4100	8940	78
SO_4	20.7	613.0	2680.0	3244.0	5440.0	9600.0	27

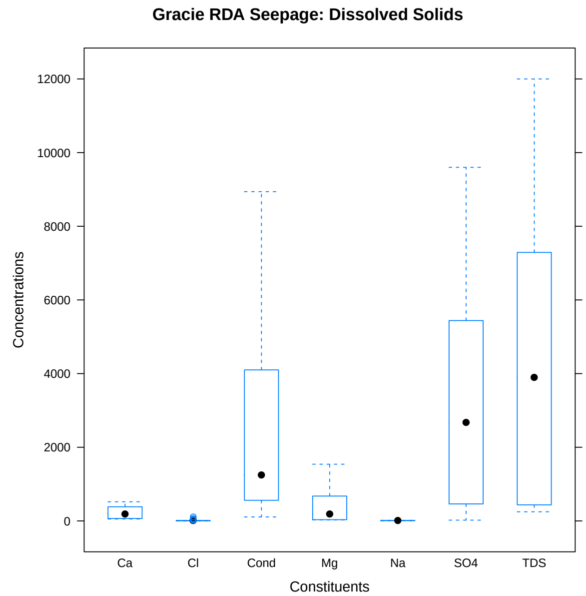


Figure 3.1.5: Box plots of Gracie RDA seepage water quality parameters related to total dissolved solids.

3.1.2.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on Gracie RDA seepage are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + Na + SO4, data = gracie.cast)
Residuals:
    Min       1Q  Median       3Q      Max
-34.038 -10.427  -1.457    8.071   53.078
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -17.90983   26.31219  -0.681   0.5065
Cond          0.30650    0.03007  10.194 3.88e-08 ***
Ca            2.99524    0.29317  10.217 3.77e-08 ***
Cl            1.89293    3.44440   0.550   0.5907
Mg           -4.75003    0.78756  -6.031 2.30e-05 ***
Na            7.92104    3.15132   2.514   0.0239 *
SO4           1.46563    0.09455  15.502 1.22e-10 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

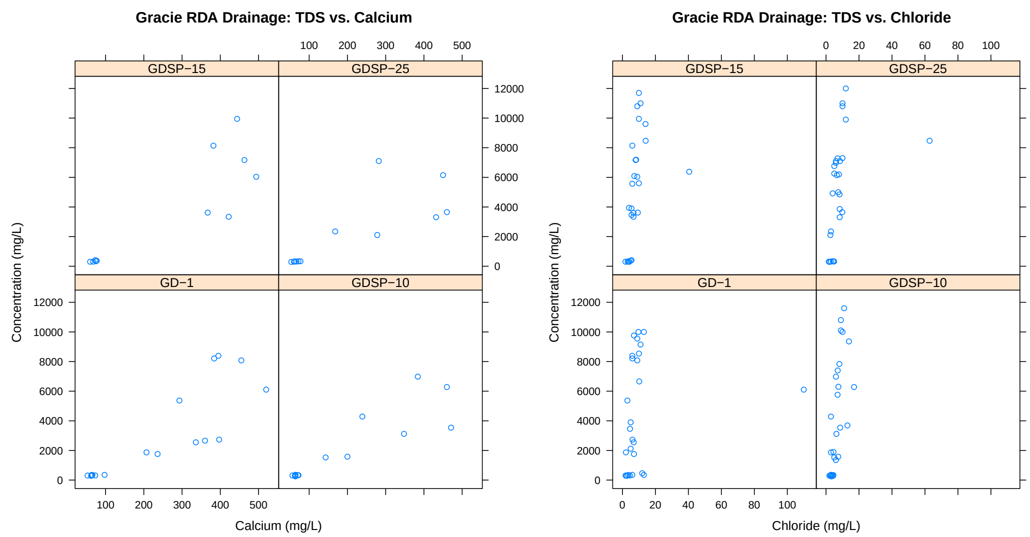
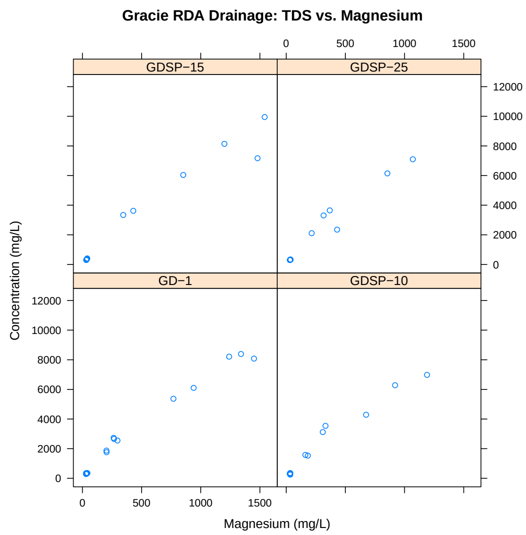


Figure 3.1.6: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along the Gracie RDA drainage.

```
Residual standard error: 21.87 on 15 degrees of freedom
  (121 observations deleted due to missingness)
Multiple R-squared: 0.9998, Adjusted R-squared: 0.9997
F-statistic: 1.117e+04 on 6 and 15 DF,  p-value: < 2.2e-16
```

Continuing the story of each stream's chemistry being different, the Gracie RDA seepage has 4 explanatory variables (conductivity, calcium, magnesium, and sulfates) which are very highly significant (less than 0.001% proability of having such values due to random events) and sodium concentrations are significant at the 5% probability level. These 5 explanatory parameters explain 99.97% of the TDS variability in this stream. Figures 3.1.6 through 3.1.8 on the following page graphically display the relationships of each parameter to TDS by site in the drainage. Site GDSP-10 was sampled much more frequently than were sites GDSP-15 or GDSP-25. The latter two were apparently sampled only when concentrations of the constituents were very low. Chloride is interesting in that there are very low concentrations of this ion associated with a very wide range of TDS concentrations at site GDSP-10 (note the almost vertical line along the left margin of the plot in Figure 3.1.6). Magnesium and sodium do not appear linearly related in the figures while the regression indicates they are significant to predicting concentrations of total dissolved solids.

To predict TDS concentrations in the Gracie RDA seepage use this equation: $TDS = -17.91 + 0.31 * Cond + 3.00 * Ca - 4.75 * Mg + 7.92 * Na + 1.46 * SO_4$.



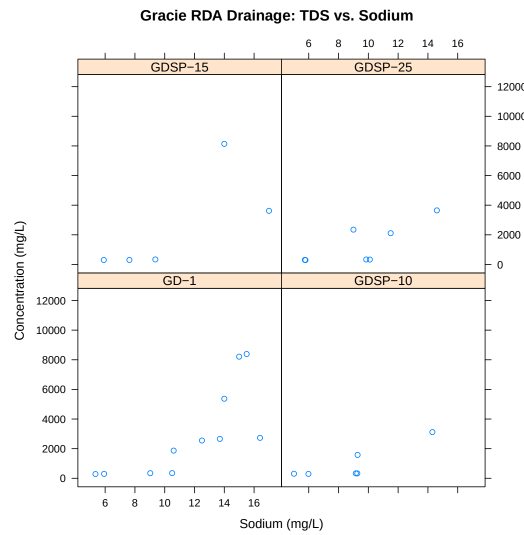
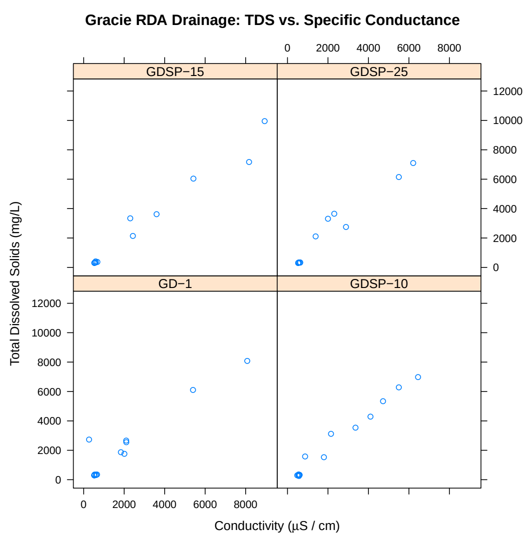


Figure 3.1.7: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations along the Gracie RDA drainage.



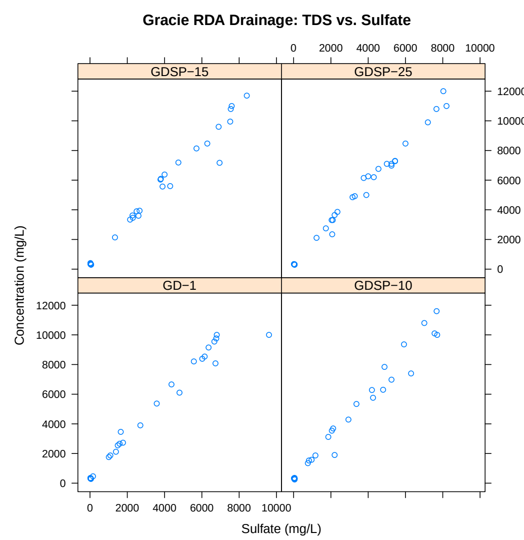


Figure 3.1.8: Relationships between conductivity (left) and sulfate (right) on TDS at sampling locations along the Gracie RDA drainage.

Table 3.1.3: Descriptive statistics for Indian Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1^{st} Quar.	Median	Mean	3^{rd} Quar.	Max.	NA's
TDS	72.0	200.0	219.5	216.5	230.0	825.0	45
Ca	19.60	43.85	48.50	45.15	50.48	55.00	95
Cl	0.100	1.000	1.650	2.424	2.200	34.000	51
Mg	7.60	20.07	22.70	20.87	23.52	26.00	99
Na	3.000	3.393	3.770	4.134	4.178	7.260	109
SC	130.0	315.0	386.4	346.0	403.0	480.0	86
SO_4	0.200	9.977	11.050	13.850	14.600	110.000	47

3.1.3 Italian Creek

3.1.3.1 Descriptive Statistics

Table 3.1.3 describes the values for the measured parameters from samples taken in Italian Creek. TDS, chloride, and sulfate have very large ranges, and TDS and sulfate are not highly skewed toward higher values based on the medians and means. Looking at the ranges between the minimum and first quartile, and third quartile and maximum values for these three constituents indicates that most measurements are within the IQR (the first and third quartile, equivalent to 1 standard deviation around the mean or 66% of observations). These values are also seen in Figure .

3.1.3.2 Linear Regression

The results on the multiple linear regression of water chemistry constituents on total dissolved solids (TDS) in Italian Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = italian.cast)
Residuals:
    Min      1Q  Median      3Q     Max
-16.344  -4.867  -1.117   5.647  23.355
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 33.91581   14.32157   2.368   0.0308 *
Cond        -0.07081    0.04126  -1.716   0.1054
Ca           1.66373    1.23165   1.351   0.1955
Cl          -0.19536    0.33310  -0.587   0.5657
Mg           5.69063    2.59428   2.194   0.0434 *
SO4          0.58237    0.33887   1.719   0.1050
---
```

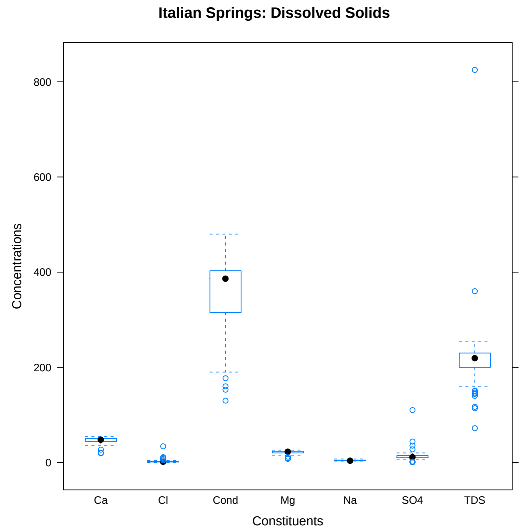


Figure 3.1.9: Box plots of Italian Creek water quality parameters related to total dissolved solids.

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 9.678 on 16 degrees of freedom
  (105 observations deleted due to missingness)
Multiple R-squared: 0.9364, Adjusted R-squared: 0.9165
F-statistic: 47.08 on 5 and 16 DF,  p-value: 5.217e-09
```

The residuals (that is, the data not explained by the regression model) are not normally distributed; the median is not close to zero and the minimum and maximum values are not similar. This might be due to having measurements taken unevenly over a 25 year period.

There is a single explanatory variable—Magnesium—that is significantly related to TDS values in Italian Creek. None of the other four constituents are close to being significant. Figures 3.1.10 on the next page through 3.1.12 on page 18 visually show the relationship of each potential explanatory variable on the TDS response variable. It is easy to see why the regression found only magnesium to be significantly associated with TDS values.

The regression equation explains 91.65% of the variation in TDS observed in Italian Creek. To predict TDS values in Italian Creek use this equation: $TDS = 33.92 + 5.69 * Mg$.

3.1.4 Jerritt Canyon Creek

3.1.4.1 Descriptive Statistics

Table 3.1.4 on page 18 presents the five characteristics of the 7 parameters in the historic

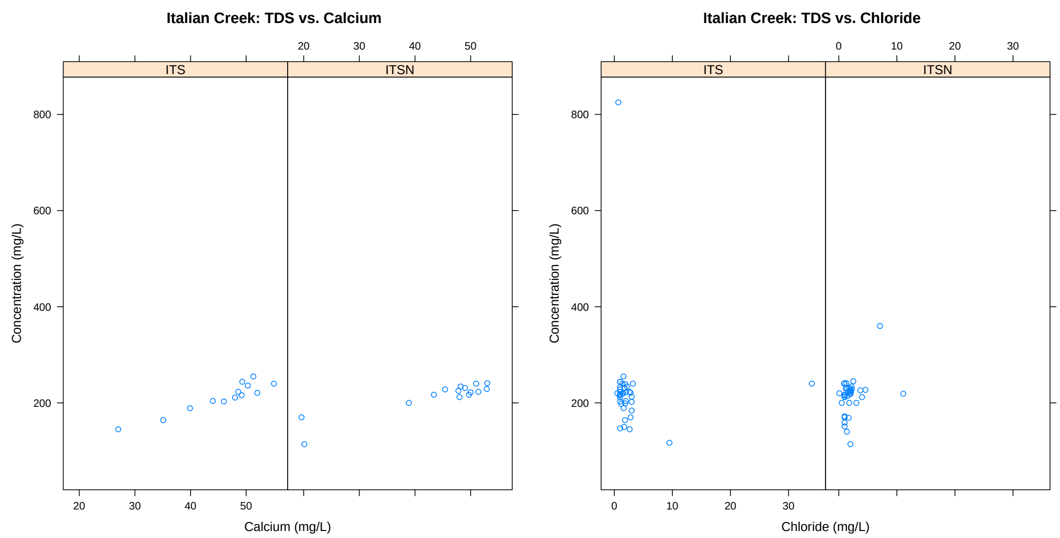


Figure 3.1.10: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along Italian Creek.

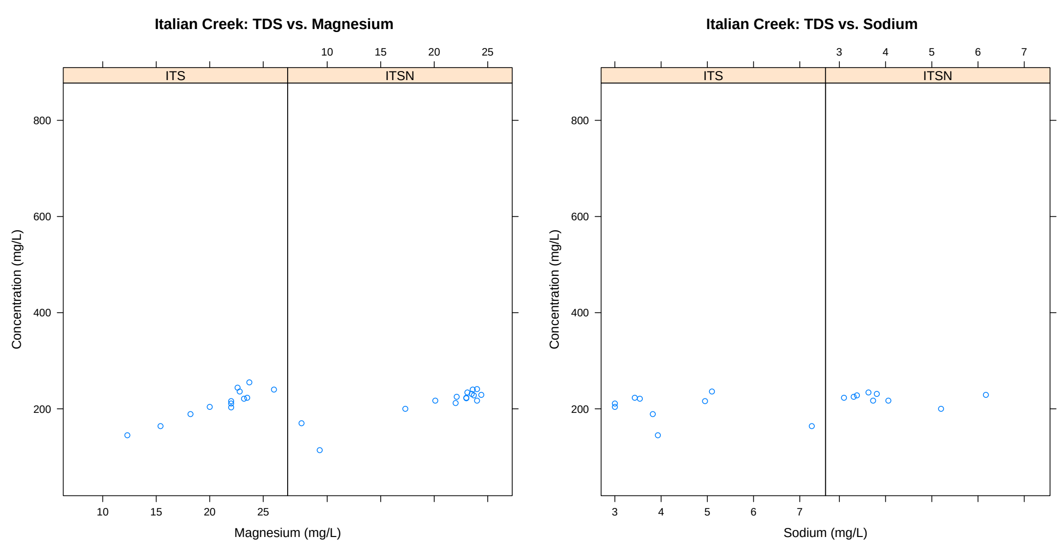


Figure 3.1.11: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations along Italian Creek.

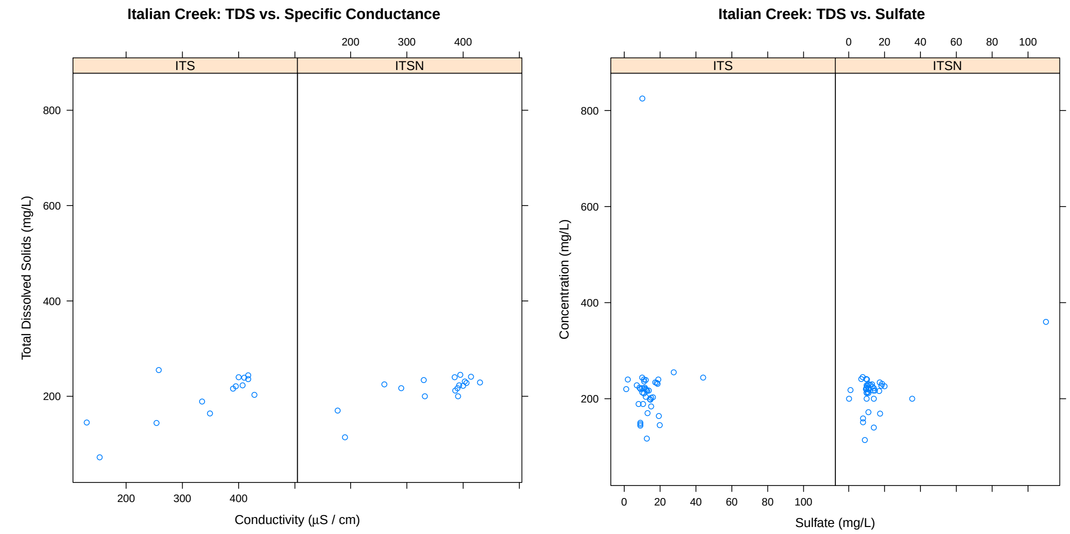


Figure 3.1.12: Relationships between conductivity (left) and sulfate (right) on TDS at sampling locations along Italian Creek.

Table 3.1.4: Descriptive statistics for Jerritt Canyon Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	14.0	370.2	614.5	726.9	1087.5	2240.0	56
Ca	29.40	61.55	86.50	97.66	122.50	263.00	80
Cl	1.480	7.518	11.000	15.072	23.250	61.00	78
Mg	12.80	31.23	59.-0	64.52	104.50	1790.00	80
Na	4.300	6.515	8.260	9.086	11.000	15.900	103
SC	1.6	481.0	785.0	914.6	1375.0	2400.0	47
SO_4	24.0	101.0	231.0	337.0	579.0	1130.0	57

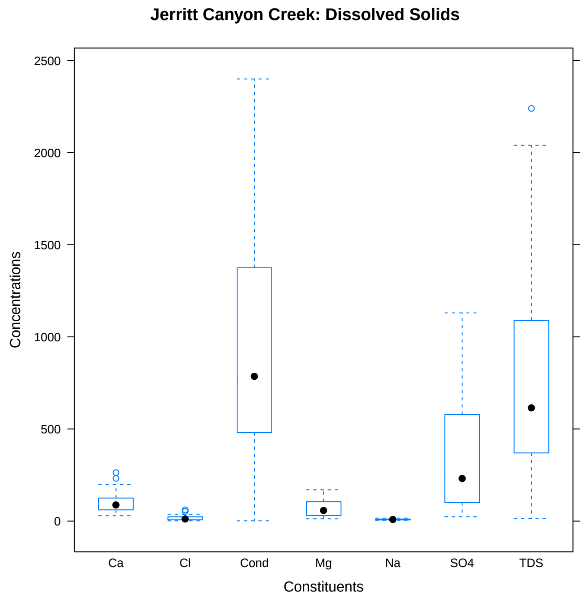


Figure 3.1.13: Box plots of Jerritt Canyon Creek water quality parameters related to total dissolved solids.

record for Jerritt Canyon Creek. The range for TDS is 160 times the minimum value of 14.0 mg/L, and the mean is closer to the median than it is to the 3rd Quartile value. This means the distribution of values is somewhat linear. While the conductivity measurements also have a very large range, the mean is just about half-way between the median and the 3rd Quartile. This indicates that the distribution of conductivity measurements is slightly skewed to the lower half of the range.The results of the multiple linear regression for TDS-related parameters on Jerritt Canyon Creek are:

For all parameters other than chloride and sodium there is a skewed distribution; that is, there are many measured values greater than 1.5 times the standard distribution. This suggests that there are infrequent events that result in very high concentrations of ions in the water samples, but these high values should not be expected without identifying the reason (or reasons) for them. These patterns are easy to see in Figure 3.1.13.

3.1.4.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on Jerritt Canyon Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + Na + SO4, data = jerritt.cast)
Residuals:
```

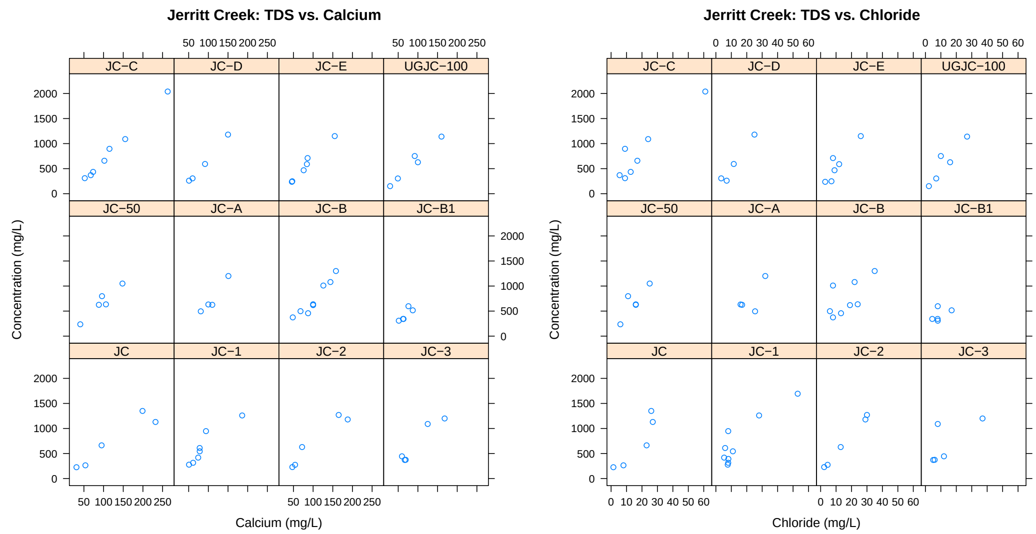


Figure 3.1.14: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along Jerritt Canyon Creek.

```
    Min      1Q  Median      3Q     Max
-82.140 -16.543   2.502  24.018  88.260
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   8.0134    51.7810   0.155  0.87809
Cond          0.1994     0.1226   1.627  0.11446
Ca           -1.0156     0.6998  -1.451  0.15743
Csummary(lm(TDS ~ Cond + Ca + Cl + Mg + Na + SO4))
l            0.9828     2.6317   0.373  0.71154
Mg            5.8481     1.8003   3.248  0.00293 **
Na           11.3806     9.7845   1.163  0.25426
SO4           0.2524     0.2136   1.182  0.24696
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 44.97 on 29 degrees of freedom
  (110 observations deleted due to missingness)
Multiple R-squared: 0.9876, Adjusted R-squared: 0.985
F-statistic: 385.1 on 6 and 29 DF,  p-value: < 2.2e-16
```

While the TDS concentrations in Burns Creek are very highly related to concentrations of calcium and sulfate, in Jerritt Canyon Creek TDS concentrations are significantly related only to magnesium concentrations. Figures 3.1.14 through 3.1.16 on the facing page are scatter plots showing the relationships between TDS and the explanatory parameters in

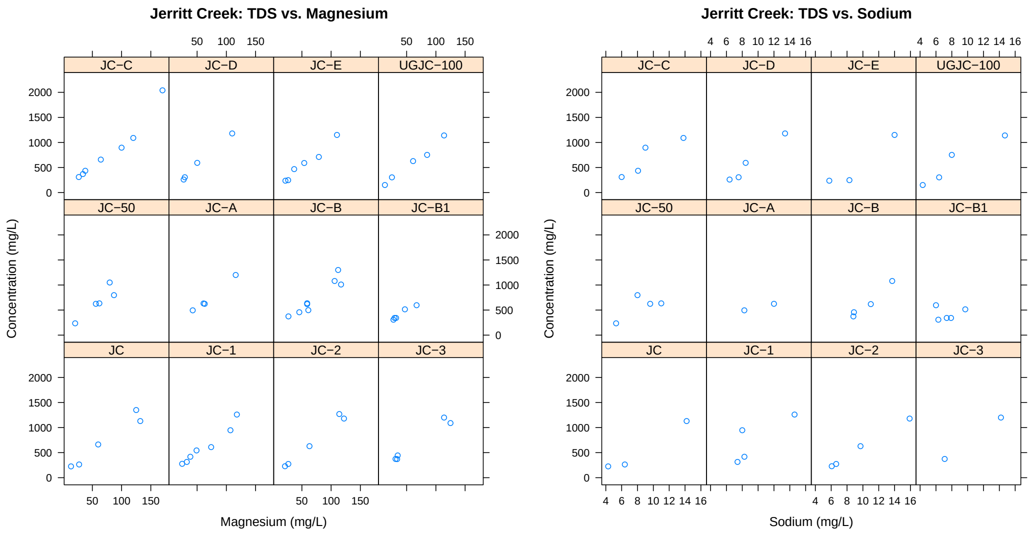


Figure 3.1.15: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations in Jerritt Canyon Creek.

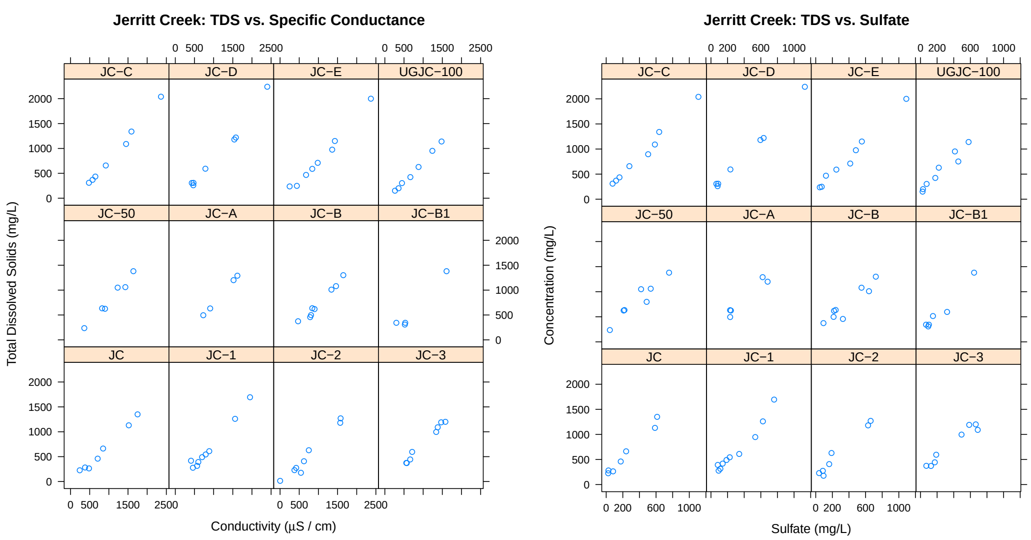


Figure 3.1.16: Relationships between conductivity (left) and sulfate (right) on TDS at sampling locations in Jerritt Canyon Creek.

Table 3.1.5: Descriptive statistics for Marlboro Canyon Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	2470	3518	3800	3750	4050	4680	6
Ca	380.0	400.8	414.5	421.7	431.0	488.0	54
Cl	43.40	60.00	68.00	72.78	78.10	280.00	9
Mg	274.0	333.2	381.0	367.9	394.8	457.0	54
Na	24.40	24.90	26.10	29.44	26.50	59.50	61
SC	1900	3178	3465	3331	3698	4220	48
SO_4	1529	2097	2415	2371	2660	3130	6

Jerritt Canyon Creek.

For the non-significant explanatory parameters, conductivity (specific conductance) has almost a random relationship with TDS despite the scatter plots for each site on the stream appearing similar to the patterns for sulfates (Figure 3.1.16 right). This is why the statistical linear regression model is necessary; the scatter plots do not reflect as accurately the true relationships at all sites along the stream.

To predict TDS concentrations in Jerritt Canyon Creek use this equation: $TDS = 8.01 + 5.85 * Mg$.

3.1.5 Marlboro Canyon Creek

3.1.5.1 Descriptive Statistics

Table 3.1.5 describes the value for the measured parameters from samples taken in Marlboro Canyon Creek. TDS is consistently higher than the nominal irrigation threshold but normally distributed across that range. Conductivity is also high in this stream with the maximum about twice the value of the minimum. Sulfate concentrations are also high with the maximum value approximately twice the minimum value. TDS, conductivity, and sulfate are all slightly skewed toward lower values as the means are less than the medians. Calcium, chloride, and sodium have much lower concentrations but their distributions also tend to be slightly skewed towed the left (lower values). These relationships can easily be seen in Figure 3.1.17 on the facing page.

3.1.5.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on Jerritt Canyon Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = marlboro.cast)
```

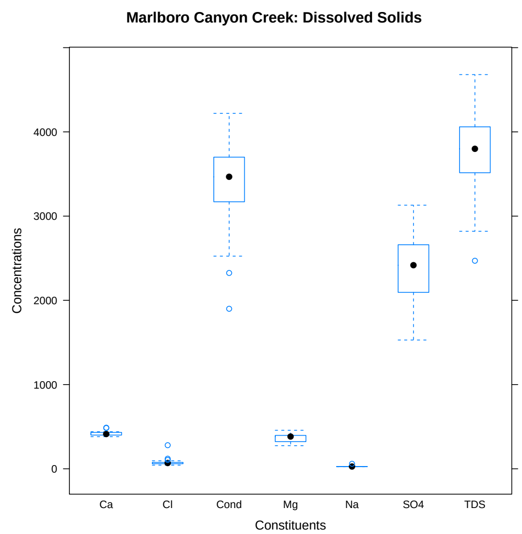


Figure 3.1.17: Box plots of Marlboro Canyon Creek water quality parameters related to total dissolved solids.

```
Residuals:
   Min     1Q Median     3Q    Max
-52.22 -37.68 -21.20  41.14  68.82
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 709.81283  519.14527   1.367   0.2138
Cond          0.01582    0.03917   0.404   0.6983
Ca            1.40218    0.77428   1.811   0.1131
Cl           -1.55309    3.82201  -0.406   0.6966
Mg            4.42613    1.31368   3.369   0.0119 *
SO4           0.32472    0.16495   1.969   0.0897 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 59.19 on 7 degrees of freedom
  (57 observations deleted due to missingness)
Multiple R-squared: 0.9742, Adjusted R-squared: 0.9557
F-statistic: 52.81 on 5 and 7 DF,  p-value: 2.083e-05
```

As with Italian and Jerritt Canyon Creeks, Marlboro Canyon Creek has only magnesium significantly predicting TDS concentrations. Sulfates are not quite significant and the others are much less meaningful. Figures 3.1.18 on the next page through 3.1.20 on page 25 are scatter plots showing the relationships between TDS and the explanatory constituents in Marlboro Canyon Creek. To predict TDS in Marlboro Canyon Creek use this equation:

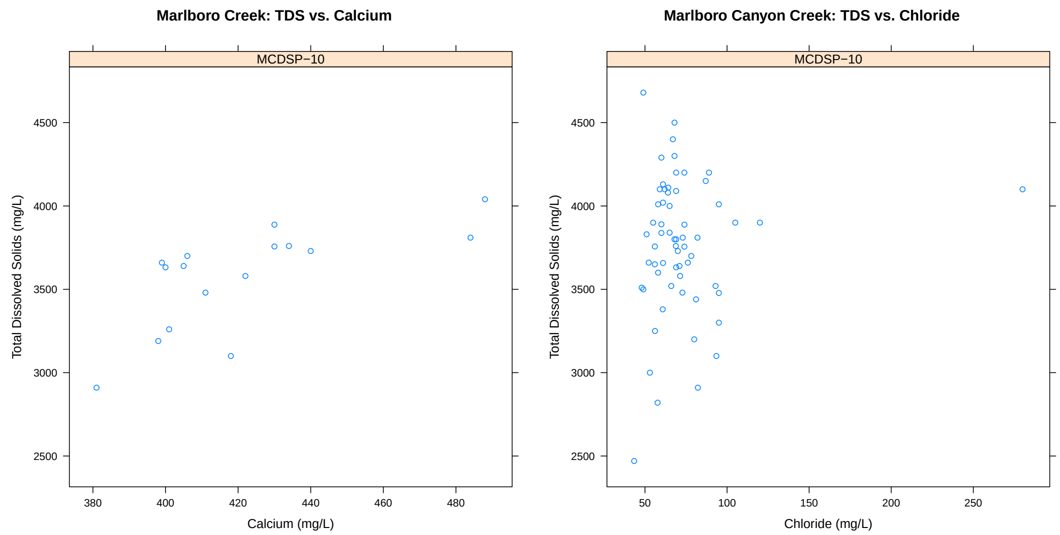


Figure 3.1.18: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along MarlboroCanyon Creek.

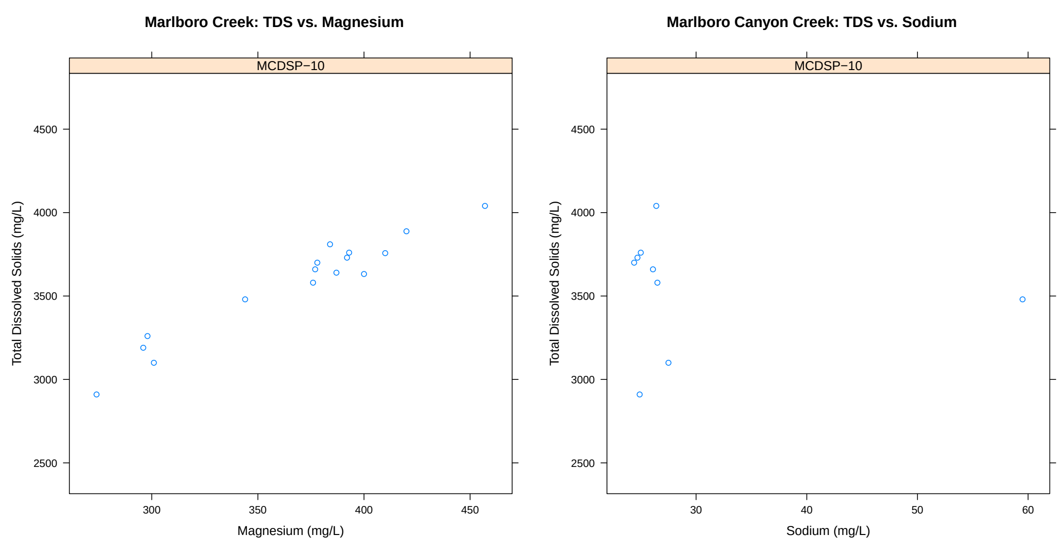


Figure 3.1.19: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations along MarlboroCanyon Creek.

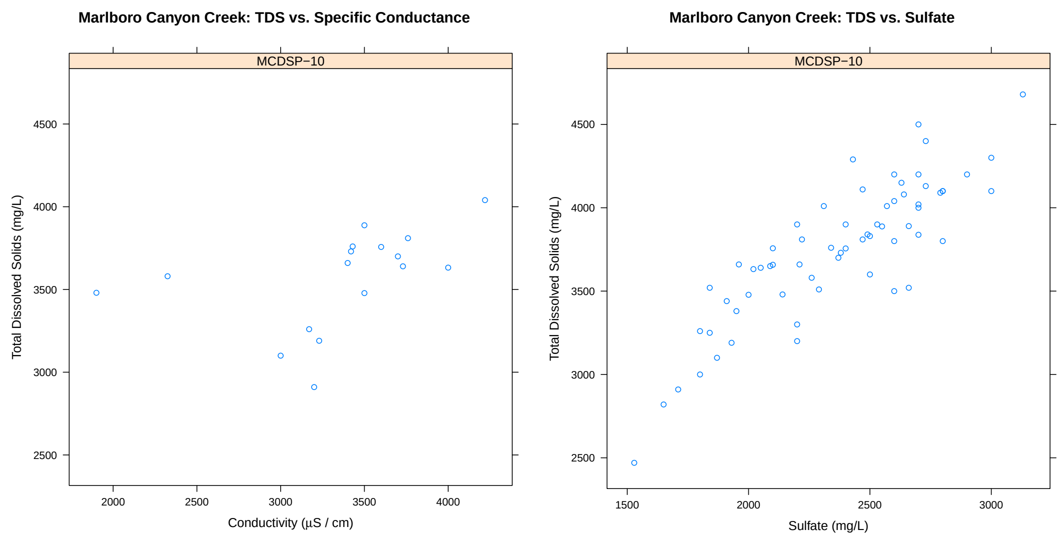


Figure 3.1.20: Relationships between conductivity (left) and sulfate (right) on TDS at sampling locations along MarlboroCanyon Creek.

$TDS = 709.81 + 4.43 * Mg.$

3.1.6 Mill Creek

3.1.6.1 Descriptive Statistics

Table 3.1.6 describes the value for the measured parameters from samples taken in Marlboro Canyon Creek. Magnesium and sodium are relatively normally distributed while the rest of the constituents are skewed to the right (toward high values). All constituents have large value ranges but conductivity is notable for ranging from 2-1350μS/cm. Many

Table 3.1.6: Descriptive statistics for Mill Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	193.0	335.5	426.0	489.2	546.0	1100.0	60
Ca	45.20	60.05	68.20	75.08	79.95	164.00	100
Cl	1.940	4.588	6.000	8.373	11.775	62.000	63
Mg	15.30	23.45	31.00	32.29	38.85	82.00	100
Na	4.760	5.995	6.560	6.649	7.354	10.000	116
SC	2.0	451.0	544.0	561.7	662.0	1350.0	88
SO_4	23.3	94.7	145.0	183.5	239.0	560.0	60

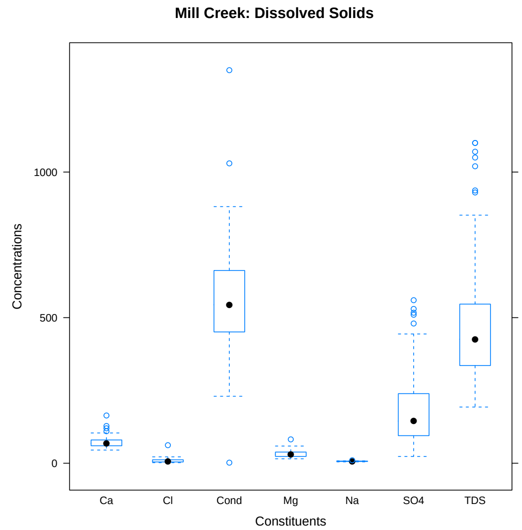


Figure 3.1.21: Box plots of Mill Creek water quality parameters related to total dissolved solids.

of these very high values that expand the concentration range and skew the distributions are outliers (Figure 3.1.21). These outliers may be important and should not be ignored until shown to be insignificant.

3.1.6.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on Mill Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = millc.cast)
Residuals:
    Min      1Q  Median      3Q     Max
-36.033 -14.221  -2.489   9.407  49.948
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  10.8400    21.1724   0.512 0.613154
Cond          0.2024     0.1152   1.757 0.091163 .
Ca            1.9930     0.7193   2.771 0.010397 *
Cl            0.2125     0.4150   0.512 0.613141
Mg            1.6854     0.9671   1.743 0.093658 .
SO4           0.5142     0.1198   4.293 0.000233 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

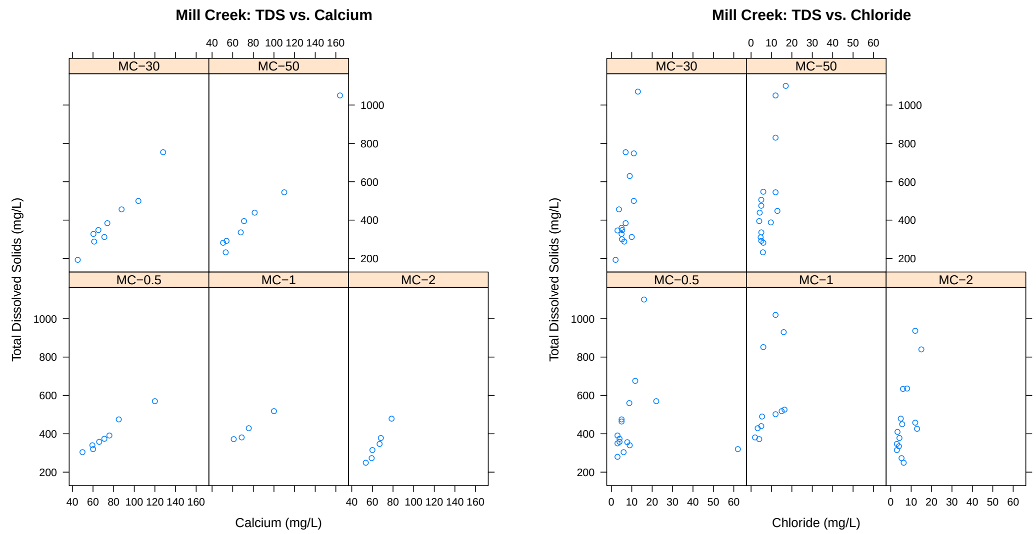


Figure 3.1.22: The relationships of calcium (left) and chloride (right) on TDS in Mill Creek.

```
Residual standard error: 22.56 on 25 degrees of freedom
  (104 observations deleted due to missingness)
Multiple R-squared: 0.9848, Adjusted R-squared: 0.9818
F-statistic: 323.9 on 5 and 25 DF,  p-value: < 2.2e-16
```

The most important predictor component of TDS in Mill Creek is sulfate; calcium is the second predictor variable. The regression model accounts for 98.2% of TDS variability in the creek and is highly significant. Relationships between the predictor variables and the response variable (TDS) can be seen in Figures 3.1.22 through 3.1.24 on the following page. To predict TDS values in Mill Creek use this equation: $TDS = 10.84 + 0.51 * SO4$.

3.1.7 Ranch Springs (West Side)

3.1.7.1 Descriptive Statistics

Table 3.1.7 on page 29 describes the values for the measured parameters from samples taken in springs on ranches on the west side valleys of the Independence Mountains. Magnesium and sodium are normally distributed and the other constituents slight skewed toward higher values. The only constituent with an extreme range of values is conductivity (2-1350 μS/cm), yet the majority of measurements are in the IQR (that is, within one standard deviation of the mean). Conductivity, sulfate, and total dissolved solids have many very high values that may be outliers because they are at the far end of the right tails of the distributions. These relationships can be seen in Figure 3.1.25.

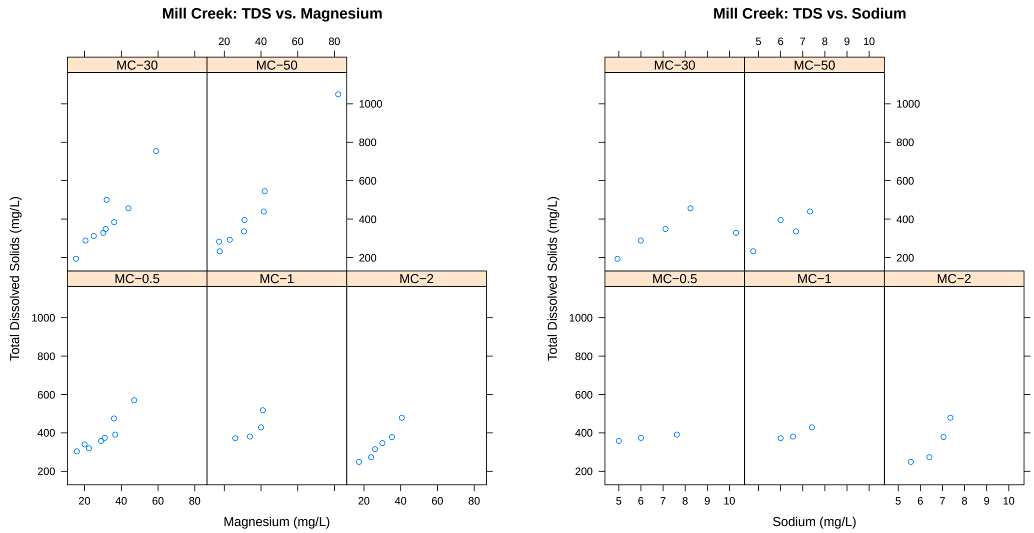


Figure 3.1.23: Relationships between magnesium (left) and sodium (right) on TDS in Mill Creek.

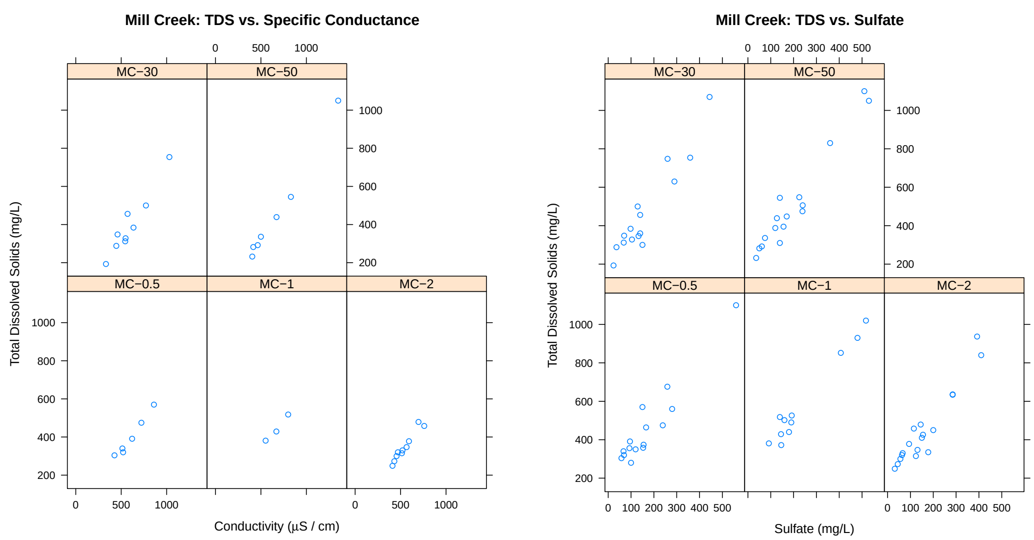


Figure 3.1.24: Relationships between specific conductance (left) and sulfate (right) on TDS in Mill Creek.

Table 3.1.7: Descriptive statistics for Snow Canyon Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	193.0	335.5	426.0	480.2	546.5	1100.0	60
Ca	45.20	60.05	68.20	75.08	79.95	164.00	100
Cl	1.940	4.588	6.000	8.373	11.775	62.000	63
Mg	15.30	23.45	31.00	32.29	38.35	82.00	100
Na	4.760	5.995	6.560	6.649	7.345	10.300	116
SC	2.0	451.0	544.0	561.7	662.0	1350.0	88
SO_4	23.3	94.7	145.0	183.5	239.0	560.0	60

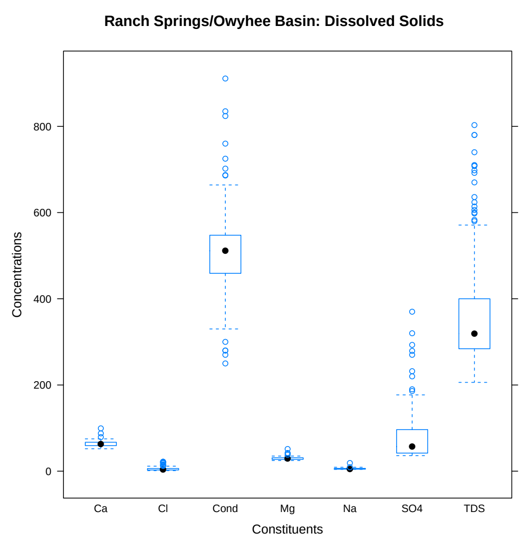


Figure 3.1.25: Box plots of Owyhee basin ranch springs' water quality parameters related to total dissolved solids

3.1.7.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters in the Owyhee basin ranch springs are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = rnch0.cast)
Residuals:
    Min      1Q  Median      3Q     Max
-35.010  -8.711  -0.759   8.665  50.474
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) 100.815475  23.288495   4.329 4.63e-05 ***
Cond         -0.002766   0.022658  -0.122  0.90316
Ca            1.049653   0.489433   2.145  0.03527 *
Cl            0.910967   0.841128   1.083  0.28231
Mg            2.613523   0.986084   2.650  0.00983 **
SO4           1.018360   0.117788   8.646 7.77e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 14.97 on 74 degrees of freedom
  (409 observations deleted due to missingness)
Multiple R-squared: 0.9445, Adjusted R-squared: 0.9408
F-statistic: 252.1 on 5 and 74 DF,  p-value: < 2.2e-16
```

These springs are on the Wright Ranch and the Van Norman Ranches and distinct from the streams draining from the Independence Mountains. The Wright Ranch springs are close to JC-1 on Jerritt Canyon Creek and the Van Norman Ranches springs are near MC-2 on Mill Creek and approximately 400 meters southwest of BC-3 on Burns Creek. There is no direct surface connection between the springs and the creeks. This is meaningful to the interpretation of the very highly significant probability of sulfate and highly significant probability of magnesium in spring water samples. (The indication that the intercept is very highly significant is meaningless.) The relationships of predictor constituents to the TDS response constituent is shown in Figures 3.1.26 through 3.1.28.

Overall in Burns Creek calcium and sulfate are significant, and sulfate alone significant overall in Jerritt Canyon Creek. Because the high significance of magnesium in the ranch springs cannot be associated with highly significant magnesium in Burns or Jerritt Canyon Creeks, a reasonable first approximation is that the very highly significance of sulfate is also independent of the streams. This relationship could be better defined by specific sampling and analyses if warranted. The levels of TDS, magnesium, and sulfate in the springs and their outlet streams are most likely benign.

To predict TDS levels in these ranch springs use this equation: $TDS = 100.2 + 2.61 * Mg + 1.02 * SO_4$.

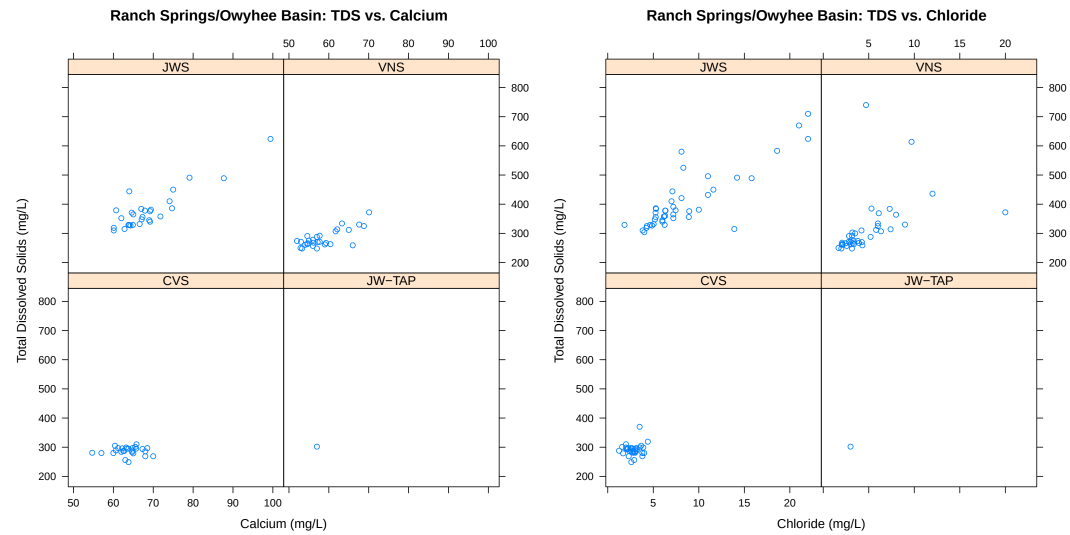


Figure 3.1.26: Relationship between calcium (left) and chloride (right) on TDS in the west side ranch springs.

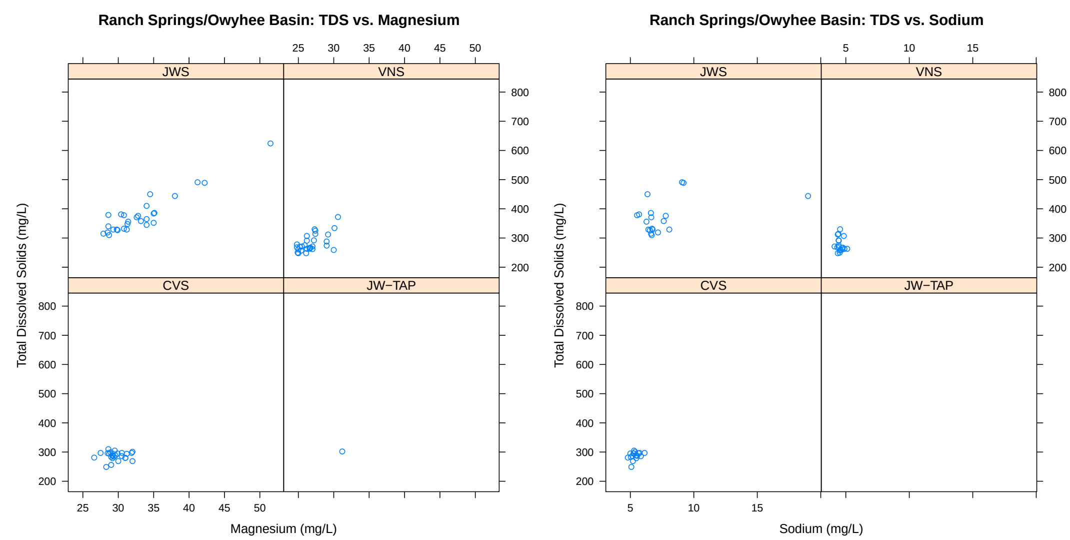


Figure 3.1.27: Relationship between magnesium (left) and sodium (right) on TDS in the west side ranch springs.

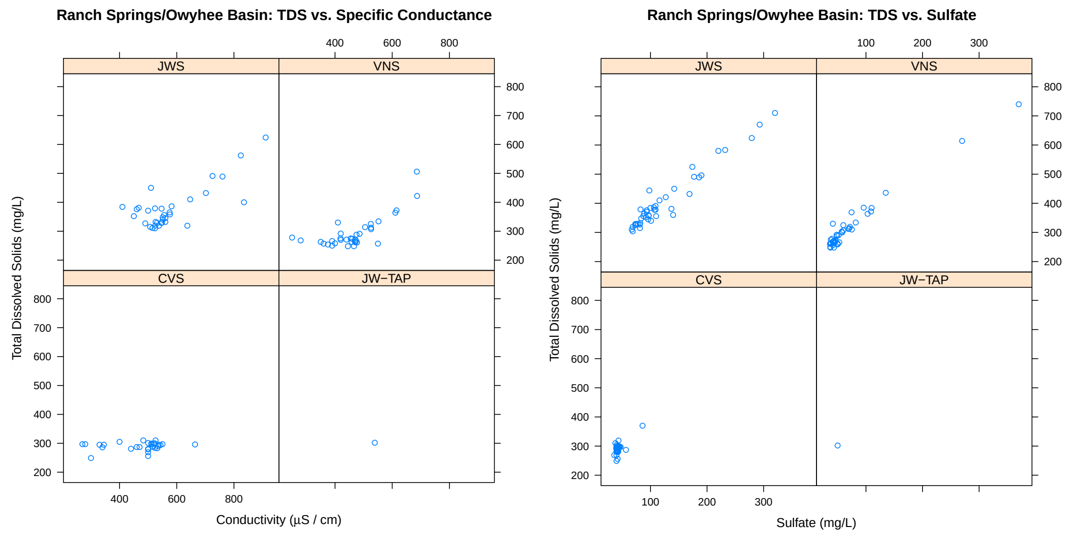


Figure 3.1.28: Relationship between conductivity (left) and sulfate (right) on TDS in the west side ranch springs.

3.1.8 Snow Canyon Creek

3.1.8.1 Descriptive Statistics

Table 3.1.8 describes the values for the measured parameters from samples taken in Snow Canyon Creek. The table shows that both TDS and conductivity have very large ranges with many comparatively low numbers but enough large measurements to make the mean values much higher than the medians. For the TDS concentrations, the mean is about three times greater than the median and more than twice the value of the 3rd quartile value. With half all measured concentrations of TDS less than 554.0 mg/L, very high

Table 3.1.8: Descriptive statistics for Snow Canyon Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	25.0	260.0	554.0	1794.0	3205.0	7210.0	63
Ca	5.60	41.18	243.00	201.60	358.00	440.00	141
Cl	0.980	2.000	3.385	9.981	14.000	49.000	71
Mg	2.2	42.4	439.5	427.7	768.8	1200.0	141
Na	2.860	3.448	8.290	10.530	17.050	21.500	171
SC	54.2	400.0	1725.0	2573.0	4832.0	6080.0	125
SO_4	7	158	350	1315	2230	5540	64

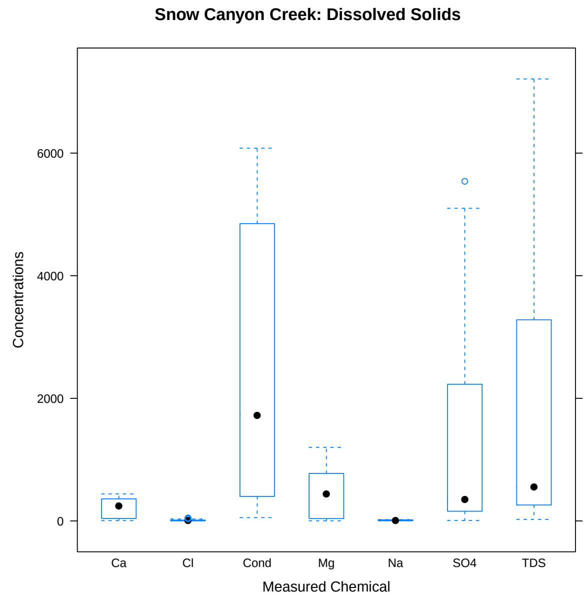


Figure 3.1.29: Box plots of Snow Canyon Creek water quality parameters related to total dissolved solids.

concentrations are comparatively infrequent but raise the mean value significantly. The majority of TDS concentrations (66%) are in the range 25.0–3205.0 mg/L, which is quite large.

Conductivity also has a large range with the maximum measurement more than 10 times that of the minimum measurement. For this component, the majority of measurements fall within the range of 400.0–4832.0 $\mu S/\text{cm}$; more than an order of magnitude from lowest to highest in that range.

Calcium is interesting because the mean concentration is less than the median concentration. Sulfate, like TDS and specific conductance, has a very large range with comparatively few very high values, but those are much larger than the majority. The mean concentration is about 4 times greater than the median, most concentrations are between 158–2230 mg/L, but a quarter of all measured sulfate concentrations are in the range 2230–5540 mg/L. These relationships are shown in Figure 3.1.29 where relationships among all parameters can be easily seen.

3.1.8.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on Snow Canyon Creek are:

```
Call:
```

```
lm(formula = TDS ~ Cond + Ca + Cl + Mg + Na + SO4, data = snow.cast)
Residuals:
     Min       1Q   Median       3Q      Max
-277.351  -32.551   -2.621   40.812  245.272
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  8.10075   51.36650   0.158   0.8762
Cond        -0.03700    0.07473  -0.495   0.6257
Ca          -0.13736    0.98329  -0.140   0.8902
Cl          13.22011    5.84693   2.261   0.0345 *
Mg           4.70170    0.28382  16.566 1.56e-13 ***
Na          18.75596   20.59638   0.911   0.3728
SO4          0.36685    0.04446   8.251 5.00e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 116.6 on 21 degrees of freedom
  (175 observations deleted due to missingness)
Multiple R-squared: 0.9984, Adjusted R-squared: 0.998
F-statistic:  2249 on 6 and 21 DF,  p-value: < 2.2e-16
```

Snow Canyon Creek has different dynamics from the previous two streams. Here magnesium and sulfates are very highly significant to TDS concentrations and chloride is significantly to TDS concentrations at the 95% level. (This means that there is only a 5% probability that this result occurred randomly.) In other words, there are three parameters in Snow Canyon Creek whose concentrations affect the measured TDS concentrations over all sampling locations. These relationships are shown in Figures 3.1.30 on the facing page through 3.1.32 on page 36. While some monitoring sites along the stream seem to have a linear relationship between the explanatory variable and TDS, the regression analyses are for all data from a stream, not individual locations.

To predict TDS concentrations in Snow Canyon Creek use this equation: $TDS = 8.10 + 13.22 * Cl + 4.70 * Mg + 0.37 * SO_4$.

3.2 Humboldt River Basin

3.2.1 California Creek

3.2.1.1 Descriptive Statistics

Table 6.1 reflects a very small sample set (82 total measurements) during a 4-month period in the summer and autumn of 1996. There is little variation in the data which probably reflects the low flow conditions in the creek during this period. While these data could contribute to broader analyses of water chemistry in the North Fork Humboldt River basin

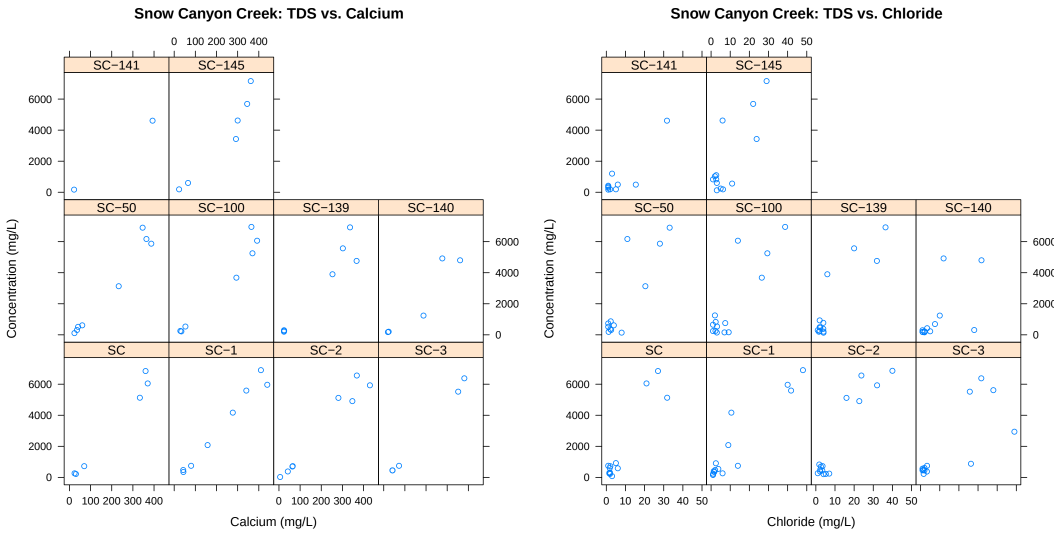


Figure 3.1.30: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along Snow Canyon Creek.

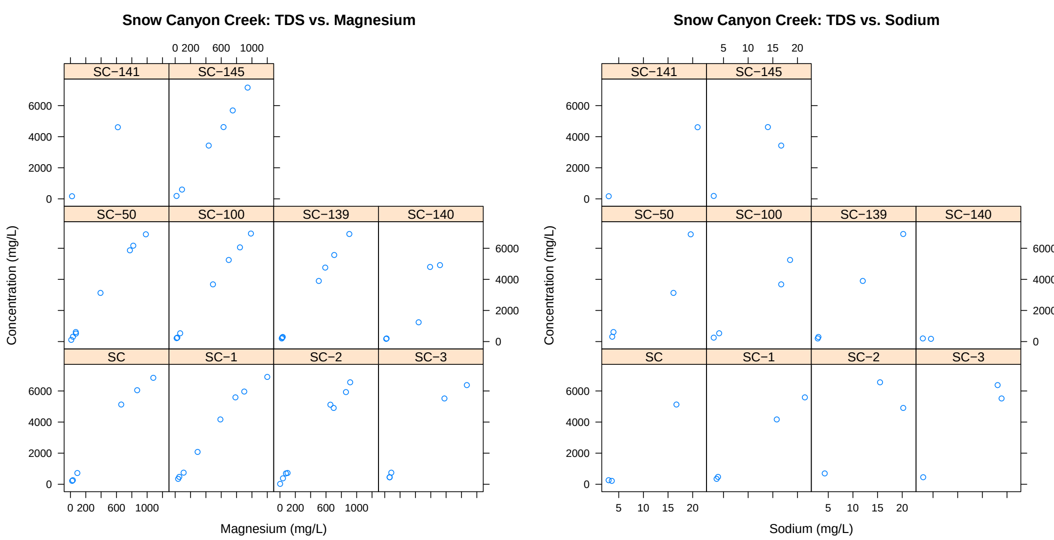


Figure 3.1.31: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations along Snow Canyon Creek.

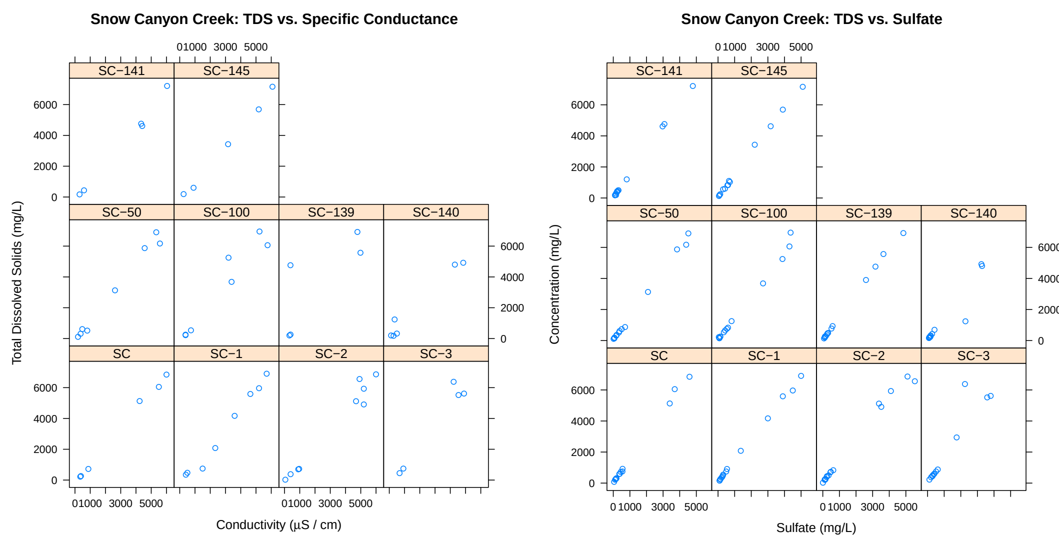


Figure 3.1.32: Relationships between conductivity (left) and sulfate (right) on TDS at sampling locations along Snow Canyon Creek.

Table 3.2.1: Descriptive statistics for California Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar.	Median	Mean	3rd Quar.	Max.	NA's
TDS	125.0	133.2	139.5	139.0	145.2	152	
Ca	13.0	13.0	14.0	15.3	16.3	20.2	
Cl	3.80	3.95	4.10	5.15	5.30	8.60	
Mg	4.200	4.350	4.700	5.018	5.368	6.470	
Na							All
SC							All
SO_4	4.600	5.650	5.000	4.875	6.225	6.900	

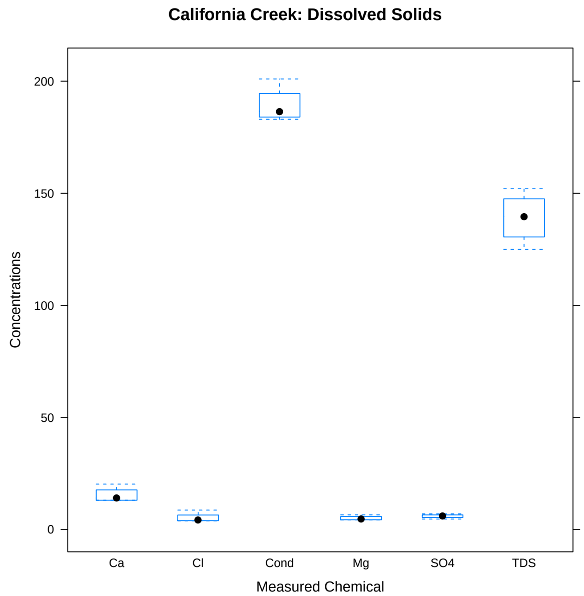


Figure 3.2.1: Box plots of California Creek water quality parameters related to total dissolved solids.

they provide no useful insights by themselves. Looking at the box-and-whisker plots of all parameters (Figure 3.2.1) we see that conductivity and TDS are very high but completely unrelated and that magnesium and sulfate are almost (but not quite) related to each other.

3.2.1.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on California Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4)
Residuals:
ALL 4 residuals are 0: no residual degrees of freedom!
Coefficients: (2 not defined because of singularities)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  633.521         NA      NA       NA
Cond          -3.274         NA      NA       NA
Ca             9.549         NA      NA       NA
Cl            -4.073         NA      NA       NA
Mg                NA         NA      NA       NA
```

Table 3.2.2: Descriptive statistics for DASH drainage water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar	Median	Mean	3rd Quar.	Max.	NA's
TDS	6390	13600	15800	15130	17000	21000	
Ca							All
Cl							All
Mg	935	2288	2610	2524	3020	3200	1
Na							All
SC							All
SO_4	4320	10800	11500	11180	12100	15000	

```
SO4                NA          NA       NA        NA
Residual standard error: NaN on 0 degrees of freedom
Multiple R-squared:     1, Adjusted R-squared:   NaN
F-statistic:   NaN on 3 and 0 DF,  p-value: NA
```

There are too few results for statistical analyses. For the same reason, the plots of TDS as functions of calcium and chloride concentrations are not included in this report.

3.2.2 DASH

3.2.2.1 Descriptive Statistics

Table 3.2.2 describes the values for the measured parameters from samples taken in the DASH drainage. These data contain only 20 more measurements than found with California Creek; a total of 102 measurements of TDS, magnesium, and sodium from 2006-12-06 to 2010-10-26.

All the values in Table 3.2.2 are high compared with other streams. However, as can be seen in Figure 3.2.2 on the next page, the three parmeters are not significantly related to each other. There is one TDS low outlier concentration measurement, but otherwise TDS concentrations are well above those of conductivity and both are well higher than the magnesium levels.

3.2.2.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters on DASH are:

```
Call:
lm(formula = TDS ~ Mg + SO4)
Residuals:
    Min      1Q  Median      3Q     Max
-2529.7  -750.5   301.2   856.8  1659.1
```

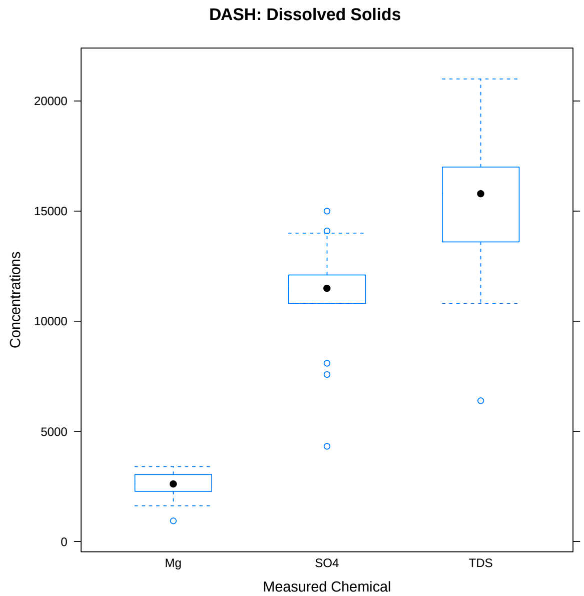


Figure 3.2.2: Box plots of DASH water quality parameters related to total dissolved solids.

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  393.8917  1360.2162   0.290   0.7767
Mg             3.2222     1.6753   1.923   0.0766 .
SO4            0.5864     0.4177   1.404   0.1838
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 1203 on 13 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared: 0.9151, Adjusted R-squared: 0.902
F-statistic: 70.05 on 2 and 13 DF,  p-value: 1.092e-07
```

While neither magnesium nor sulfate individually has a statistically significant relationship with TDS in the DASH drainage, magnesium is slightly non-significant (as indicated by the dot in the above results) and the overall model is significant (probability of 1.092e-07 and accounts for 90.2% of the observed variability in TDS concentrations. The dynamics of TDS are, again, different in this stream than in the others analyzed. The scatter plots of magnesium and sulfate with TDS are in Figure 3.2.3 on the following page.

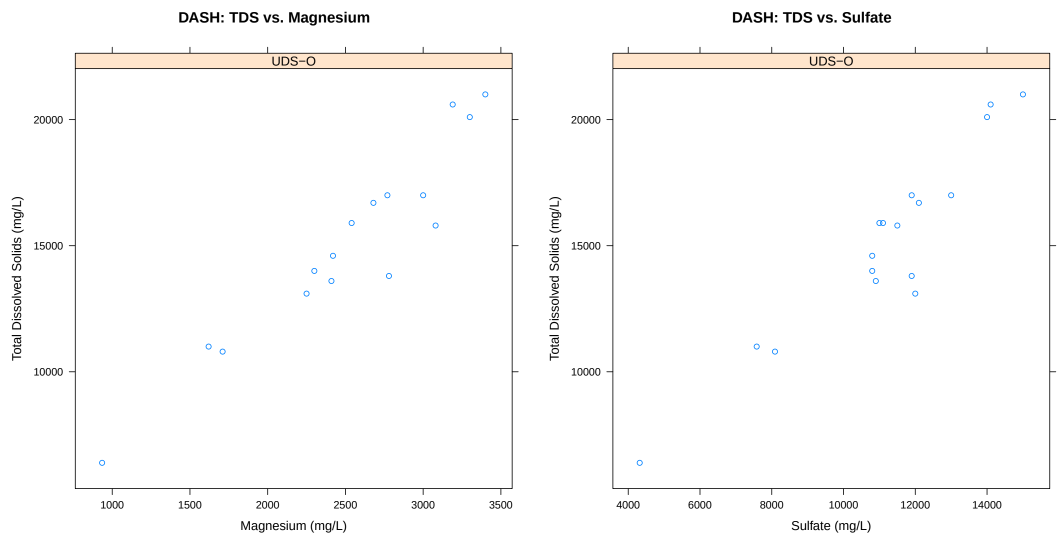


Figure 3.2.3: Relationships between magnesium (left) and sulfate (right) on TDS at sampling locations along the DASH drainage.

3.2.3 Ranch Springs (East Side)

3.2.3.1 Descriptive Statistics

Table 3.2.3 describes the values for the measured parameters from samples taken from the east side ranch springs. In these results all parameters normally distributed, with mean values almost the same as the median values except for conductivity which is slightly skewed toward the right tail (lower values). Each paramater (other than specific conductance) also has a narrow range of measured values in the 2859 measurements taken from there. Looking at the graphic of these distributions (Figure (3.2.4)) it is clear that con-

Table 3.2.3: Descriptive statistics for the east side ranch springs water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar	Median	Mean	3rd Quar.	Max.	NA's
TDS	294.0	301.8	308.0	307.5	311.2	326.0	11
Ca	56.00	57.48	59.80	59.80	60.75	67.00	11
Cl	1.940	2.647	3.000	3.094	3.680	4.300	1from 1978 to May of this year1
Mg	30.20	31.18	32.45	32.83	34.25	36.00	11
Na	6.800	6.940	7.200	7.178	7.375	7.750	11
SC	440.0	522.5	530.0	521.0	536.5	586.0	11
SO_4	48.00	52.30	53.80	53.98	56.02	57.00	11

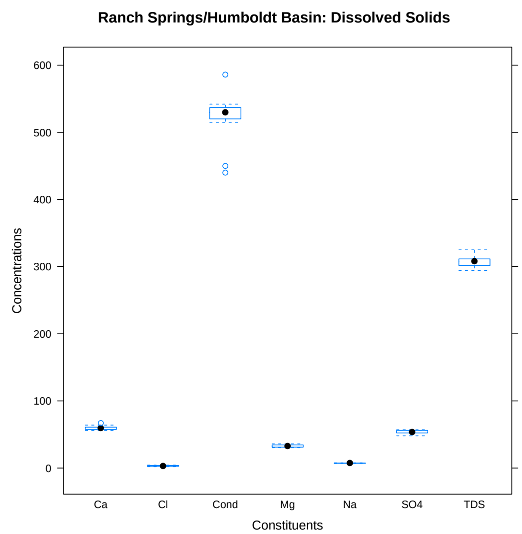


Figure 3.2.4: Box plots of east side ranch springs water quality parameters related to total dissolved solids.

ductivity is much higher than is total dissolved solids and has more outliers on both the upper and lower tails of the distribution. The other five constituents have much narrower ranges.

3.2.3.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters in the east side ranch springs are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = rnchH.cast)
Residuals:[1]
      8       9      10      11      12      13      14      16      20
21
-2.1926  3.2306 -3.9823 -4.0491  0.5284  1.9354  2.4798  0.8952 -3.0642
0.8781
     22
 3.3408
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
```

[1]This presentation of residuals is different from other streams because there are only 5 degrees of freedom in the analysis.

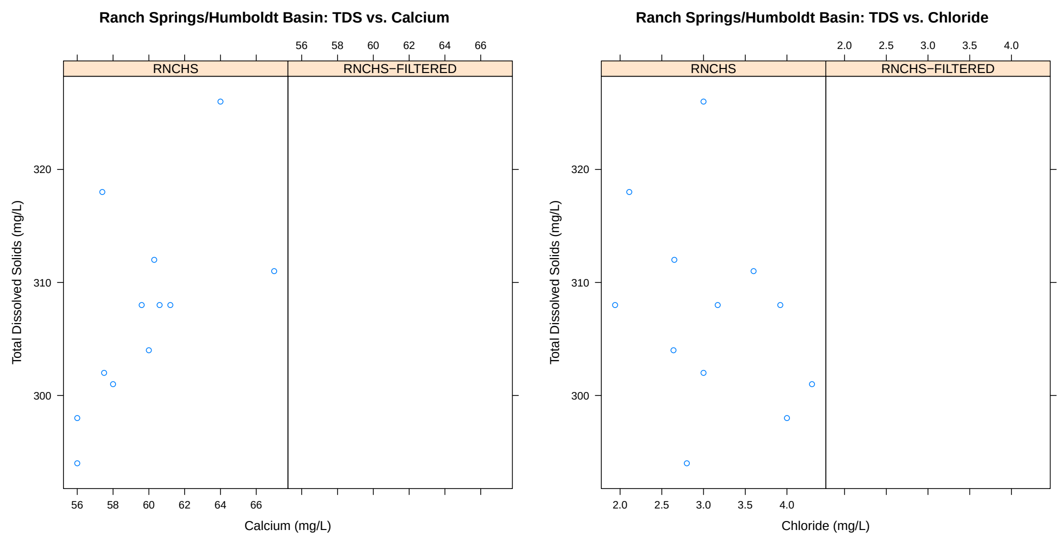


Figure 3.2.5: Relationships between calcium (left) and chloride (right) on TDS at sampling locations in the east side ranch springs.

```
(Intercept) 156.80514   43.62549   3.594   0.0156 *
Cond         -0.11737    0.05122  -2.291   0.0705 .
Ca            2.65343    0.73649   3.603   0.0155 *
Cl           -0.41709    2.19380  -0.190   0.8567
Mg           -1.78454    0.87453  -2.041   0.0968 .
SO4           2.10822    0.58059   3.631   0.0150 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 3.995 on 5 degrees of freedom
  (12 observations deleted due to missingness)
Multiple R-squared: 0.9038, Adjusted R-squared: 0.8076
F-statistic: 9.397 on 5 and 5 DF,  p-value: 0.01401
```

While Figure 3.2.3 on page 40 does not indicate an obvious cause-and-effect relationship between calcium, sulfate, and TDS, the multiple linear regression model shows that they are significant at the 5% level in predicting TDS levels. This model explains only 80.8% of total dissolved solids concentrations in these waters. The scatter plots of each potential explanatory parameter with total dissolved solids are in Figures 3.2.5through 3.2.7 on the facing page and show no apparent cause-and-effect relationship between most explanatory parameters (calcium being the exception) and TDS. To predict TDS concentrations in the east side ranches springs use this equation: $TDS = 156.81 + 2.65 * Ca + 2.11 * SO_4$.

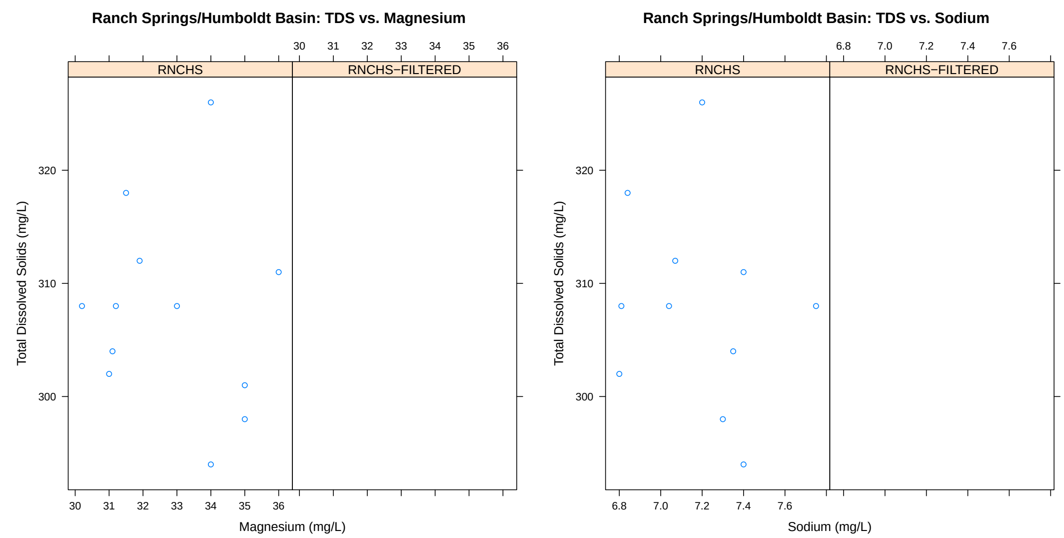


Figure 3.2.6: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations in the east side ranch springs.

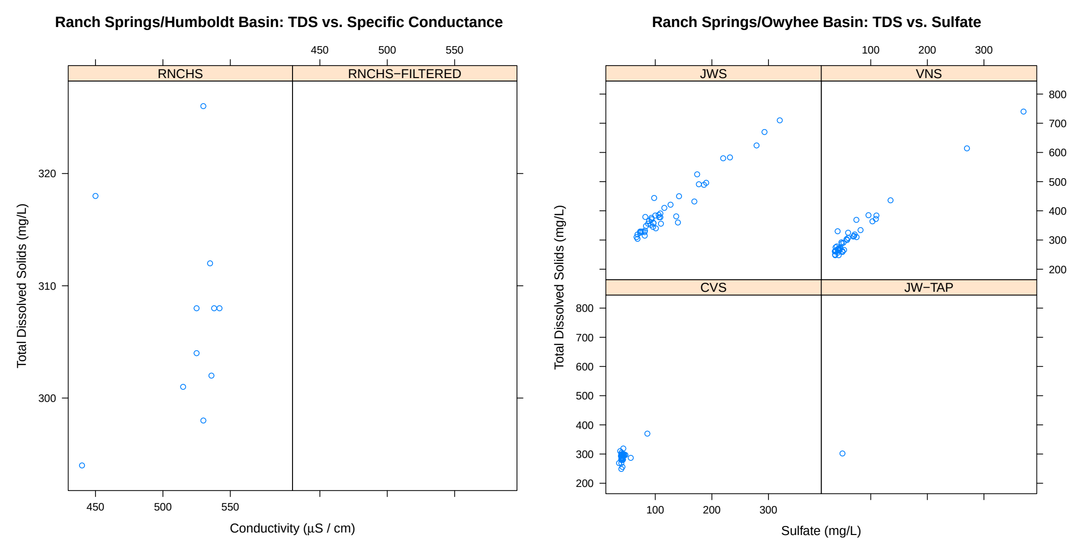


Figure 3.2.7: Relationships between conductivity (left) and sulfates (right) on TDS at sampling locations in the east side ranch springs.

Table 3.2.4: Descriptive statistics for the Sheep Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar	Median	Mean	3rd Quar.	Max.	NA's
TDS	7.7	221.1	379.0	979.5	446.5	15400.0	1
Ca	6.2	30.8	67.9	165.9	316.0	576.0	104
Cl	0.10	5.85	8.28	12.26	12.00	79.00	88
Mg	2.10	13.45	25.75	273.92	53.25	1770.0	109
Na	3.00	6.50	37.00	31.14	49.00	67.00	122
SC	66.3	349.5	524.0	2045.5	750.5	11400.0	99
SO_4	2.20	26.00	60.60	678.35	89.65	11200.0	30

3.2.4 Sheep Creek

3.2.4.1 Descriptive Statistics

Table 3.2.4 describes the values for the measured parameters from samples taken in Sheep Creek. This stream is hydrologically below the DASH East RDA. All constituents have broad ranges, and TDS, conductivity, and sulfate have exceptionally high maximum values. While the distribution of values for all constituents are heavily skewed to the right tail (higher values) as seen from the differences between median and mean values, it is important to put the maximum values in perspective.

Notice that the differences between the 3rd Quartile values and the maximum values are very large for all constituents, particularly TDS, specific conductance, and sulfate. The majority of measurements in this stream system (approximately 66% or $+/-$ one standard deviation around the mean) are in much narrower ranges of measured values. While the maximum recorded TDS value is 15,400 $\mu S/cm$, the IQR ranges from 221.1—446.5 mg/L. For sulfate, the maximum measured value was 11,200.0 mg/L while the majority of measured values are in the range 26.00—89.65 mg/L. The maximum values are extreme outliers while the IQR values represent normal water chemistry, the most likely situation in this creek.

The huge discrepancies between normal and extreme values are easily seen in Figure 3.2.8 on the facing page.

3.2.4.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters in Sheep Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = snow.cast)
Residuals:
     Min       1Q   Median       3Q      Max
```

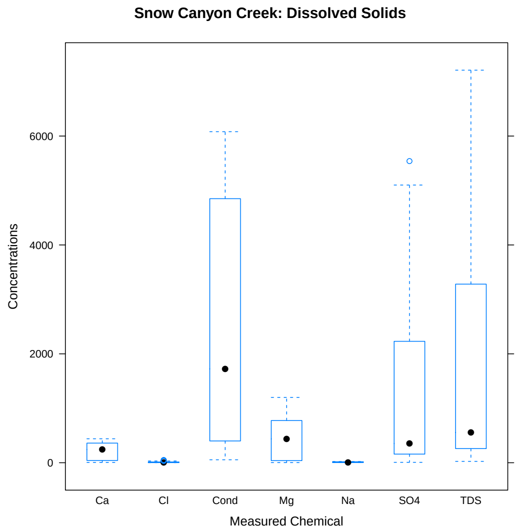


Figure 3.2.8: Box plots of Snow Creek water quality parameters related to total dissolved solids.

```
-1373.95   -72.85    34.77    80.54   835.73
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -78.87685   81.98805  -0.962  0.34075
Cond          0.21396    0.06692   3.197  0.00243 **
Ca            2.35501    1.25534   1.876  0.06662 .
Cl            5.95856    7.96346   0.748  0.45789
Mg            3.10238    0.55952   5.545 1.17e-06 ***
SO4           0.32648    0.10628   3.072  0.00347 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 333.7 on 49 degrees of freedom
  (148 observations deleted due to missingness)
Multiple R-squared: 0.9858, Adjusted R-squared: 0.9844
F-statistic: 680.8 on 5 and 49 DF,  p-value: < 2.2e-16
```

It is not at all surprising to see that conductivity, magnesium, and sulfate are highly (and very highly) significant predictors of TDS concentrations in Sheep Creek after examining the descriptive summaries in tabular and graphic formats. These relationships can also be seen in Figures 3.2.9 on the next page through 3.2.11 on page 47. The model accounts for 98.4% of measured TDS values with an over-all probability less than $2.2 * 10^{-16}$ that such results occurred randomly. To predict TDS values in Sheep Creek use this equation: $TDS = -78.88 + 0.21 * Ca + 3.10 * Mg + 0.33 * SO_4$.

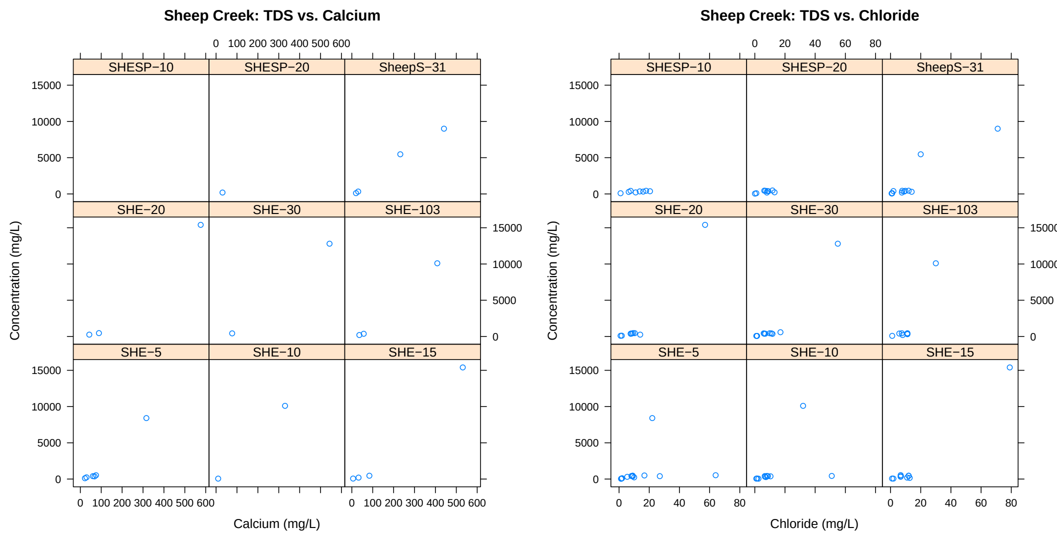


Figure 3.2.9: Relationships between calcium (left) and chloride (right) on TDS at sampling locations in Sheep Creek.

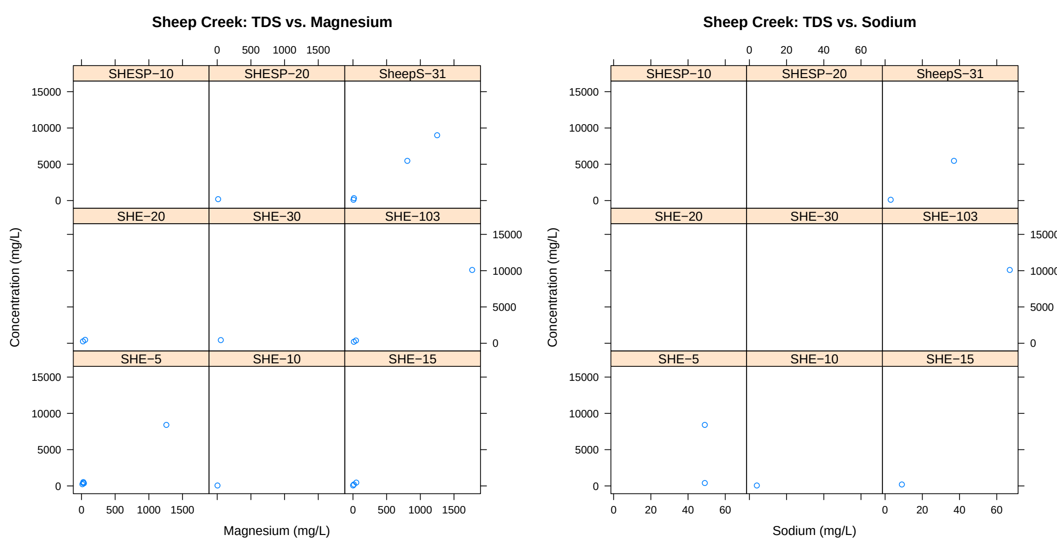


Figure 3.2.10: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations in Sheep Creek.

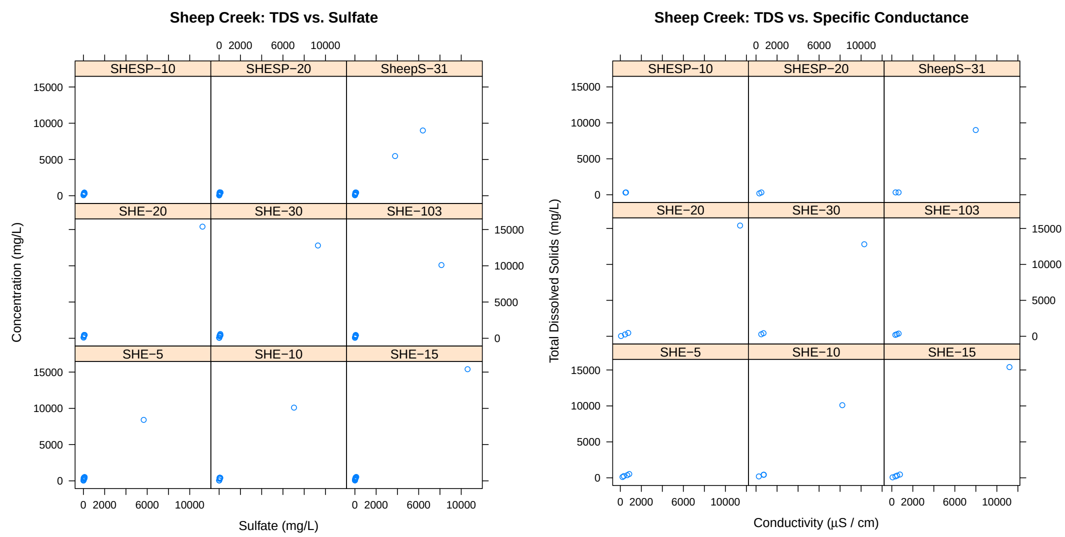


Figure 3.2.11: Relationships between specific conductance (left) and sulfate (right) on TDS at sampling locations in Sheep Creek.

3.2.5 Stump Creek

3.2.5.1 Descriptive Statistics

Table 3.2.5 describes the values for the measured parameters from samples taken in Stump Creek. There are no extreme outliers among most constituents (conductivity being the exception), but there are large differences between the 3rd Quartile and maximum values indicating occasional measurements at the right tail (high end) of the distributions. The

Table 3.2.5: Descriptive statistics for Stump Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1st Quar	Median	Mean	3rd Quar.	Max.	NA's
TDS	14.0	131.2	174.0	176.9	195.5	430.0	2
Ca	0.60	23.35	28.35	32.77	40.55	64.30	50
Cl	1.000	2.000	4.000	4.076	5.600	13.000	11
Mg	9.10	11.00	17.40	17.85	22.10	32.50	51
Na	4	4	4	4	4	4	62
SC	2.2	214.8	282.5	294.6	372.0	636.0	42
SO_4	4.00	7.00	9.40	16.31	17.00	105.00	3

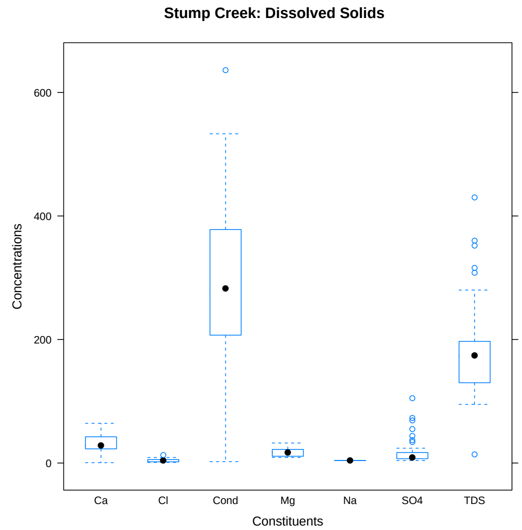


Figure 3.2.12: Box plots of Sump Creek water quality parameters related to total dissolved solids.

range of conductivity values is exceptionally great. These relationships are easily seen in Figure 3.2.12.

3.2.5.2 Linear Regression

The results of the multiple linear regression for TDS-related paramaters in Stump Creek are:

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + SO4, data = stump.cast)
Residuals:
       3        5       22       34       36       38       54       55
  38.776  -26.069  -57.315   31.126   45.608   22.190   73.183 -133.070
      58       63       64
  -2.323   58.632  -50.739
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   53.888    116.979   0.461    0.664
Cond           1.593      1.508   1.057    0.339
Ca            -7.075      6.287  -1.125    0.312
Cl           -25.124     34.130  -0.736    0.495
Mg            -2.214     16.623  -0.133    0.899
SO4           -1.469      3.656  -0.402    0.704
```

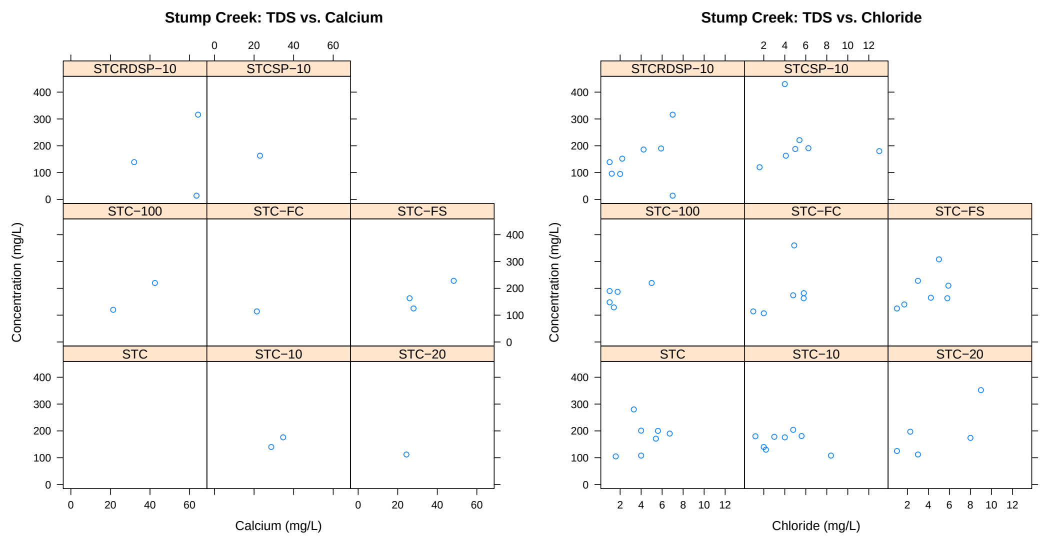


Figure 3.2.13: Relationships between calcium (left) and chloride (right) on TDS concentrations in Stump Creek.

```
Residual standard error: 87.28 on 5 degrees of freedom
  (53 observations deleted due to missingness)
Multiple R-squared: 0.3671, Adjusted R-squared: -0.2658
F-statistic:  0.58 on 5 and 5 DF,  p-value: 0.7177
```

For this stream, too, there are relatively few samples and the residual degrees of freedom are only 5. No constituent is a significant predictor of TDS in stump creek. However, the relationships of the various constituents to TDS for each site can be seen in Figures 3.2.13 through 3.2.15 on the following page.

3.2.6 Winters Creek

3.2.6.1 Descriptive Statistics

Table 3.2.6 on page 51 describes the values for the measured parameters from samples taken in Winters Creek. The graphic display of these statistics is seen in Figure 3.2.16. This figure shows the very large range of conductivity values and the smaller, but still large, range of TDS concentrations. It is not immediately obvious from this figure whether any explanatory parameter is a significant determinant of TDS concentrations.

3.2.6.2 Linear Regression

The results of the multiple linear regression for TDS-related parameters in Winters Creek are:

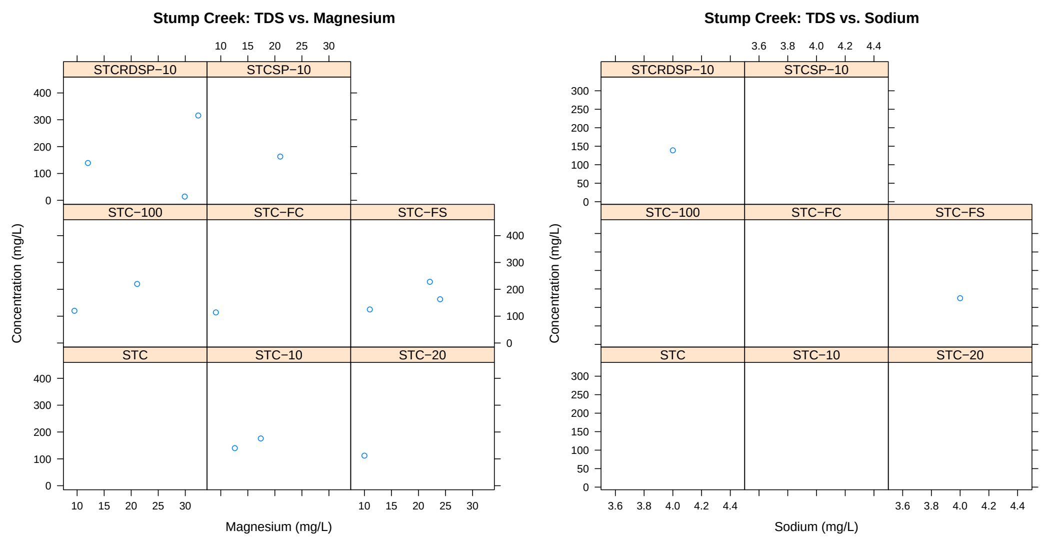


Figure 3.2.14: Relationship between magnesium (left) and sodium (right) on TDS concentrations in Stump Creek.

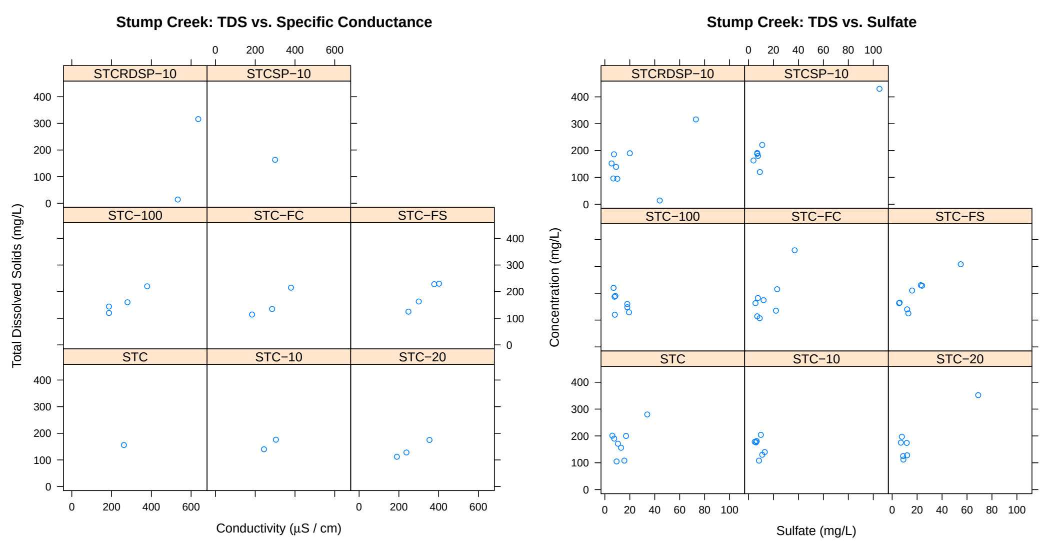


Figure 3.2.15: Relationships between specific conductance (left) and sulfate (right) and TDS concentrations in Stump Creek.

Table 3.2.6: Descriptive statistics for the Winters Creek water chemistry. SC is specific conductance; NA means data are missing for a sampling event.

Param.	Min.	1^{st} Quar	Median	Mean	3^{rd} Quar.	Max.	NA's
TDS	48.0	237.2	300.0	319.3	372.0	728.0	38
Ca	32.00	42.90	51.75	63.57	90.75	110.00	78
Cl	1.000	6.975	13.000	16.660	22.420	61.000	42
Mg	12.60	17.00	28.00	31.49	42.70	82.70	79
Na	4.000	6.652	7.805	7.626	8.858	10.200	86
SC	203.0	356.0	439.0	507.9	682.0	1111.0	69
SO_4	28.0	74.0	120.0	130.7	170.0	484.0	37

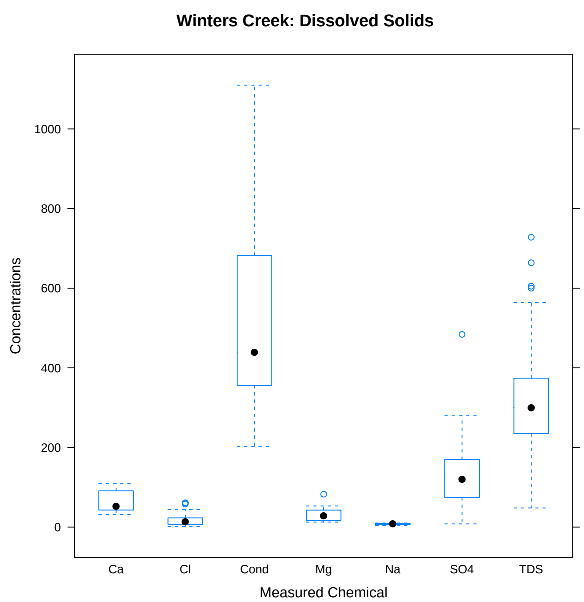


Figure 3.2.16: Box plots of Winters Creek water quality parameters related to total dissolved solids.

```
Call:
lm(formula = TDS ~ Cond + Ca + Cl + Mg + Na + SO4)
Residuals:
    Min      1Q  Median      3Q     Max
-15.348  -9.658  -1.550   6.614  24.732
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -6.738664  23.058178  -0.292 0.775537
Cond        -0.006805   0.105064  -0.065 0.949518
Ca           2.199954   0.560071   3.928 0.002360 **
Cl           0.834403   0.311634   2.678 0.021504 *
Mg           3.462978   1.297383   2.669 0.021825 *
Na           2.593377   4.549458   0.570 0.580106
SO4          0.688599   0.136359   5.050 0.000372 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 15.05 on 11 degrees of freedom
  (88 observations deleted due to missingness)
Multiple R-squared: 0.9923, Adjusted R-squared: 0.9881
F-statistic: 236.7 on 6 and 11 DF,  p-value: 5.656e-11
```

The regression model shows that sulfate is a very highly significant predictor of TDS concentrations, that calcium is a highly significant predictor, and that both chloride and magnesium are significant predictors. It is interesting to see that specific conductance (conductivity) is not significant while it is often considered a surrogate for TDS measurements. The model itself is very highly significant with the probability of the results being random less than $5.646 * 10^{-11}$, an extremely small value. Winters Creek is second only to the Gracie RDA drainage in the number of significant explanatory variables contributing to measured TDS concentrations. The individual pairs of scatter plots are in Figures 3.2.17 on the facing page through 3.2.19 on page 54. To predict TDS concentrations in Winters Creek use this equation: $TDS = -6.73 + 2.20 * Ca + 0.83 * Cl + 3.46 * Mg + 0.69 * SO_4$.

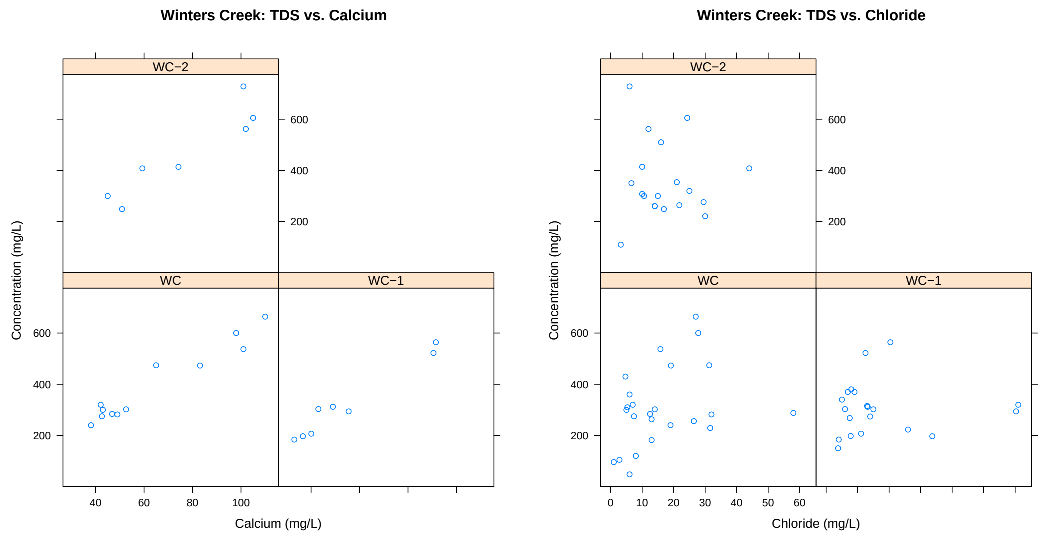


Figure 3.2.17: Relationships between calcium (left) and chloride (right) on TDS at sampling locations along Winters Creek.

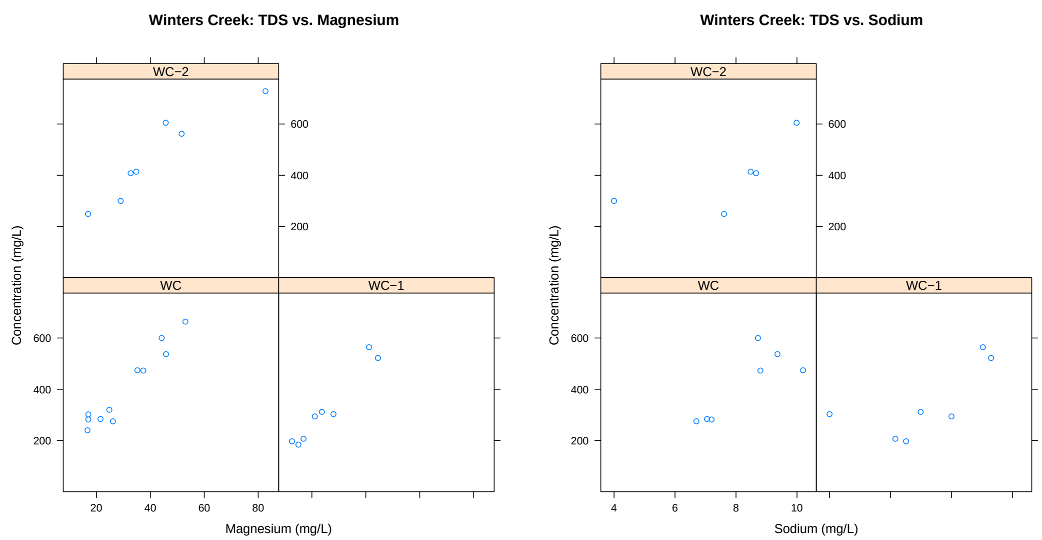


Figure 3.2.18: Relationships between magnesium (left) and sodium (right) on TDS at sampling locations along Winters Creek.

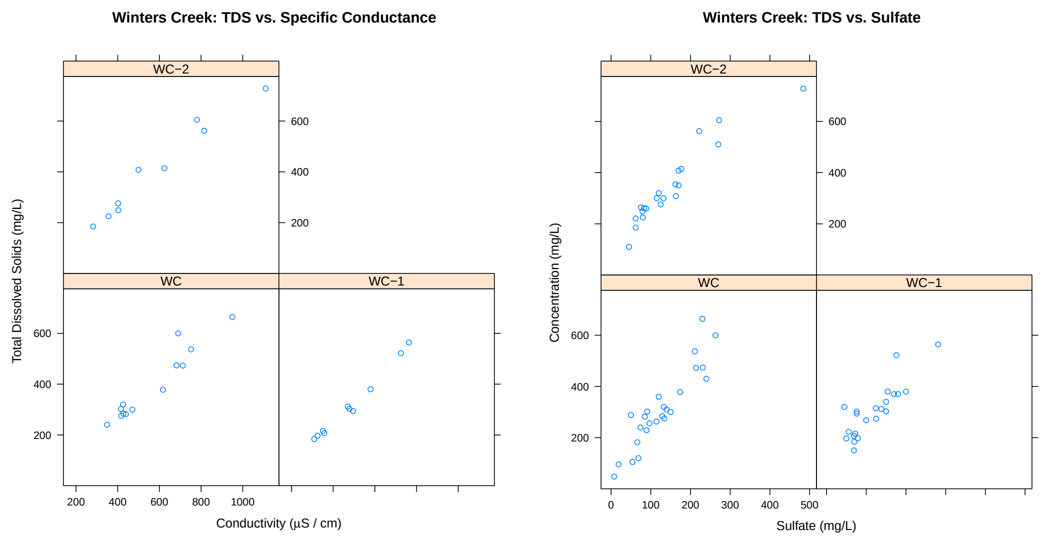


Figure 3.2.19: Relationship between conductivity (left) and sulfate (right) on TDS in Winters Creek.

4 Summary of TDS and its Constituents

No comparison at the river basin level (Owyhee and North Fork Humboldt) is made at this time because only a few streams in each basin were analyzed for this report. What this preliminary analysis shows is that total dissolved solids values vary greatly from stream to stream (and within each stream at individual monitoring sites). Further, there is no consistent constituent consistently and strongly associated with TDS concentrations. The purpose of this analysis is not to make predictions about TDS levels in a particular stream (although equations are provided to do so) but to determine whether such predictions could be made. With the available data the conclusion is that while TDS levels for a given stream may be calculated generalized prediction for any stream is not possible. Furthermore, in several streams, those hydrologically below RDAs, exceptionally high values of several water chemistry constituents have been measured on occasion. However, these are outliers well beyond 2 standard deviations of the mean value. This means that these extreme values occur less than 2% of the time.

While individual streams have predictable TDS concentrations based on the constituents used in these analyses there are non-chemical fluvial and geomorphic factors that could also contribute to these levels but were not included in these models. They will be incorporated in the future to produce a more comprehensive explanation of TDS and other constituent concentrations in individual streams and, perhaps, in streams of a given river basin.

An important conclusion of these analyses is that a single threshold for TDS concentration in a water sample is not supportable by the data from these streams. That is, if that single value is predicated on a single beneficial use, then the spatial relationships of that beneficial use to the streams of the Independence Mountains needs to be modeled and analyzed, too. A single TDS concentration threshold is not likely to protect any particular beneficial use (irrigation, for example). A more robust approach which incorporates more site-specific explanatory variables will be developed. It is important to acknowledge that these analyses use surface water samples and would apply only to beneficial uses with surface withdrawals. If the beneficial use (e.g., domestic potable, irrigation) depends upon ground water withdrawal this report is not applicable. Another important conclusion is that exceptionally high measurements below RDAs occur in fewer that 2% of the samples that have been analyzed for various periods over more than 30 years. The most common situation is moderate values of all constituents in all these streams.

Table 4.0.1 on the following page summarizes the results of the multiple linear regression modeling. It is clear that different predictor constituents contribute to the values of TDS in different streams. Italian, Jerritt Canyon, and Marlboro Canyon creeks all have

Table 4.0.1: Equations to predict TDS from its constituents in each Independence Mountains stream.

Stream Name	Predictive Equation
Burns Creek	$TDS = 28.21 + 4.20 * Ca + 1.08 * SO_4$
California Creek	Too few data to analyze.
DASH East RDA	No significant predictor constituents.
Gracie RDA Seepage	$TDS = -17.91 + 0.31 * Cond + 3.00 * Ca - 4.75 * Mg + 7.92 * Na + 1.46 * SO_4$
Italian Creek	$TDS = 33.92 + 5.69 * Mg$
Jerritt Canyon Creek	$TDS = 8.01 + 5.85 * Mg$
Marlboro Canyon Creek	$TDS = 709.81 + 4.43 * Mg$
Mill Creek	$TDS = 10.84 + 0.51 * SO4$
Ranch Springs- East	$TDS = 156.81 + 2.65 * Ca + 2.11 * SO_4$
Ranch Springs - West	$TDS = 100.2 + 2.61 * Mg + 1.02 * SO_4$
Sheep Creek	$TDS = -78.88 + 0.21 * Ca + 3.10 * Mg + 0.33 * SO_4$
Snow Canyon Creek	$TDS = 8.10 + 13.22 * Cl + 4.70 * Mg + 0.37 * SO_4$
Stump Creek	No significant predictor constituents.
Winters Creek	$TDS = -6.73 + 2.20 * Ca + 0.83 * Cl + 3.46 * Mg + 0.69 * SO_4$

magnesium as the only significant predictor constituent. Burns Creek and the east side ranch springs have both calcium and sulfate as significant predictor constituents. The Gracie RDA seepage and Winters Creeks have the most predictor constituents (5 and 4, respectively) and the Gracie RDA seepage is the only system to have sodium as a significant predictor constituent.

The differences among systems in predictor constituents, the relative amounts of each predictor, and the intercept[1] (the first value to the right of the equals sign) document how variable total dissolved solids concentrations are in different surface waters in the Independence Mountains.

[1]These equations represent a straight line relating TDS concentrations to the predictor constituents. The intercept is where the line crosses the y axis when the x axis is zero.